Optimization

Case Studies

Introduction

- An airline is full of incredible opportunities for operations research. There are a large variety of resources to be planned (people, aircraft, gates, fuel, etc.) Planning efficiency can be the difference between profit and loss for an airline.
- At the same time, you also must optimize your product in order to satisfy as much consumer demand as you can, in order to maximize your revenue. You have to sell flights that passengers want to fly on at prices they're willing to pay.

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Fuel Tankering

Fuel Tankering

- Let's start with one of the easiest, most valuable problems: fuel tankering.

- Each flight requires a minimum amount of fuel be carried. This minimum is the sum of the fuel that is planned to be burned to fly the flight, and a certain amount of reserve fuel that is not planned to be burned. In some cases, for example when there is bad weather forecast at the destination, the amount of reserve fuel required can be increased.

- Before each flight we could just add enough fuel to fly the flight. That's the basic answer, with no tankering.

Fuel Tankering Opportunity

- Fuel prices vary from airport to airport, though. This cost is usually made up of a number of factors, from the global price of a barrel of oil, to property prices near the airport, to the distance from the airport to the nearest oil refinery. Prices in hard to reach airports, like on islands, can be even higher.

- Many people have a favorite gas station with good prices where they fill up their car. The problem is similar here, with a catch: we can buy extra fuel where it is cheaper, and carry it around, but carrying the additional fuel weight causes the aircraft to burn more fuel.

- How can we minimize our fuel costs while meeting all of our fueling requirements?

Fuel Tankering Requirements

- An aircraft is planned to fly a string of flights for the day.
- Each flight must have the required amount of fuel for each flight.
- Each flight has a maximum take off weight, and cannot take off too heavy.
- Each flight has a maximum landing weight, and cannot land too heavy.
- Each flight has a maximum amount that the fuel tanks will hold.
- Each airport has a fuel price.
- For a given flight, any additional tanker fuel that is carried will have some small percentage burn off. That percentage will vary based on the length of the flight and the fuel efficiency of the aircraft, among other things.

Fuel Tankering Model and Solution

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Maintenance Routing

Aircraft Routing

- Aircraft routing offers lots of planning options. At Southwest Airlines, we plan lines of flying. A line of flying is a string of flights that one aircraft will do in one day. When all of the aircraft are parked overnight, they can be assigned a new line for the next day.
- Some airports will only have one aircraft parked overnight, and so will only have one available line for the next day. Other airports might have a dozen aircraft parked overnight and a dozen lines to be assigned the next day, and the lines can be assigned to the aircraft in many ways (12! in this example.)
- Aircraft and lines are assigned on a 1-1 basis. In planning, there number of aircraft matches the number of lines, and a solution is always possible.

System Routing

- Each line will have a departure airport and time, and an arrival airport and time at the end of the day. One line might leave from Dallas and end the day in Orlando. Another line might start the day in Los Angeles and end the day in Seattle. One line might start the day in Houston and end the day in Houston.
- Because the schedule has to balance, we have the same number of lines ending the day in one location as we have lines departing from that location the next day.
- At the moment we have around 700 aircraft and lines that must be assigned each day.

Maintenance Routing

- Each aircraft has required maintenance that must be performed on a regular basis at a maintenance station. Some maintenance can be performed where we have mechanics stationed overnight, and some more intensive maintenance can only be performed where we have maintenance hangars.
- Each maintenance event is called a work order. Work orders will have an earliest and latest date that they can be performed, and a number of labor hours that are required to perform the work order. Some work orders require a hangar, too.
- Each maintenance location has an available number of labor hours each night, so we can't assign too much work to any one maintenance station per night.
- How do we route the aircraft so that each aircraft gets all of its work orders scheduled?

Maintenance Routing

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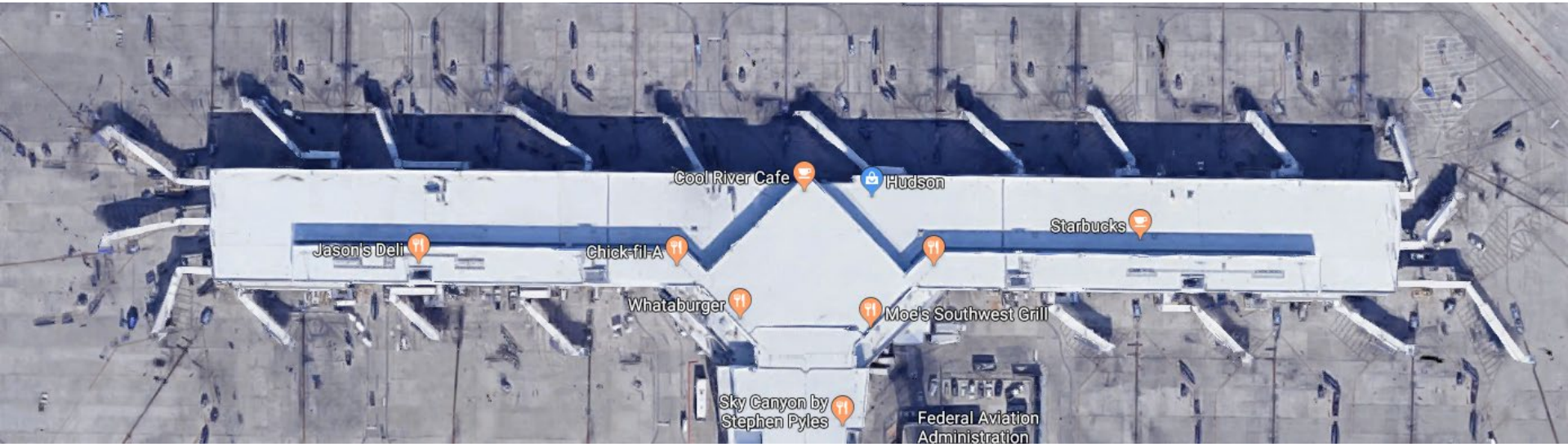
Gating

The Gating Problem

This is Dallas Love Field's passenger terminal.



The Gating Problem

The Gating Problem

- We have a schedule of flights that will arrive in Dallas, park at a gate to load and unload, and then depart. From the gating perspective, the busy times are when the aircraft is parked at the gate.
- There are many different ways to assign the aircraft to gates, however, so we want to try to do it in the best way possible:
- Allow downtime on each gate between operations. This slack allows for some flights to arrive a little early or some flights to leave a little late without having to change the gate schedule.
- Consider whether the passengers or crew for a flight have to make a connection to different flights within the airport. If so, try to arrange them to make the connections as easy as possible – the shortest distances within the airport.

The Gating Problem Continued

- There are ground crews supporting each gate, and we want to even out the workload between those ground crews. In the Dallas case, if we assigned all of the inbound flights to the eastern side of the terminal, we'd be overwhelming the ground crews on the east side and leaving those on the west side with nothing to do.
- At some airports (not Dallas), due to demand, we close some gates at certain times of the day.
- At some airports, some gates can block other gates, and so only one of two gates can be occupied at one time.
- International arrivals have to be assigned to a gate that has customs controls.

The Gating Problem Continued

- We will often park more aircraft at an airport overnight than there are gates. This requires unloading an aircraft at the end of the day, and then towing it to a remote parking spot. Then, in the morning when a gate is free, we tow the aircraft back to a gate.
- Some gates are restricted in various ways, such as being shared with other airlines, not fitting certain types of aircraft, or perhaps being an overflow gate. Overflow gates are not used in planning and are not staffed, but are available for parking or unloading during irregular operations.

- We have a large number of competing objectives here. How do we optimize this problem?

The Gating Model

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Crew Planning

Crew Planning

- At its most basic, Crew Planning works to ensure that each flight has exactly on pilot crew and exactly one flight attendant crew onboard each flight in order to operate that flight.
- This is an example of what are called Set Partitioning problems. A set partitioning constraint requires that of a set of variables, exactly one is chosen (x=1) and all others are zero.
- The Crew Planning problem is one of the hardest in the industry.

Crew Pairings

- The variables that we are selecting from are called pairings. A crew pairing is a set of flights, starting from a crew base, and ending back at that same crew base. The pairing can be one day long, or it can be multiple days long and include overnight rests. Here are some sample pairings:

- DAL-HOU-MSY-BNA-DAL (one day)

- HOU-LAS-SEA / overnight / SEA-MDW-BWI / overnight / BWI-HOU

- With over 4000 flights per day, the number of pairings (up to 4 days long) numbers in the billions.

Crew Pairings

- Crew pairings have to meet several contractual and regulatory requirements:
- • Duty time limits
- • Flying time limits
- • Minimum rest requirements

- Additionally, we can move crew around on flights where they are not operating the flight. This is known as deadheading.

- If the crew need to change aircraft, we need to allow a certain amount of time to reliably get from one aircraft to another and perform all of their functions on the new aircraft before takeoff (preflight checks for pilots, loading passengers for flight attendants.)

Crew Costs

- Each pairing has a pay value that a pilot or flight attendant will get paid to operate the pairing. This is contractually specified and contains several guarantees:
- The actual flight time of operating legs plus deadheading legs
- A guaranteed minimum amount per day. If the actual flight time is less than this, the crew member is paid the minimum anyway.
- A guaranteed average over the length of the pairing.

- Pay is a complicated, nonlinear function. Fortunately, all of the variables (different pairings that may be selected) are binary integer variables: they may be selected (1) or not selected (0). Once the cost is calculated, we can model it with a linear objective function.

Staffing

- We also have to follow limits on the amount of staffing that we assign to each of our 10-12 crew bases. Staffing changes month to month as we have retirements, new hires, and first officers upgrading to captain.
- Besides assigning each flight exactly one crew, we have to stay within staffing limits.

Crew Pairings

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