Study Based on Integer Linear Programming on the Optimization of Airline Operation Strategies During the COVID-19 Pandemic

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Abstract: The aviation industry witnessed a severe decline in the volume of traffic due to the spread of Covid-19 in 2020. The profits of major airlines plummeted. The previous passenger experience-oriented flight arrangement strategies no longer adapt to the rapid-changing market, and even make things escalated. Thus, an optimized model based on integer linear programming was proposed aims at cutting down the overall cost of operation. Key variables like oil price, aircraft types, capacity are considered in this model. We testify our model on a data set that recorded transportation information of six busiest airways in China. Results show our model can help airlines save money effectively and productively.

Keywords: COVID-19 Pandemic, flight operations, assignment model

1 Introduction

China acted quickly, placing strict quarantine protocols from the start of 2020, when the COVID-19 pandemic first began. While everybody was staying at home, the entire aviation industry is facing a serious economic crisis. In as early as April 2020, the 2020 annual revenue of global Civil Aviation Industry is proposed to decrease 44% than 2019, which amounts to 252.5 billion USD. [1] According to estimates, most airline companies around the world cannot sustain their finance for more than three months without new relief or new loans. Some companies have already announced bankruptcy, while most companies are still struggling to survive with methods such as cutting the number of flights, using less planes, and delaying plane handovers. The impact of the pandemic also forced plane production organizations to slow or stop producing planes, which also directly affects the aviation industry by damaging the supply chain, and some medium- or small-sized suppliers with low-risk resistance will suffer from increased management and operation risks. In this crisis, organizations such as the main production companies and first-class supplier companies have more ways to survive because their large scale is easier to obtain relief from the government and loans from banks. On the other hand, third- and fourth-class suppliers are more likely to go bankrupt because of their small scale and larger difficulty to receive help and will lead to mergers and acquisitions by larger companies.

In a study by WANG Zhanchao, optimistic, neutral, and pessimistic speculations anticipate the global flight levels to return to pre-pandemic conditions by the summer of 2021, 2022, and 2023, respectively. According to the study, RPK values (think of it as a product of passengers and the

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distance they travel) will be restored by 2022, 2023, and 2024, respectively. The study also proposes that the demand for airplanes will decrease by one half for the next five years, which will affect the wider airplanes (such as Boeing 747 and Airbus A380) more than others due to the slow recovery of international flight routes. [2] The inadequacy of short-term debt-paying abilities of China Eastern Airlines (CEA) is mainly due to the impact of the pandemic. To stabilize the flow of finance, CEA spread out the short-term liabilities. [3]

In another study, authors WU Donghua, XIA Hongshan, and FAN Yongjun created a Fuzzy optimization algorithm to improve the operation efficiency of aviation. With a guaranteed rate of success, the algorithm the team proposed can increase the average daily flight time by 2% and cut the grounded time by 14.3%. [4]

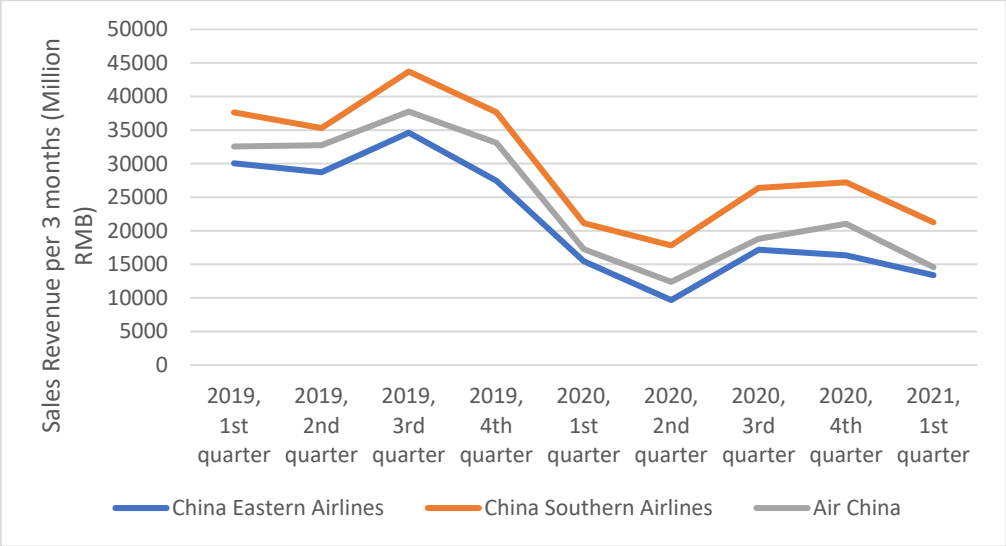
As proposed by FAN Wei and NING Junwen, a multi-objective optimization model for hub city selection in airline network can optimal airline network structure basing on rational selection of hub city and effectively reduce the total transportation cost. [5]

In a most recent report of Beijing Business Today by journalists GUAN Zichen and WU Qiyun, statistics provided by China Eastern Airlines, China Southern Airlines, and Air China all show promising signs of improvement from the losses of 2020 and early 2021. By June 30, 2021, the three corporations' losses in year 2021 still total to 16.5 billion RMB, or 2.55 billion USD. But with less COVID-19 cases appearing in China and more measures taken by the corporations such as increasing the use the airplanes to transport cargo, the industry finally sees a silver lining from the impact of the pandemic. [6]

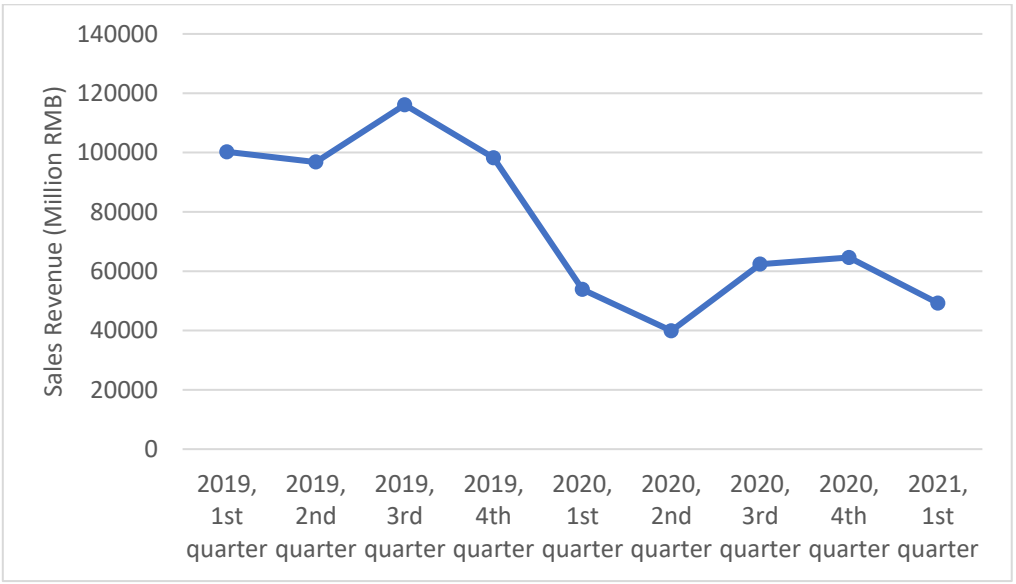
As of the end of March 2021, revenue coming from all main domestic flight routes are still significantly behind the pre-pandemic levels. It is imperative to maximize the profit of every trip in days which the entire aviation industry is put under such difficult situations. Doing so can help mitigate some of the layoffs and preserve jobs. In this study, p main flight routes and three renowned corporations will be analyzed by looking into their income, the number of passengers involved and attendance in these routes over the past two years and combining them with the specific capacities of the most popular airplane models and all related costs. An optimal Assignment Model will be proposed based on all the data collected. A more reasonable assignment of planes to flight routes can be more economical, which in turn helps the industry to recover faster.

2 Analysis of Airline Operations Data

The aviation industry suffered great losses in 2020. In Graphs 1, 2, and 3 below, the revenue of China Eastern Airlines, China Southern Airlines, and Air China from the first quarter of 2019 to the first quarter of 2021 is presented respectively with intervals of one quarter of a year. Graph 4 represents the sum of revenue from the three corporations.



Graph 1 Sales Revenue of the Three Airline Companies, Separately



Graph 2 Three companies combined

As in Graph 2, overall the pre-pandemic year of 2019 saw a 4% percent increase in revenue than 2018. But by the end of the first quarter of 2020, the number was already down by 46.2% than the same period in 2019. This decline grew to 52.4% by the end of June 2020, but retreated to 46.3% by the end of 2020. This signals that all the major airline companies in China suffered great losses throughout 2020, with the first half more severe than the second half. The income is still far from 2019 despite the slight rebound in July-December. As of the end of March 2021,

the revenue still dropped from the already low numbers of 2020. There may be the following factors:

-In January 2020, when the COVID-19 cases were just emerging, there were no complete policies to tackle the incident, and the people were not fully aware of the dangers of the virus. Plane travels still persisted and thus gathered more revenue than January 2021.

-2021 started with tight control of various regions where outbreaks of the virus have been spotted, and the government advised people not to travel unless necessary, and to celebrate the Chinese New Year where they were at the time (that is not traveling back home). A number of provinces and cities lengthened the quarantine or observation time needed after traveling to further keep the people doing so.

Each Airline Company shares similar trends with the overall income.

China Eastern Airlines ended 2019 with a 5.1% increase in annual income than 2018, but that of 2020 is 51.4% lower than 2019—more than a half. The first three months of 2021 saw another 13.3% decline than that of 2020.

China Southern Airlines concluded 2019 with a 7.4% increase than last year, but still lost over 40% of its annual income in 2020 than 2019. The first three months of 2021 for China Southern Airlines, however, differed from CEA by achieving a slight increase from 2020.

Air China reported a lower income by the end of 2019 than 2018. 2020 ended with a 49% decrease from 2019, and the company suffered another 15.5% dive in the first three weeks of 2021.

According to the latest news from August 4, 2021, most of CEA flights are suspending most of the onboard services and moving to pre-packed food. They also stopped handing out pillows, earbuds, newspapers, and magazines to prevent the spread of COVID-19. [7]

3 Problem description and model building

3.1Problem description

This study will be focusing on six flight courses which connects four major cities in China. By analyzing the number of daily travelers between the cities, the rate of occupancy, and combining them with the capacities and costs of three different aircraft models, and considering pandemic precautions, the assignment model will be used to determine the best combination of planes and flight routes so that the total cost is minimal.

3.2Nomenclature

Here the parameters and variables of this study will be explained:

n: Number of planes used

p: Number of flight routes

i: # of flight routes, i=1, 2, …, p

j: # of planes, j=1, 2, …, n

c_{ij}: Total cost, when the j-th plane is assigned to the i-th flight route

$x_{ij} = \begin{cases} 1 \\ 0 \end{cases}$, 1, The j-th plane will be assigned to the i-th route; 0, the j-th plane will not be assigned to the i-th route

b_i: Mean daily traveler flow on the i-th route, or the demand

a_j: The maximum capacity of the j-th plane

3.3Model Building

The target function is that of the total cost, $c_{ij} \cdot x_{ij}$

Constraint Conditions:

Ensuring that every plane only carries out one flight route:

$$\sum_{i=1}^{p} x_{ij} \leq 1 \quad (1)$$

The regulations require occupying every other seat, so a maximum of 50% occupancy is assumed:

$$\frac{1}{2}\left(\sum_{j=1}^{n} a_j \cdot x_{ij}\right) \geq b_i \quad (2)$$

4 Case analysis

4.1 Data Collection

4.1.1 Choice of Aircraft models (Based on capacity)

Up to now, the main models of China Eastern Airlines, China Southern Airlines, and Air China are Boeing 777, 747, 757, 737 and Airbus A330, 321, 320, 319, 300, 380. This study will focus on the more representative models of Boeing B777-300ER, B737-800, and Airbus A319. Boeing B777-300ER will be considered as a large model, Boeing B737-800 a middle-sized model, and Airbus A319 a small model. [8]

Table 1 Data of Aircraft

Aircraft Model	B777-300ER	B737-800	A319
Typical Capacity	361	189	124
Cruise speed	Mach 0.84 (560mph, 901 km/h) at 35,000 feet cruise height[64]	Mach 0.785 (514mph, 828km/h)	Mach 0.78 (450 knots; 833km/h)
Travel distance at max capacity	5,500 Nautical Miles (10,190km)	3,060 Nautical Miles (5,665km)	3,700 Nautical Miles (6,850km)
Maximum fuel storage	181,280 L	26,020 L	29840L

Calculated fuel consumption at max capacity	17.79L/km	4.59 L/km	5.06L/km

4.1.2 Calculation of Operation Costs

In terms of cost accounting of the Airline companies, the total cost can be broken down into the direct operation costs and the indirect operation costs. Direct operation costs contain the salary of the flight crew, the total owning cost of the aircraft (deprecation, operating leasing fares, insurance), fuel costs, maintenance fees, and other direct operation costs including budget for training the pilots and costs of business travels. Indirect operation costs include payments for maintenance personnel, management costs, attire costs, and more. In the Chinese domestic air transportation, the owning cost of the aircraft, fuel costs, and maintenance fees comprise about 57% — most of the total costs considered, and thus great indicators of the charististics and trends of costs of airline companies. Therefore, this study will model and analyze the deprecation and fuel costs separately as fixed costs and variable costs.

(1) Fixed Costs

The ownership of the aircrafts is also a factor of the total costs. This includes renting charges of the aircrafts or the costs of directly buying them. For easy comparison, this study will assume that the aircrafts are bought by airline companies and the deprecation term is 20 years, or 7300 days, and the price of the plane is spread out evenly during this time period. From China Aviation News (http://www.cannews.com.cn/) The November 2018 Boeing and Airbus prices in China can be found. [9]

Table2 Cost of Aircraft

Aircraft Model	**B777-300ER**	**B737-800**	**A319**
Price as of November 2018 (Million USD)	361.5	102.2	92.3
Deprecation Term (20 years /7300 days)	7300		
Deprecation **(USD/day)**	49521	14000	12644
2020 average USD-CNY exchange rate	6.8974 (Data source: *Statistical Communique of the People's Republic of China on the 2020 National Economic and Social Development*, Chinese National Bureau of Statistics, published Feb 28)		
Deprecation **(CNY/day)**	341566	96564	87211
Deprecation **(CNY/3h)**	113855	32188	29070

(2) Variable Costs

- Price of aviation kerosene

According to the statistics of aviation fuel on oilchen.net (https://dc.oilchem.net/), the average factory price for 2020 is 2915.81CNY/ton for Sinopec Group, or SINOPEC; 2891.31CNY/ton for China National Petroleum Corporation, or CNPC. This study will take the average of the two numbers of 0.5* (2915.81+2891.31)=2903.56CNY/ton. Assuming 1 ton of aviation fuel holds 1235 liters, then the price for aviation fuel is 2.35CNY/L.

- Fuel Consumption per Mile

The fuel consumption of an aircraft is influenced by the weather, taxiing/waiting time, cruise time, and rising/descending time. This study chooses **"**travel distance at max capacity" and "maximum fuel storage" to calculate the fuel consumption in an ideal case, and use the data we arrive at. (Data source: Wikipedia).

Therefore, the total operation cost of the plane is the sum of fixed costs and variable costs, or the product of fuel price, fuel consumption, and distance. [10]

(3) Airline and Mileage

As the economy grows in China, an increasing number of cities harbor two or more civil airports, so choosing different airports in the same city will affect the outcome. This study chooses Beijing Capital International Airport, Shanghai Hongqiao Airport, Chengdu Shuangliu International Airport, and Guangzhou Baiyun International Airport. The distance between the airports are the following (source: Ctrip):

Airline 1: Beijing-Shanghai: 1178km

Airline 2: Shanghai-Guangzhou: 1209km

Airline 3: Guangzhou-Chengdu: 1235km

Airline 4: Beijing-Chengdu: 1541km

Airline 5: Shanghai-Chengdu: 1668km

Airline 6: Beijing-Guangzhou: 1906km

(4) Operating Cost per single trip (Based on three hours)

Table3 Data Of Airline

B777-300ER				
	Mileage	Fuel Consumption	Fixed Costs	Operating Costs
Airline 1	1178	41.8065	113855	163103
Airline 2	1209	41.8065	113855	164399
Airline 3	1235	41.8065	113855	165486
Airline 4	1541	41.8065	113855	178279
Airline 5	1668	41.8065	113855	183588

Airline 6	1906	41.8065	113855	193538
B737-800				
	Mileage	Fuel Consumption	Fixed Costs	Operating Costs
Airline 1	1178	10.7865	32188	44894
Airline 2	1209	10.7865	32188	45229
Airline 3	1235	10.7865	32188	45509
Airline 4	1541	10.7865	32188	48810
Airline 5	1668	10.7865	32188	50180
Airline 6	1906	10.7865	32188	52747
A319				
	Mileage	Fuel Consumption	Fixed Costs	Operating Costs
Airline 1	1178	11.891	29070	43078
Airline 2	1209	11.891	29070	43446
Airline 3	1235	11.891	29070	43755
Airline 4	1541	11.891	29070	47394
Airline 5	1668	11.891	29070	48904
Airline 6	1906	11.891	29070	51734

4.1.3 Number of Flight Passengers

- Airline 1: Beijing Capital International Airport-Shanghai Hongqiao International Airport

According to the statistics of www.Umetrip.com on 12th September 2021, flights departing from Beijing Capital International Airport are 414 in total, of which 31 flights are destinated to Shanghai Hongqiao International Airport, accounting for 7.5%; the average number of the passengers taking off from Beijing Capital International Airport is 3,800 per hour, thus, the total number of passengers from Beijing Capital International Airport would be 60,800 based on 16 hours per day. And the passengers from Beijing to Shanghai would be 4,560 (60,800*7.5%).

- Airline 2: Shanghai Hongqiao International Airport- Guangzhou Baiyun International Airport

According to the statistics of www.Umetrip.com on 12th September 2021, flights departing from Shanghai Hongqiao International Airport are 333 in total, of which 33 flights are destinated to Guangzhou Baiyun International Airport, accounting for 10%; the average number of the passengers taking off from Shanghai Hongqiao International Airport is 3,500 per hour, thus, the total number of passengers from Shanghai Hongqiao International Airport would be 56,000 based on 16 hours per day. And the passengers from Shanghai to Guangzhou would be 5,600 (56,000*10%).

- Airline 3: Guangzhou Baiyun International Airport- Chengdu Shuangliu International Airport

According to the statistics of www.Umetrip.com on 12th September 2021, flights departing from Guangzhou Baiyun International Airport are 460 in total, of which 26 flights are destinated to Chengdu Shuangliu International Airport, accounting for 5.7%; the average number of the passengers taking off from Guangzhou Baiyun International Airport is 4,500 per hour, thus, the total number of passengers from Guangzhou Baiyun International Airport would be 72,000 based on 16 hours per day. And the passengers from Guangzhou to Chengdu would be 4,100 (72,000*5.7%).

- Airline 4: Beijing Capital International Airport - Chengdu Shuangliu International Airport

According to the statistics of www.Umetrip.com on 12th September 2021, flights departing from Beijing Capital International Airport are 414 in total, of which 32 flights are destinated to Chengdu Shuangliu International Airport, accounting for 7.7%; the average number of the passengers taking off from Beijing Capital International Airport is 3,800 per hour, thus, the total number of passengers from Beijing Capital International Airport would be 60,800 based on 16 hours per day. And the passengers from Beijing to Chengdu would be 4,680 (60,800*7.7%).

- Airline 5: Shanghai Hongqiao International Airport- Chengdu Shuangliu International Airport

According to the statistics of www.Umetrip.com on 12th September 2021, flights departing from Shanghai Hongqiao International Airport are 333 in total, of which 15 flights are destinated to Chengdu Shuangliu International Airport, accounting for 4.5%; the average number of the passengers taking off from Shanghai Hongqiao International Airport is 3,500 per hour, thus, the total number of passengers from Shanghai Hongqiao International Airport would be 56,000 based on 16 hours per day. And the passengers from Shanghai to Chengdu would be 2,520 (56,000*4.5%).

- Airline 6: Beijing Capital International Airport - Guangzhou Baiyun International Airport

According to the statistics of www.Umetrip.com on 12th September 2021, flights departing from Beijing Capital International Airport are 414 in total, of which 15 flights are destinated to Guangzhou Baiyun International Airport, accounting for 3.6%; the average number of the passengers taking off from Beijing Capital International Airport is 3,800 per hour, thus, the total number of passengers from Beijing Capital International Airport would be 60,800 based on 16 hours per day. And the passengers from Beijing to Guangzhou would be 2,200 (60,800*3.6%).

We estimate the number of passengers during the COVID-19 pandemic as 30% of that at the normal time, and the number of aircraft are considered at an adequate allocation of 30 of each type for the six airlines.

4.2 Results and Discussions

After solving the model by using python, the result is: [4, 0, 11, 8, 0, 0, 0, 1, 13, 0, 12, 2, 0, 8, 0, 0, 6, 0], which shows that by arranging the aircrafts and airlines as below, the least operating cost would be BMB 5,163,054.

Table4 Results

	B777-300ER	**B737-800**	**A319**
Airline 1	4 flights	0	11 flights

Airline 2	8 flights	0	0
Airline 3	0	1 flight	13 flights
Airline 4	0	12 flights	2 flights
Airline 5	0	8 flights	0
Airline 6	0	6 flights	0

5 Conclusion

This study investigates the arrangement of domestic flights in China under pandemic circumstances. The aircrafts' models, capacities, fuel prices, and passenger flow for each route are considered in establishing an integer programming model with the smallest operation cost as our objective function. The results prove that the improved plane-route assignment can significantly cut the operation costs.

(1) Adjust or reduce the transport capacity reasonably, and arrange flight routes scientifically.

The output should contract in this new market of reduced demands of travel, and the flight route arrangements should be adjusted. For example, middle-sized aircrafts should be added to some flight routes, and large aircrafts should be replaced. Transport capacity should be allocated to markets with greater demand, to increase flights in popular routes.

(2) Control the costs, and improve the operational system.

Airline companies need to take measures such as suspending flights, grounding planes, seeking for early maintenance, shifting the staff members, as well as stop renting some of the planes to lower the cost since the income is less than normal.

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