McGill University

Desautels Faculty of Management

MGSC 662
Decision Analytics

Project Report
The impact of COVID-19 in the airline industry

Team 5

Ramprakash Babu	260958970
Alfonso Cabello	260951697
Arnaud Guzman-Annès	260882529
Jules Zielinski	260760796

Due date: December 3rd

I. Introduction

The economic impact of COVID-19 is being felt on a large scale and more so in the aviation industry. United Airlines, one of the most affected companies, has taken drastic measures to conserve as much liquidity as possible to be profitable in the short and medium term. The goal of our project is to help United Airlines do such a thing by maximizing the profit of its domestic flights. This means that our model is trying to find the best possible combination of airplanes in routes that will both increase revenue and reduce costs for the company.

This project is interesting in the sense that it can be applied to the real world. The optimized number of plane and type per route is a useful information that a business can use to leverage its assets in the best way possible. United Airlines will therefore know for example that they need 7 Boeing 737 in their Denver to Newark Route.

This type of insight also comes with a touch of reality as the constraint we have implemented during our modelling reflect the constraints that the company has to deal with on a daily basis. Starting from demand, aircraft availability and flight frequency, this model is a reflection of what any airline company is subject to when running their business.

Another major problem that can be dealt with using this model is the effect of COVID-19 on United Airlines. As mentioned earlier, the aviation industry was greatly affected by the pandemic, these changes having a major effect on customer demand and operational costs among other things. The model we have built has been created in a way that makes it able to handle these temporary economic setbacks by tampering with the different constraints. For example, to still get an optimized airplane distribution for this airline.

II. Problem Description and Formulation

United Airlines took some drastic measures which directly affected the way they would be conducting business from now on. Some of those measures which also affected our project included the retirement of older airplanes such as the Boeing 747 from its fleet or the price cuts on tickets from and to most of their destinations. Our model has the task to take all those changes into consideration and maximize the profit of United Airlines. Mathematically speaking, this means maximizing the number that results from the difference between the total revenue and the total costs of the company. The objective function is presented by equation 1.

$$Maximize: Profit = Total\ Revenue - Total\ Costs \tag{1}$$

To maximize the profit, we must take into consideration other factors, which are also known as constraints. Let us go over them one at a time.

The first constraint that will be discussed is a simple yet essential for the proper functioning of the model. Put simply, this constraint ensures that a plane will not be serving a route from a given airport going to that same airport. For example, a plane would not be able to fly from Denver to Denver as this brings no value to United Airlines. Constraint 1 is presented by equation 2.

$$Route_{ij} = 0 \tag{2}$$

Where I and J are airports and I$= J$

The second constraint that we will be discussing covers the need that customer demand from each route be met. Mathematically, the sum of all the seats in all the flights covering two airports must be superior or equal to the demand for that route. Constraint 2 is presented by equation 3.

$$\sum(S_i * X_{ijk}) \geq Route_{ij} \tag{3}$$

Where X is the total number of planes of a certain type
X is total planes of a given type
I and J are airports

Another important constraint that was included in this model is the one involving the aircraft's daily availability. Given that a United Airlines plane can only be in the air for a total of 20 hours per day, the sum of all those hours for all of the airplanes on that route has to be greater than or equal to the time of flight between the two destinations multiplied by the total number of flights that are required daily between the two airports. Twenty hours per day constraint can be explained by the need to give airport employees time to fuel the planes, board passengers and prepare it for the next flight. Constraint 3 is presented by equation 4.

$$20 * \sum X_{ijk} \geq F_{ij} * A_{ij} \tag{4}$$

Where X is the total number of planes of a certain type
F is the required daily frequency of flights
A is the flight time for that route

Flight frequency is an important constraint that needs to be added to our model, in the sense that each route must be covered a certain number of times by the fleet of airplanes between two destinations. Let us take the example of the Chicago-Newark trip that has the highest demand out of all the flights offered by United Airlines. Some of the clients are interested in taking morning flights, while others might be interested in flying in the evening. This constraint ensures that all those options are covered when the airplanes are dispatched to their destination. Constraint 4 is presented by equation 5.

$$\sum X_{ijk} \geq F_{ij} \tag{5}$$

Where X is the total number of planes of a certain type
F is the required daily frequency of flights

Finally, this last constraint might seem trivial but can easily throw off United Airlines' scheduling process if not added to our model. This restriction restricts the total number of planes of each type that can be used by the company. Put simply, if United Airlines owns 48 Boeing 787, they cannot have more than 48 aircraft assigned to their different routes. Constraint 5 is presented by equation 6.

$$X_{ijk} \leq C \tag{6}$$

Where X is the total number of planes of a certain type
C represents a constant of maximum plane availability

III. Numerical Implementation and Results

Please refer to file: Project_United.ipynb

United Airlines being one of the biggest companies in the airline industry, we decided to reduce the scale of our optimization models to only focus on their domestic flights. As we started doing more research, we realized that covering their 238 local destinations was unfeasible in the amount of time that was given to us. Therefore, we focused on maximizing the revenue from their 7 hub cities, which meant optimizing the airplane distribution on a total of 42 routes, since a customer could go to any of the other 6 hubs when starting their trip at one of those 7 places. (7 * 6 = 42) Those seven hubs are shown as Figure 1-A in the appendix and are also listed below:

- Denver (DEN)
- Chicago (ORD)
- Newark (EWR)
- Washington (IAD)
- San Francisco (SFO)
- Los Angeles (LAX)
- Houston (IAH)

Those cities are called hubs as any passenger that needs to go to a secondary airport needs to have a stopover at one of these places before going to their final destination.

Then came the aircraft that need to be assigned to a given route. As of October 2020, United Airlines' fleet was composed of 806 airplanes, all of them being built by either Boeing or Airbus. Domestically, United Airlines only uses 5 aircraft types which are:

- Boeing 787
- Boeing 777
- Boeing 767
- Boeing 737
- Airbus 320

Each of those airplanes can fly from one hub to another in one trip. They can also be in the air for a total of 20 hours a day, the remaining 4 hours being needed to refuel and load the plane with passengers and luggage (Turnaround time). After doing some research and filtering for the data that we needed, we created a table that included each of the aircraft's seating capacity, operating costs (in $/hour) and the number of each type of plane that United Airlines reserved for their domestic flights. Table 1 present this information plus a description of each aircraft.

Table 1: United domestic aircraft description

Aircraft	Seating capacity	Operating costs ($/hr)	Number of planes used domestically	Comments
Boeing 787	300	5,310	48	Wide body twin jet. Capable to flight very long distances and carry 300 passengers. The B787 is the state of the art in terms of fuel efficiency and operating costs.
Boeing 777	320	7,220	97	Wide body twin jet with long haul capabilities. Capable of carrying 320 passengers. It is currently United Airline's biggest aircraft.
Boeing 767	260	4,980	136	Wide body twin jet of medium size. United Airlines' fleet of B767's is getting old and it is being considered removing them from the fleet soon.
Boeing 737	160	3,010	54	Narrow body aircraft with good short- and medium-haul capabilities. Can carry up to 160 passengers.
Airbus 320	150	2,840	94	Direct competitor of the B737. United Airlines is interested in investing in the new NEO version with more efficient engines as one of its main features.

Once we set our data into different arrays in our pulp model, our next step was to create the variables which we are trying to optimize. We first decided to call those variables X. Each of those X would represent a specific route flown by a specific plane. We represented those variables in pulp by adding three components: component *i* representing a plane's starting airport, component

j representing a plane's destination airport and k representing the type of plane used to cover that route. Variable description is presented by equation 7.

$$X_{ijk}$$

Where i is the starting airport
j is the destination airport
k is the type of plane used. (7)

In real life terms, this means that every route has a total of 5 variables attached to it, representing the 5 different types of planes that United Airlines uses domestically. In total our model therefore must optimize a total of 210 possible options. (42 routes * 5 plane types = 210 variables)

We then proceeded to add our objective function and our constraints in the way that we have discussed earlier. The only thing that was left for us to do was to run the model and find the optimal solution, which turned out to be a profit of **$2 722 859**. The specifics of that result are listed in Table 2.

Table 2: Profit for each plane and total number of planes assigned

	Optimized Values
Profit	$2 722 859
Number of Boeing 737	136 planes
Number of Boeing 767	38 planes
Number of Boeing 777	0 planes
Number of Boeing 787	41 planes
Number of Airbus 320	97 planes

This solution makes a lot of sense to us as we expected the number of planes required to cover United Airlines' demand to be big simply by looking at the overall customer demand. In terms of the profit, despite being very high, $2.7 million seems like a realistic number, since our model has not considered all of the company's costs, but only the costs of flying the planes. Once costs such as management, pilots and personnel salary for example are removed from the total profit, we would be getting a result that is more representative of the real profit United Airlines makes on a daily basis.

In terms of the flight, we were able to extract the specifics on how many airplanes of each type are needed on each route by looking at the sensitivity report. Figure 2-A presents the 20 largest values of X_{ijk} to get an idea of the plane distribution in each route. The final value column in that figure describes the total number of planes of a certain type that a route needs to have to maximize profit. By looking at this report, we can say that the 5 largest routes in terms of total plane of a single type require a combined 59 aircraft to maximize profits. These solutions seem valid, since the routes with the highest number of required planes are also the ones with the highest customer demand.

Another interesting information that we can extract from that report is that some of the routes bring in more revenue than others. By looking at the reduced cost column, we can say for example that the Newark to San Francisco flight using a Boeing 737 brings in a total of $18 812.50 per trip, which makes it the most profitable route of our model. On the other hand, each Newark to Denver's flight only brings in a profit of $3762.50, which makes it the least profitable route of all the ones we have covered in our model. This information can be very useful for United Airlines, as they can adjust their prices according to these marginal profits to increase their revenue margin for example and increase their cash inflow at year end.

The nature of the solution is compatible with the understanding of our problem, since we are trying to maximize profit based on the airplane distribution of United Airlines' fleet. Having an optimal value being positive with a given number of airplanes being attached to a given route is exactly what we were hoping for when first building our model.

IV. Problem Extension

Please refer to file: Project_United_Stochastic.ipynb

Today, the airline industry is one of the most highly competitive sectors in the world, generating billions of dollars every year with a cumulative profit margin of less than 1%. Low margins in the industry could be attributed to the fact that profits gained by a company is largely impacted by the uncertainty of various factors. Price and route demands vary drastically in a short time, which forces businesses to constantly evolve and alter their strategy to the changing trends. In the wake of COVID-19, things have taken a turn for the worse as demands have plummeted due to various travel restrictions imposed all over the world.

In our project, we have used historical data to estimate the average demand for each route along with the cost associated with flying. However, our model does not consider the above-mentioned uncertainty. To make the project more representative of the real world, we have developed a stochastic model which is an extension of our solution, to consider factors that affect the variability in the price and demand. In this model, we assumed that the price and demand for each route varied in a normally distributed fashion, around the true mean that we have set in the original model.

We modelled the demand and the cost per flight for each aircraft, to be normally distributed with a standard deviation of 1000 for cost and 100 for demand per route. In pre-pandemic conditions, we can attribute these uncertain demands to various factors like wage inflation and union strikes. The demand for air travel has had a steady increase from 2007 to 2017 with an increase of around 15% according to US Bureau of Transportation. With this, the labour demands have risen, and employees are demanding higher compensation for their service. This has had a significant impact on United Airlines' business which adds to the extremely variable planning horizons. This, along with competition from other airline companies, make demands for each route vary drastically and this subsequently results in low profit margins and vulnerability.

Price is another factor that changes radically due to the economic impact. Prices of oil, fuel, landing fees, catering and crew expenses are unpredictable and could spell disaster for companies if their variability is overlooked. One thing we can note here is that the more a flight operates on air, the lesser the company has to pay for variable costs. Thus, situations like flight cancellations, or unfavourable weather conditions could add to the variable expenses and takes a toll on profit. Also, different flights have different costs per nautical miles. A jet for instance would be more expensive in terms of nautical miles, but it could travel much faster, and thus decreasing the duration of flight time.

With the above-mentioned conditions in place, we were able to run a simulation of 14 trials, each time with varying demands and prices per route for different aircraft. From this experiment, we noticed that the overall profit at optimal conditions range from $2 million to $4 million USD with changes in the optimal number of flight combinations for each aircraft for each trial.

This model gives us a better understanding of the amount of uncertainty and risk involved in running an airline business as we are constantly forced to anticipate the best flight schedules, passenger demands and variable costs that can be incurred for each route. This is one of the primary reasons why optimization and operations research are of paramount importance in the world of aviation and companies are actively investing to strengthen their analytical capacity to get ahead of their competitors.

V. Conclusion

Besides setting up the different fleets that are required for each route as we discussed earlier, our recommendation for United Airlines would be to purchase more Boeing 737. The reasoning behind this recommendation is that the company just got rid of its Boeing 747 airplanes, meaning that they would have to be replaced. Since the 737 brings in the most profit out of all the airplanes that United Airlines currently owns, it seems intuitive to purchase more of them to increase the business' profit margin. It is also well known that the performance of Boeing 737 is a game changer. Indeed, their low ratio cost per passenger make it an extremely efficient airliner.

Furthermore, we have learnt from this project that despite the airline industry having some of the most complicated optimization problems, there is still a way for them to make a profit when their resources are used properly. Even United Airlines which is one of the companies that was the most affected by the pandemic can still manage to stay afloat in those hard times using proper scheduling and operation management techniques.

If we were to do this project again, we would probably try to find a dataset that contains all the information that we need rather than having to scrape United Airlines' website. By doing so, we will ensure to get information that is timely and fits together rather than having to assemble what seems like a dataset puzzle. This would also allow us to automatize our model rather than having to manually input data for each of our variables.

This experiment, despite being full of insights, is not quite real world ready, since it does not fully represent the extent to which United Airlines does business (e.g., cargo division, leasing contracts of airplanes, tourist packages, fidelity programs and company alliances). There are hundreds of secondary airports that were not included in our model, both domestically and internationally.

However, our model is still very relevant, and more data can be added to it so that it can eventually be used in a real-life context.

VI. Appendix

Figure 1-A: United Airlines Hubs

Figure 2-A: Top 20 routes flown by United Airlines

	Variables	Final Value	Reduced Cost
145	LAX_to_EWR,type_Airbus_320	15.0	-13916.0
55	EWR_to_LAX,type_Airbus_320	14.0	-13916.0
46	EWR_to_IAD,type_Boeing_737	10.0	-3762.5
110	IAH_to_EWR,type_Airbus_320	10.0	-9940.0
125	IAH_to_LAX,type_Airbus_320	10.0	-9656.0
50	EWR_to_IAH,type_Airbus_320	9.0	-9940.0
66	EWR_to_SFO,type_Boeing_737	9.0	-18812.5
155	LAX_to_IAH,type_Airbus_320	9.0	-9656.0
171	LAX_to_SFO,type_Boeing_737	9.0	-4214.0
231	SFO_to_LAX,type_Boeing_737	9.0	-4214.0
181	ORD_to_EWR,type_Boeing_737	8.0	-6622.0
76	IAD_to_EWR,type_Boeing_737	7.0	-3762.5
176	ORD_to_DEN,type_Boeing_737	7.0	-7675.5
216	SFO_to_EWR,type_Boeing_737	7.0	-18812.5
26	DEN_to_ORD,type_Boeing_737	6.0	-7675.5
61	EWR_to_ORD,type_Boeing_737	6.0	-6622.0
172	LAX_to_SFO,type_Boeing_767	6.0	-6972.0
5	DEN_to_EWR,type_Airbus_320	5.0	-10224.0
16	DEN_to_IAH,type_Boeing_737	5.0	-7224.0
24	DEN_to_LAX,type_Boeing_787	5.0	-12213.0