Air cargo load and route planning in pickup and delivery operations

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Abstract

In aerial pickup and delivery of goods in a distribution network, transport aviation faces risks of cargo unbalancing due to the urgency required for loading, for fast take-off, and mission accomplishment, especially in times of crisis, disaster relief missions, short deadlines for contracting customers, or any external pressure for immediate take-off. In addition, there are no commercially available systems that can assist the load and trip planners with the pallet building and aircraft loading and balancing demands for transport at each hub. This enables other risks, such as improper delivery, excessive fuel burn, and longer than necessary turn-around time. We defined and solved the problem of planning the loading and routing of an single aircraft according to a utility score, weight and balance principles, and fuel consumption in a tour of simultaneous pickup and delivery at intermediate hubs. This NP-hard problem, named *Air Cargo Load Planning with Routing, Pickup, and Delivery Problem (ACLP+RPDP)*, is mathematically modeled using standardized pallets in fixed positions, obeying center of gravity constraints, delivering each item to its destination, and minimizing fuel consumption costs. We performed multiple experiments with a commercial solver and four well-known meta-heuristics on data based on the transport history of the *Brazilian Air Force*. We also designed a new heuristic that quickly finds good solutions for a wide range of problem sizes: an essential contribution, which solved all test scenarios within an acceptable operational run time.

Keywords: Load Planning, Air Palletization, Weight and Balance, Pickup and Delivery, Vehicle Routing

1. Introduction

Air cargo transport involves several sub-problems that are difficult to solve. Recently, Brandt and Nickel [30, p. 401] defined the *Air Cargo Load Planning Problem* (ACLPP) as four sub-problems: *Aircraft Configuration Problem* (ACP), *Build-up Scheduling Problem* (BSP), *Air Cargo Palletization Problem* (APP) and *Weight and Balance Problem* (WBP). Several aspects were considered in this modeling: characteristics of the items to be transported (dimensions, scores, dangerousness, etc.); types and quantities of *unit load devices* (ULDs), commonly called pallets; when these pallets are assembled; how items are allocated to pallets; in which positions these pallets are to be placed; how the total cargo weight is balanced; etc. They also presented a comprehensive bibliographic survey of solving methods that had been developed in different situations.

However, there are still other important challenges in air cargo transport that go beyond the definition of the ACLPP, especially with regard to the flight itinerary and the loading and unloading at each destination (or node) of this travel plan. In this context, at least two more important sub-problems can be considered: pickup and delivery operations at each node, called *Pickup and Delivery Problem* (PDP), and the search for the lowest cost route, which is the well-known *Traveling Salesman Problem* (TSP).

Considering air cargo transport, Table 1 lists the main works in the literature and the corresponding sub-problems addressed. We also indicate whether the dimensions of the items were taken into account (**3D** or **2D**) and which solution method was used: heuristic search methods (**Heu**), integer programming (**Int**), or linear programming (**Lin**).

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Table 1: Air cargo transport: literature, problems and features

Work	APP	WBP	PDP	TSP	2D	3D	Heu	Int	Lin
Larsen and Mikkelsen [1]	.	★	.	.	.	.	★	.	.
Brosh [2]	.	★	.	.	.	.	.	.	★
Ng [6]	.	★	.	.	.	.	.	★	.
Heidelberg *et al.* [11]	.	★	.	.	★	.	★	.	.
Mongeau and Bes [13]	★	★	.	.	.	.	.	★	.
Fok and Chun [14]	.	★	.	.	.	.	.	★	.
Chan *et al.* [16]	★	.	.	.	.	★	★	.	.
Kaluzny and Shaw [17]	.	★	.	.	★	.	.	★	.
Verstichel *et al.* [19]	.	★	.	.	.	.	.	★	.
Mesquita and Cunha [18]	.	.	★	.	.	.	★	.	.
Limbourg *et al.* [20]	.	★	.	.	.	.	.	★	.
Roesener and Hall [21]	★	★	.	.	.	★	.	★	.
Vancroonenburg *et al.* [22]	★	★	.	.	.	.	.	★	.
Lurkin and Schyns [23]	.	★	★	.	.	.	.	★	.
Roesener and Barnes [24]	.	★	.	.	.	.	★	.	.
Paquay *et al* [25, 26]	★	★	.	.	.	★	★	★	.
Chenguang *el al.* [28]	.	★	.	.	★	.	★	.	.
Wong and Ling [31]	★	★	.	.	.	.	.	★	.
Wong *et al.* [33]	★	★	.	.	.	.	.	★	.
Zhao *et al.* [34]	.	★	.	.	.	.	.	★	.
This article	★	★	★	★	.	.	★	★	.

As can be seen, so far Lurkin and Schyns [23] is the only work that simultaneously addresses an air cargo (WBP) and a flight itinerary (PDP) sub-problem. Although it is innovative, strong simplifications were imposed by the authors: in relation to loading, APP was ignored; with regard to routing, it is assumed a predefined tour plan restricted to two legs. It is important to note that these authors consider an aircraft with two doors, and the minimization of loading and unloading costs at the intermediate node was modeled through a container sequencing problem. Referring directly to this work, Brandt and Nickel [30, p. 409] comment: *However, not even these sub-problems are acceptably solved for real-world problem sizes or the models omit some practically relevant constraints.*

There are real situations that are much more complex. In this work, we consider a practical case in Brazil, which is the largest economy in Latin America. Due to its dimensions, this country has the largest air market on the continent with 2,499 registered airports, of which 1,911 are private and 588 are public. Although it is an immense distribution network, the *Brazilian Air Force* missions have always considered 3 to 5 nodes per flight plan.

It is important to emphasize that this data is not an imposed limitation, but a historical fact that we will explore in our resolution method. Throughout this work we approach routes with up to 7 nodes, as can be seen in Table 2 and in Figure 1. Although there are many other airports of interest to *Brazilian Air Force*, these 7 nodes were chosen due to their high demand and short transport times. The other Brazilian airports tend to have a lower demand, which is usually met, in a less expensive way, by cabotage, rail or road transport.

Table 2: Brazilian airports distances (km)

Node IATA*	l_0 GRU	l_1 GIG	l_2 SSA	l_3 CNF	l_4 CWB	l_5 BSB	l_6 REC
GRU	0	343	1,439	504	358	866	2,114
GIG	343	0	1,218	371	677	935	1,876
SSA	1,439	1,218	0	938	1,788	1,062	676
CNF	504	371	938	0	851	606	1,613
CWB	358	677	1,788	851	0	1,084	2,462
BSB	866	935	1,062	606	1,084	0	1,658
REC	2,114	1,876	676	1,613	2,462	1,658	0

*International Air Transport Association
Source: www.airportdistancecalculator.com

Figure 1: A route with 7 Brazilian airports

Cargo handling at modern airports usually involves powerful equipment such as dollies, motorized conveyors, elevator transfer vehicles, caster decking, scissor lifts, electrical controls, hydraulically adjustable heights, forklift trucks, and plenty of room in the airport cargo terminal (see Figure 2). These facilities, together with the use of standardized pallets with predefined positions on the aircraft, allow loading and unloading at each node to be carried out in about 30 minutes.

Figure 2: Cargo handling equipment
Source: NARA & DVIDS Public Domain Archive

However, as reported by Fok and Chun, *load planning (...) is usually done in roughly 2 hours before departure, when all the details of the cargo are present.* [14]. This is because there are no specific software to solve this problem. In addition, there is still the time needed to plan the route. In these circumstances, it is of great importance to find a method that defines the load planning and the flight tour within 30 minutes.

Our work proposes a method that prioritizes the transport of the most relevant items at each node and the fuel economy along the tour. We developed a heuristic that can be run on a simple handheld computer (such as a laptop or a tablet) that previously defines a flight plan, and provides a quick solution for cargo handling to be carried out in up to 30 minutes. This method certainly reduces the stress that transport planners are subjected to, because they have to deal with a lot of information in planning the aircraft route, assembling the pallets (regarding their positions), and a pick up and delivery plan to each node.

To the best of our knowledge, this is the first time that an air cargo transport problem that simultaneously involves APP, WBP, PDP and TSP has been addressed. This new problem is named *Air Cargo Load Planning with Routing, Pickup and Delivery Problem* (ACLP+RPDP).

This article is organized into six more sections. In Section 2, we give a brief review of the literature. In Section 3, we present the problem context and assumptions, and in Section 4, we describe the mathematical model and how we dealt with its issues. In Section 5, we describe the elaborate algorithms, whose results are presented in Section 6. Finally, our conclusions are in Section 7.