Computers & Industrial Engineering 102 (2016) 44–57

Contents lists available at ScienceDirect

Computers & Industrial Engineering

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

Aircraft gate assignment: Using a deterministic approach for integrating freight movement and aircraft taxiing

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ARTICLE INFO

Article history:
Received 6 February 2016
Received in revised form 5 October 2016
Accepted 6 October 2016
Available online 8 October 2016

Keywords:
Operation research
Gate assignment
Freight operations planning
Job shop scheduling
Genetic algorithm

ABSTRACT

With the increase in fuel prices, the efficient movement of aircraft around an airport can impact the profitability of a flight and an airline. The assignment of a flight to a specific gate not only impacts passenger satisfaction, but also impacts the efficient movement of aircraft from the departure gate to the runway. There have been bodies of research investigating aircraft taxi problems and gate assignment problems. However, each of these research bodies has not included the effects of the other research areas into their respective areas. This paper presents a proposed framework that integrates the passenger or freight movement within a terminal with the taxiing of the aircraft to support an integrated approach to solving the gate assignment problem. A solution technique that incorporates a job shop scheduling solution method is presented and demonstrates that a large problem can be solved efficiently and in a short time.

1. Introduction

Within the airline industry, there are two main revenue generating operations, the transport of passengers and freight. While these operating environments or systems are needed to move goods and passengers within and between geographical areas, the high cost of operations presents challenges to meeting customer expectations and service goals. The challenges often force reconciling customer convenience and comfort with costs and cost recovery. This balancing act causes management to look for ways to gain efficiencies and requires an efficient operation.

Operating within this industry incurs high costs relating to the acquisition and operation of the main piece of equipment, the airplane. To maintain profitability, airlines must look for opportunities to manage costs and reduce them when appropriate. This task is further complicated by the environment that each airline must operate within. This environment involves, at some level, cooperating with rivals, complying with government regulations, and having day to day operations controlled by a third party.

This third party controls the air traffic system and airports throughout the world. They control the movement of aircraft from the point of departure from the gate until the flight arrives at the destination gate. This system can be broken into several segments that work together. Within the research communities, these breaks have provided convenient points to define research bounds; however, little research has been conducted to measure the impact of one area on another. All the research has the ultimate goal of streamlining operations for the specific segment being researched.

This paper presents a framework for connecting the aircraft taxi problem with the gate assignment problem. This framework includes translating the taxi portion of the combined problem into a job shop scheduling problem. To support the framework, we present a nonlinear program formulation for solving the problem and defining optimality and then utilize a genetic algorithm to optimally solve the problem.

In Section 2, we present an overview of the key parts of the air traffic system and research to date for the taxi problem and gate assignment problems. Section 3 presents the framework and problem definition for the combined approach. Section 4 presents the results of the solution process, and Section 5 summarizes the research and identifies potential research opportunities.

2. Background

While the customers' views of the system provide a simplistic window into the movement of passengers and freight, they do not provide sufficient detail to adequately describe the complexities of the system and the movement between an origin and destination. This hidden complexity has driven airlines' cost and schedule structures. Some of these costs are directly related to the customer and their interaction with the service provider. Over the past few years, customers have been bombarded by a number

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http://dx.doi.org/10.1016/j.cie.2016.10.004
0360-8352/

of fees for everything from bringing an extra bag to paying for a meal on a flight. However, these fees, while beneficial to the airline, do not impact the base operation of the airline, moving the flight from an origin to a destination.

The system used for moving aircraft between two points is often referred to as the air traffic system. This complex system provides a process for safely moving aircraft within a designated air space. As air travel and the demand for air freight movement has increased over time, the complexity of the control systems has increased. The complexity of the airspace in turn has driven higher operating costs in the airline industry, and the need for determining the most efficient method of operating the system has become a ripe area for research. In order to understand the research and the problems faced in operating an airline and the air traffic system, it is important to comprehend how each operates and interacts.

2.1. Service models

The airline business provides a simple service, moving passengers and freight between two points using three operation models: passenger only, mixed (passenger and freight), and freight only. Each model may operate a point-to-point or a hub and spoke system. In a point-to-point operation, the passengers and/or freight are moved from a specific origin to a specific destination. In a hub and spoke system, the airline collects passengers and/or freight from a number of origins (spokes), moves them to a central location (hub), sorts the passengers and/or freight, and moves each item/person to its destination.

The passenger model focuses on the movement of passengers through the airline system, with the main interaction point being the customer and the main measures being their convenience and satisfaction. In the literature, the focus has been on moving passengers through the terminal facility and minimizing the distance the passenger travels within the facility while allowing the flight to depart on time (Bihr, 1990; Dongxuan & Changyou, 2007; Li & Xu, 2012; Narciso & Piera, 2015; Prem Kumar & Bierlaire, 2014; Yan & Huo, 2001). In this context, customer satisfaction is measured by the movement around the terminal, while in reality customer satisfaction is most achieved by arriving at the desired destination by the promised time.

In the mixed model, excess cargo space in the flight (the space remaining after the passenger luggage has been loaded) is used to move freight. The limiting factors for this operation model are the amount of space available and the destinations available, since the cargo must travel where passenger flights are already planned. The passenger portion of this model operates in the same manner as the pure passenger model. In both research and reality, cargo customer satisfaction is measured by the cargo arriving at the desired location at the stated time.

Freight only operations follow one of three modes: charter operations, scheduled operations, and scheduled operations handling express and parcel movements. In charter operations, an aircraft is contracted to move specific freight between two defined points with the charter freight carrier providing the aircraft and staff, and operating on an as needed basis. Satisfaction is measured by the service provider meeting the terms of the contract or charter. Scheduled operations encompass not only large freight units, but also parcels. Larger freight units are tendered to the freight line, moved through a sorting and transportation network and then delivered to the destination. Parcel transportation follows the same essential process as the larger freight units, with the sort processes utilizing more automation to complete the sort process. The scheduled operation functions within defined operating and movement parameters and timeframes (much like a scheduled passenger airline). The customer interaction points are at the tendering site at the start of the process and at delivery, and satisfaction is measured in terms of on-time delivery of the parcel or freight.

2.2. Air traffic system

All airline operations are impacted by two basic, interrelated factors: fuel costs and air traffic movement. Efficient movement of an aircraft through the air traffic system will naturally lead to more efficient fuel usage through the use of more direct routings, shorter holding time waiting for a landing spot and fewer mid-route changes due to conflicts (potential violation of horizontal and vertical separations between aircraft). The complexity of the procedures involved in moving the flight from the origin to the destination combined with the sheer volume of flights moving through the system introduces a level of uncertainty in maintaining schedules.

The air traffic system is designed to safely move aircraft from origin to destination by maintaining horizontal and vertical separation between each aircraft, and is controlled by a series of air traffic controllers who each oversee a sector or portion of the system. The routing of a flight through the air traffic system is determined by a set of way points which represent fixed points on a map. Although flights may be routed through any number of way points, scheduled airlines tend to use preferred routings or sets of way points. These choices are typically made for fuel conservation and schedule adherence. Once the routing is determined and the flight has been initiated (left the gate), the air traffic system guides the flight safely through the chosen routing.

For all flights, there are a series of steps or phases that the plane passes through as it moves through the air traffic control system. While there are a number of steps, the following are the steps impacted by the research:

- *Pushback or gate departure* – The flight departs the gate and prepares for taxiing around the airport. The time associated with this phase is used by the regulatory bodies to measure on-time departure performance.
- *Taxi out* – Once the flight leaves the gate, it moves to the runway for take-off. Depending on the status of the operation (hub or non-hub airport), the flight may taxi in areas controlled by an airline. This is commonly termed ramp movement or control. Prior to entering the airport controlled area, the flight will pass a point where control of the flight is passed from the ramp controller to the ground controller who coordinates the movement of each flight moving around the airport. In this phase, the flight is moved to the runway for take-off.
- *Take-off or airport departure* – At this point, the flight is handed off to the local controller who sequences it with other departing and arriving flights for use of the runway and air space. After the flight clears the runway, it is handed off to the approach controller. This phase not only includes the use of the runway, but also the departure air space around the airport.

The air traffic system is complex with a number of independent and dependent features making modeling it difficult. Within the air traffic system, there are assignment problems, network flow problems, inventory problems and scheduling problems. Each one of these problems has unique formulation and solution techniques.

The goal of any analysis of passenger movement is to minimize the distance traveled, with the distance measured from three aspects: (1) passengers departing the terminal, (2) passengers arriving at the terminal and (3) passengers traversing the terminal (connecting flights). Numerous efforts have been made to study assigning gates to minimize the time spent transferring between aircraft (Bihr, 1990; Dongxuan, 2007; Li, 2012; Narciso & Piera, 2015; Prem Kumar & Bierlaire, 2014; Yan & Huo, 2001). Ding,