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A Study on Spare Aircraft in Brazilian Airlines

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Aviation Management Program – Class of 2019

EMBRY-RIDDLE
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CENTRAL & SOUTH AMERICA

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A Capstone Project Submitted to Embry-Riddle Aeronautical University in Partial Fulfillment of the Requirements for the Aviation Management Certificate Program

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This Capstone Project was prepared and approved under the direction of the Group's Capstone Project Chair, Dr. Leila Halawi.
It was submitted to Embry-Riddle Aeronautical University in partial fulfillment of the requirements for the Aviation Management Certificate Program

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Abstract

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Title: A Study on spare aircraft in Brazilian Airlines

Institution: Embry-Riddle Aeronautical University

Year: 2019

All around the globe, the airlines struggle to sustain profitability. They are deeply affected by the region's economy. It goes from the fuel price and exchange rate to the level of employment and average salary. That makes it imperative to control the cost, and also to balance very well the cost and level of service. Aircraft utilization is one KPI that measures productivity. Once the airline has a high aircraft utilization, it means that the resource has been productive, hence more cost-efficient.

On the other hand, flight cancelations and delays result in costs and passengers' dissatisfaction. In Brazil, there is a law that establishes how the airline must compensate the passenger; it is called "Resolução 400". According to the local law, the airlines are responsible for compensating the passenger even in weather deterioration that causes delays or cancelations. The researchers calculated the compensation cost with a flight cancelation and compared that value with the cost of one spare aircraft added to the fleet

The researchers used the software LINDO™ Classic student version to find the optimal fleet size of the network. The same network was uploaded in actual aviation network

optimizer, the AirVision® Planning, and Scheduling, and they obtained the same value. By increasing one aircraft to the fleet, the researchers could evaluate the effect on the aircraft utilization rate. The study provides the annual break-even point and compares the effectiveness of the spare aircraft with the investment of an extra airplane. If the spare aircraft, in a year, is capable of preventing 365 cancelations or more, it would pay the investments. The researchers considered only a fraction of the total cost of cancelation due to the availability and sensitivity of the data.

In conclusion, the researchers recommend that every airline proactively study and act on how beneficial having a spare aircraft can be to their operation. However, they should conduct it thoroughly, including all departments. So the total cost of flight cancelation or delay can be calculated, as well as the effectiveness of the spare aircraft. The investment with the aircraft can bring cost reduction and increment of passenger satisfaction.

Reumo

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Em todo o mundo, as companhias aéreas lutam para se manter lucrativas. Elas são profundamente afetadas pela economia da região. Esses impactos vão desde o preço do combustível e da taxa de câmbio ao nível de emprego e salário médio na região. Isso torna imperativo controlar o custo e também equilibrar muito bem com nível de serviço. A utilização de aeronaves é um KPI que mede a produtividade. Uma companhia aérea tem uma alta utilização da aeronave, significa que seus recursos apresentam alta produtividade, portanto, apresentam uma eficiência de custo superior.

Por outro lado, cancelamentos e atrasos de voos resultam em custos e insatisfação dos passageiros. No Brasil, existe uma lei que estabelece como a companhia aérea deve compensar o passageiro; chamado "Resolução 400". Que dita como as companhias aéreas são responsáveis por compensar o passageiro, mesmo com a deterioração de condições climáticas que venham causar atrasos ou cancelamentos. Os pesquisadores calcularam o custo da compensação com um cancelamento de voo e compararam esse valor com o custo de uma aeronave sobressalente adicionada à frota

Os pesquisadores usaram a versão de estudante do software LINDO ™ Classic para encontrar o tamanho ideal da frota da malha. A mesma rede foi carregada no otimizador de malha, o AirVision® Planning e Scheduling, e eles obtiveram o mesmo valor. Ao aumentar uma aeronave para a frota, os pesquisadores puderam avaliar o efeito na taxa de utilização da aeronave. O estudo forneceu o ponto de equilíbrio anual, podendo comparar com eficácia das aeronaves sobressalentes e o investimento necessário par se ter uma aeronave extra. Se a aeronave sobressalente, em um ano, for capaz de impedir 365 cancelamentos ou mais, pagaria seu investimento. Os pesquisadores consideraram apenas uma fração do custo total do cancelamento devido à disponibilidade e confidencialidade de dados.

Em conclusão, os pesquisadores recomendam que todas as companhias aéreas estudem proativamente os benefícios se de ter uma aeronave sobressalente para sua operação. No entanto, a análise deve ser conduzida por completo, incluindo todos os departamentos. Portanto, o custo total do cancelamento ou atraso do voo pode ser calculado, bem como a eficácia da aeronave sobressalente. O investimento na aeronave pode trazer redução de custos e aumento da satisfação do passageiro.

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Chapter I

Introduction

Commercial aviation is a highly competitive business. All airlines need to watch their operating costs to be economically sustainable carefully. Brazil provides a harder challenge when it comes to passenger compensations. Differently from the American legislation, in Brazil, the airline is obligated by law to provide compensations to the passenger in irregular operation. While in the United States, it is up to the airline to define its policy of compensations. This Brazilian law increment costs for the airline, especially in the operational disruption.

This project researched, based on the cost of compensation, when it is economically viable to have an extra aircraft. The benefit comes from preventing flight cancellations. The cost of having another aircraft was compared with the cost of providing compensations to travelers according to the Brazilian Law, 400 Resolution.

Project Definition

Airlines present small profit margins. In an environment deeply affected by economics and market index, such as inflation, level of employment, gross domestic product (GDP), aviation fuel price. On top of that, considering the Brazilian airlines, the volatile exchange rates play an important role. Fuel and aircraft costs are usually dollar-based. The weaker is the country exchange rate, and the worst will be the results for the airline— for instance, an airline in Brazil, whose currency is the Brazilian Real. When the Real loses value before the dollar, the airline revenue stays invariable; as a result, there is a deterioration of the net profit of the Brazilians airlines. It happens because of the fuel and leasing cost will increase (in the airline country currency), which will corrode the profit of the airline.

In figure 1.1, it is possible to see how the operating margin of the airline industry has been affected, economically, by events over recent years. It also shows how the margins have been improving continually over the years since 2008.

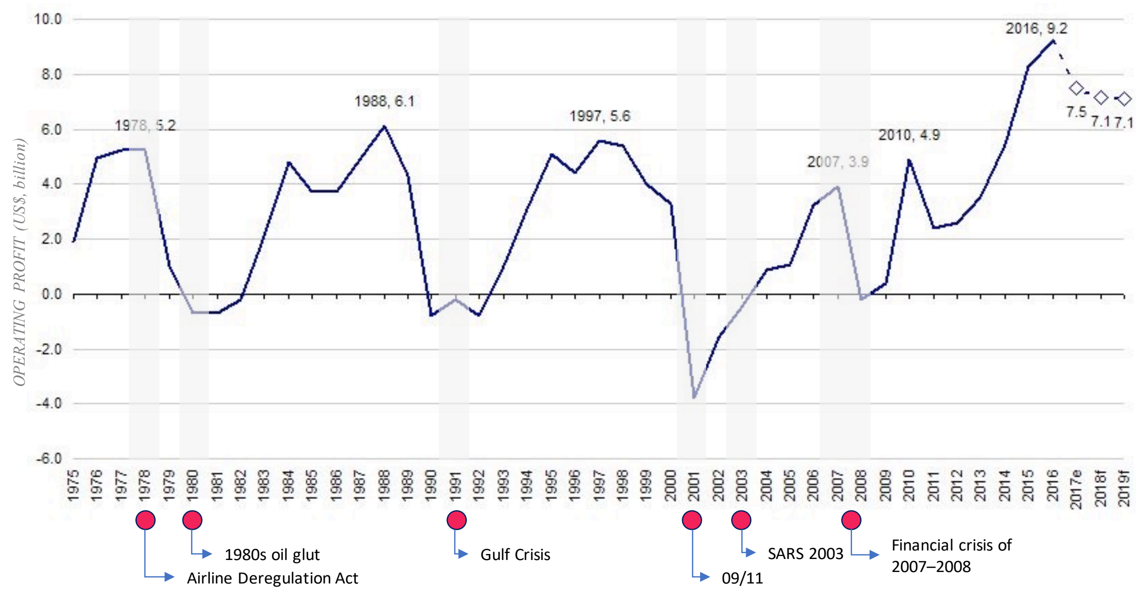


Figure 1.1. World airline industry operating margin (% of revenue) 1975 to 2019. CAPA. (2018).

In the report Vision 2050, the International Air Transport Association (IATA, 2011) addressed how volatile is the flight demand. People may travel for many reasons, such as visit friends or relatives, vacation, school events, conferences, and business. Usually, a company has as rival a company that offers the same kind of service. However, in the transportation service, it can be different. According to IATA (2011) the passenger, has as an alternative, more than the transportation service of another company.

Nevertheless, they can also choose not to travel, which can be expected to the leisure traveler. However, the business traveler travels because they need to meet someone and resolve an issue. From that perspective, the location may not be the final goal of the flight trip. But rather the conversation that those people will carry with each other. Once the main reason for the travel, for business, is the quality of the communication between people. The recent communication revolution brought new kinds of alternatives to flight travel, reinforcing the not travel alternative. The internet speed increased, the quality of virtual conferences is incredible and very useful. During periods of economic health, there are increments in flight demand (IATA, 2011), but the opposite happens during economic downturns. In the second situation, the likelihood of potential passengers to choose other means of transportation, such as car, bus, train, or even decide not to travel and hold online conferences increases (IATA, 2011).

The airline industry is intensely competitive, where the alternatives play a significant role. Constant efforts to reduce costs and improve productivity are crucial for an airline to survive. Legacy carriers have struggled against a tradition of high labor costs and high debt under a capital-intensive cost structure. However, in recent years, the surviving legacy carriers have made significant strides in bringing cost structure down toward the range of low-cost carriers (Vasigh, Fleming & Tacker, 2018). All airlines have fuel costs as a major expense and are continuously striving to improve fuel efficiency as well as aircraft utilization.

In Brazil, it is a common practice to have a spare aircraft to be used to replace another out of service airplane due to any structural, safety, or maintenance issue, well-known as Aircraft on the Ground (AOG).

As one of the goals of any airline is to increase the aircraft utilization index, those spare aircraft can reduce that number significantly. Consequently demonstrating lower operating efficiency and higher costs. Considering the airline's members of ABEAR, that represented 99% of Brazil's domestic aviation market (ABEAR, 2018). The cost with the ownership of aircraft is one of the highest overall costs of any company, as presented in figure 1.2.

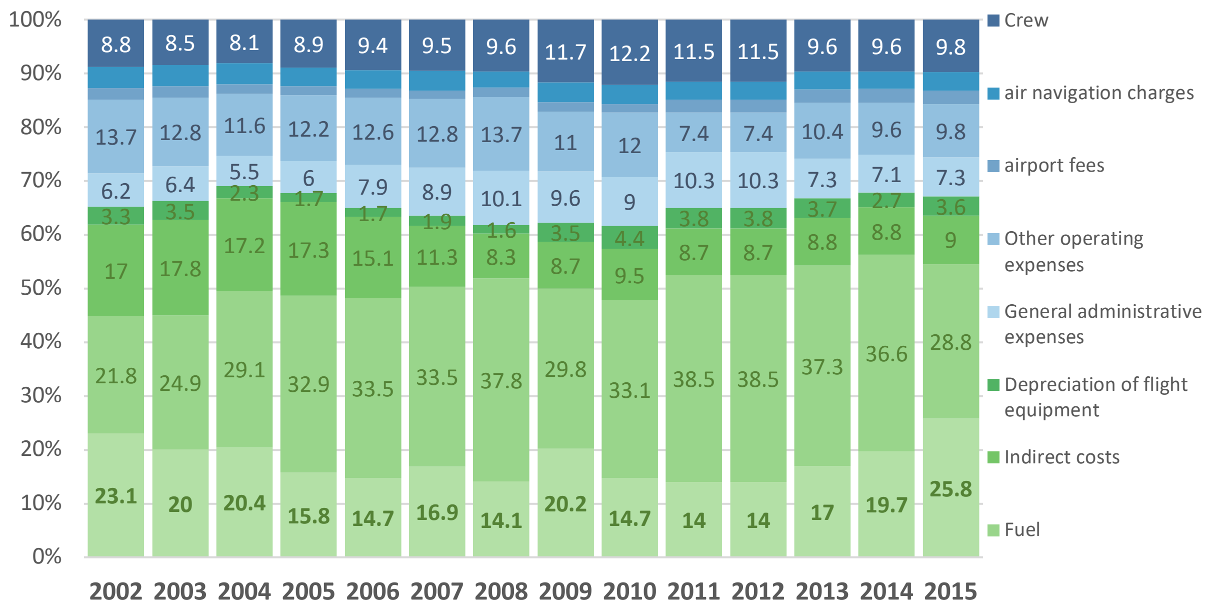


Figure 1.2. Breakdown costs of ABEAR Airlines Members in BRL from 2002 to 2015 (ABEAR, 2016a)

Those airplanes provide a backup plan for the flights that would be canceled or delayed due to the lack of planes available. That would prevent the airline from spending money with passengers' compensations, lawsuits filed by passengers, and fines as well. Differently, from other countries, Brazil has a regulation that declares the passenger rights and airline obligations; it is called "Resolução 400" or 400 resolution (ANAC, 2016). This regulation stated all compensations that passengers affected by delays, cancelations, and denied boarding should receive, which is applicable in the national territory.

The 400 resolution brought the additional cost under an irregular operation for the airline. Because of that, the researchers compared the cost related to "400 resolution" with the cost of having a spare aircraft. Other costs were included, such as lawsuits filed by passengers. In the Brazilian scenario, it was necessary to consider it; once Brazil is a high-level litigious country where it is common to take matters to court.

Project Goals and Scope

There is a challenge to balance operating costs versus customer experience. Vasigh et al. (2018) mention that cost reduction and productivity improvement are crucial for an airline to maintain its competitiveness. This project focuses on cost efficiency, taking into consideration the 400 resolution regarding passenger compensations in times of disruption.

This project aimed to evaluate and discover the optimal fleet size based on the Brazilian legacy airline network. The researchers evaluated the cost of an aircraft on ground (AOG) without a spare aircraft and compared it with a scenario where there is an extra airplane. The researchers took into account the financial and customer experience perspective of a Brazilian legacy airline.

The research question was: Is a spare aircraft necessary for a Brazilian Legacy airline that wants to control their On-time performance, costs, and improve passenger satisfaction?

This project aimed to study the benefits of an airline having a spare aircraft and evaluate its cost-efficiency. Costs related to passenger compensation and court condemnation played an essential role in this project. Those costs were used to compare and calculate the cost of having a spare aircraft as well the cost of having a flight canceled, based on the current laws established in Brazil.

The researchers used LINDO™ Classic Software to obtain the optimal fleet size. The two scenarios analyzed were:

1) The airline has only the optimum number of aircraft.
2) The airline has one spare aircraft on the ground.

In both cases, the same flight network is used. With that information, the researchers could calculate the potential cost with customer compensation and compare it with the cost of having a spare aircraft.

Definitions of Terms

400 Resolution	Is the current Brazilian regulation that determines the passenger compensations and duties, according to the Brazilian Authority
PAX	Passenger

List of Acronyms

ABEAR	Brazilian Association of Air Carriers
ACFT	Aircraft
ANAC	Brazilian National Civil Aviation Agency
AOG	Aircraft on ground characterized as out of service
ASK	Available Seat Miles
ATAG	Air Transport Action Group
BRL	Brazilian Real – the Brazilian currency
CASM	Cost Available Seat Mile

CEO	Chief Executive Officer
GDP	Gross Domestic Product
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
IROPS	Irregular Operations
JURCAIB	Board of Representatives of International Airlines of Brazil
KPI	Key Performance Indicator
LCC	Low-Cost Carrier
LP	Linear Programming
OCC	Operation Control Center
OP	Operational Research

Summary

The Brazilian legacy airlines are continuously facing financial challenges to sustain and generate profit, considering several environment variables as dollar-based costs, fuel prices, and customer regulations. In this context, this project reviewed in more detail relevant literature that encompasses these challenges and analyzed options to reduce its operational cost and be less exposed to market instability.

Chapter II

Review of the Relevant Literature

In this chapter, the researchers discussed how the airline business is such a challenging environment, both from an economic and competitive perspective. The researchers also brought information about how Brazilian laws, cultures, and economic condition that made the Brazilian aviation market even more challenging. In this section, the researchers discussed the concept of spare or backup aircraft to build a complete context of the scenario.

Challenges of a highly competitive market

For the last few years, there were some airlines bankrupted. A recent example is Avianca Brasil, a legacy airline that, due to financial insolvency, ended its operations in April 2019. This situation demonstrated how tough and competitive the airline sector is in the country. Tony Tyler (IATA, 2016a), IATA Director General and CEO, stated how the new cooperation formed between airlines. Joint ventures and the Joint Business Agreement (JBA) had increased efficiency and delivered options to the passenger. Now passengers have more diverse options to fly to a destination. It creates competition, which usually results in a price reduction or quality improvement. For instance, alliances between airlines make the world smaller, because far away destinations get better connected, making it easier to travel to the other side of the world. These cooperations also created more robust competition in the aviation market in Brazil. JBA, for instance, allowed signatory airlines to plan a network together, providing better connection points and flight schedules for passengers. Referring to 2017, the following IATA CEO Alexandre de Juniac (IATA, 2016b) stated that controlling cost is a continuous battle for the airlines in a hyper-competitive industry. It reinforces how competitive the market is.

An IATA (2011) report offered a comprehensive explanation of Porter's five forces model as it applies to aviation.

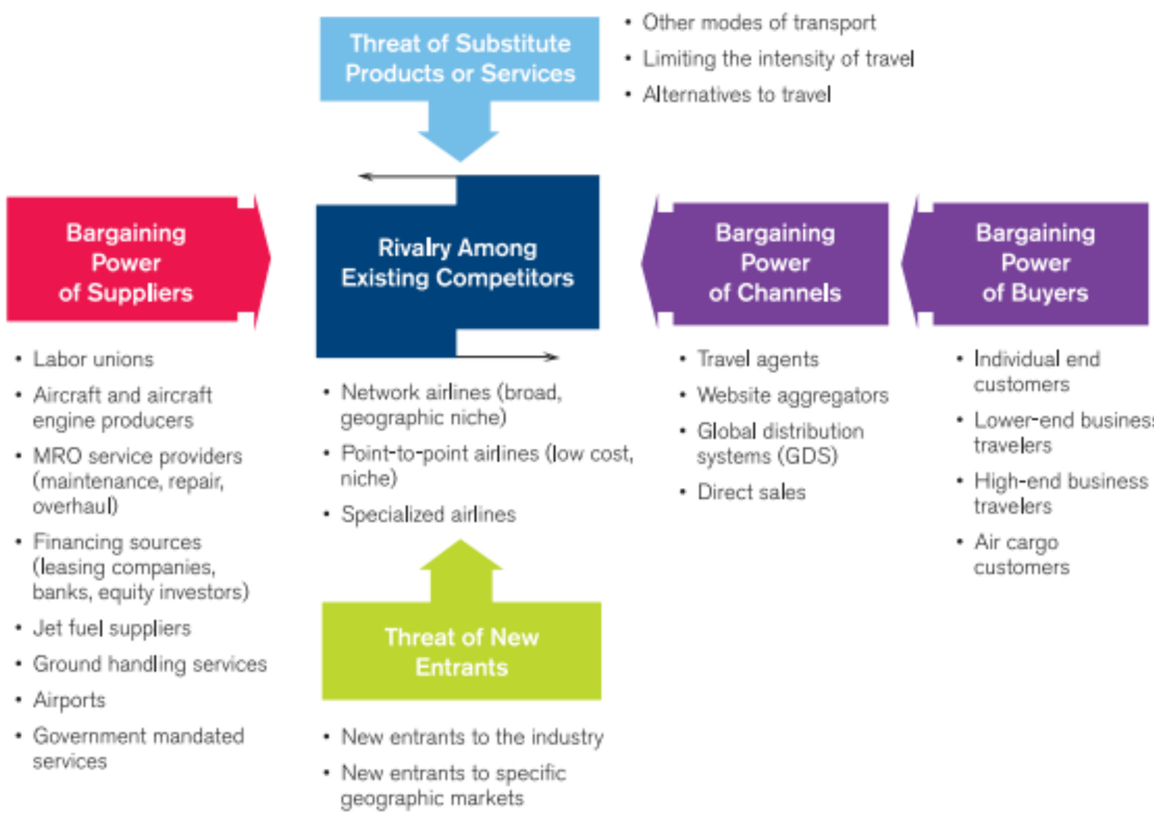


Figure 2.1. Determinants Porter's forces for airline industry profitability.

According to figure 2.1, this diagnosis is a useful methodology to analyze the external environment in which the aviation industry operates.

- Power of Suppliers: labor, aircraft, fuel, and third-party services (such as catering and ramp operations) are directly affected by the external environment.

- The Power of Buyers inside the aviation industry is moderated to high. Customers have a vast of options through the proliferation of online ticketing and competitiveness;
- Power of channels: currently, several other channels as travel agencies and websites focused on offering airline tickets have strong power for the airline.
- The threat of substitutes: other transport modes as train and drones, and even the advent of telecommunication, replacing a business meeting trip with a video conference call.
- New entrants: expansion of low-cost carriers in specific geographic markets and expansion of global economic aviation groups;

Statements of such prominent business people bring the investors' standpoint of view of the airline business. The IATA CEOs Tony Tyler (IATA, 2016a) and Alexandre de Juniac (IATA, 2016b) also touched on another very critical issue, the controlling cost aspects of the sector.

The passenger perspective

As mentioned in Porter’s five forces model, the bargaining power of the buyers is high and rising. This force is a well-known threat in the aviation industry (Porter, 1996) not just by the individual end customers but also by the lower-end and high-end business travelers. Dealing with a possible reduction in aircraft spare raises a concern regarding the experience of the customer. The impact that flight delays or cancellations would have on customers' experience and their decision on choosing to buy a future ticket is not objective data that could be easily measured. So it is indispensable to know what matters most for the passengers. First of all, it is essential to understand the passenger's profile.

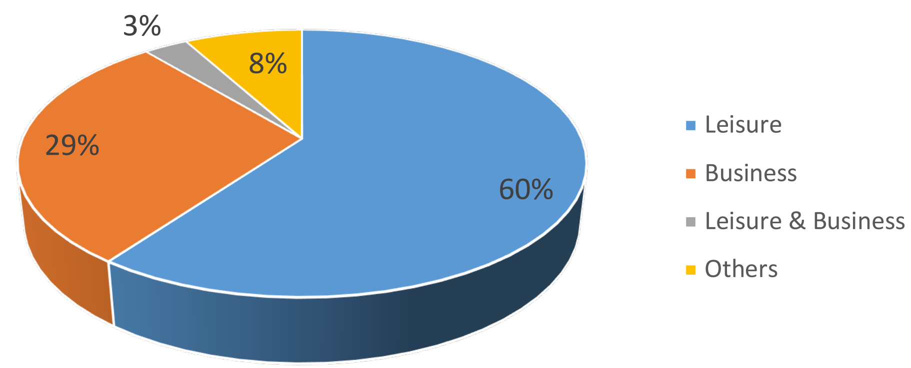


Figure 2.2 Percentage of travelers in Brazilian Airports by purpose (1st quarter 2018). Source: Brazilian Civil Aviation Secretary

Nowadays, more than ever, Brazilian passengers are traveling by air for leisure. As it can be seen in figure 2.2, in the Civil Aviation Secretary 1st quarter 2018 survey, shows that 60% of the traveler have leisure purposes. 29% are business travelers, while 3% represents those who travel for leisure and business purposes together, and 8% are others. The first quarter cannot be seen apart due to the school holidays. In 2018 second quarter the percentage of business travelers are increased by 7%, representing a total of 36% of the travelers in that period.

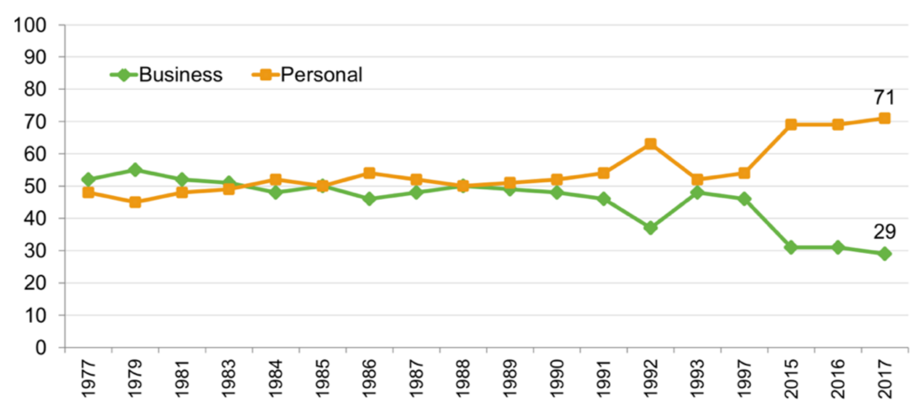


Figure 2.3. % of American Trips by purpose from 1977 to 2017. Airline for America (2018). Gallup and Ipsos Public Affairs

The average percentage of Brazilian business travelers, according to the Civil Aviation Secretary (2019) in 2018, is 32%, very close to the Americans (Airline for America, 2018). In figure 2.3, it is possible to see the reduction of business travelers over the years; the same 29% of American business travelers were found in the 2018 Airline for America survey.

The aviation industry knows the importance for the passengers to be on been on-time, OAG is one of the companies that reward the airlines around the globe for the KPI. The larger four airlines in Brazil in 2018 (LATAM, Azul, Gol, and Avianca Brasil), represent an average of 82.91% OTP. While North America companies represent a total of 79.87% OTP, as it can be seen in tables 2.1 and 2.2:

Rank	Coverage	Airline name	Code	OTP 2018
1	98.2%	Hawaiian Airlines	HA	87.52%
2	99.5%	Delta Air Lines	DL	83.08%
3	99.6%	Alaska Airlines	AS	82.61%
4	98.1%	Spirit Airlines	NK	80.83%
5	99.5%	Southwest	WN	78.20%
6	99.6%	United Airlines	UA	78.06%
7	99.7%	American Airlines	AA	77.65%
8	98.2%	Virgin America	VX	77.57%
9	97.2%	Allegiant Air	G4	76.92%
10	99.7%	Westjet	WS	76.26%

Table 2.1. North American Airlines ranking by OTP in 2018

Rank	Coverage	Airline name	Code	OTP 2018
1	98.9%	Copa Airlines	CM	89.79%
2	90.7%	LATAM Airlines Group	LA	85.60%
3	99.0%	Azul	AD	85.21%
4	98.0%	Volaris	Y4	82.04%
5	98.4%	Avianca Brazil	O6	81.15%
6	98.9%	Aerolineas Argentinas	AR	80.51%
7	98.4%	Aeromexico	AM	80.45%
8	96.3%	Sky Airline	H2	79.89%
9	87.5%	GOL Linhas Aereas	G3	79.70%
10	86.0%	Caribbean Airlines	BW	79.24%

Table 2.2. Latin America Airlines ranking by OTP in 2018

To evaluate an airline performance from the customer perspective, there are two vital indicators. The first is the on-time performance, which measures if the flight departed or arrived within 15 minutes of their scheduled time. The second is regularity, which is the flight cancelation rate. For people that are not traveling for business, price is the most crucial factor for their decision (IATA, 2011).

It is possible to see in Figure 2.4 that the Airline real unit costs went down throughout the years and so on the real price of air transport. By combining the information of figure 2.5, it is possible to see how the CASK and RASK go together, which shows us that cost reduction has beneficiated travelers with lower fares.

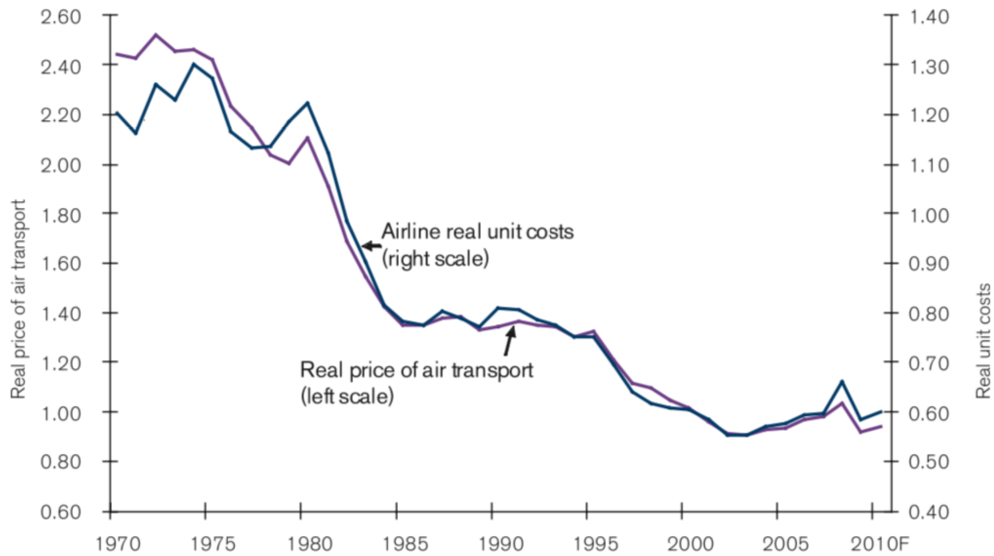


Figure 2.4. The real cost of air transport has more than Halved. IATA (2011). Source: ICAO, IATA

Focus on cost management

Vasigh et al. (2018) explained a few factors that make aviation such a difficult business to succeed. They named that seasonal component plays an important role.

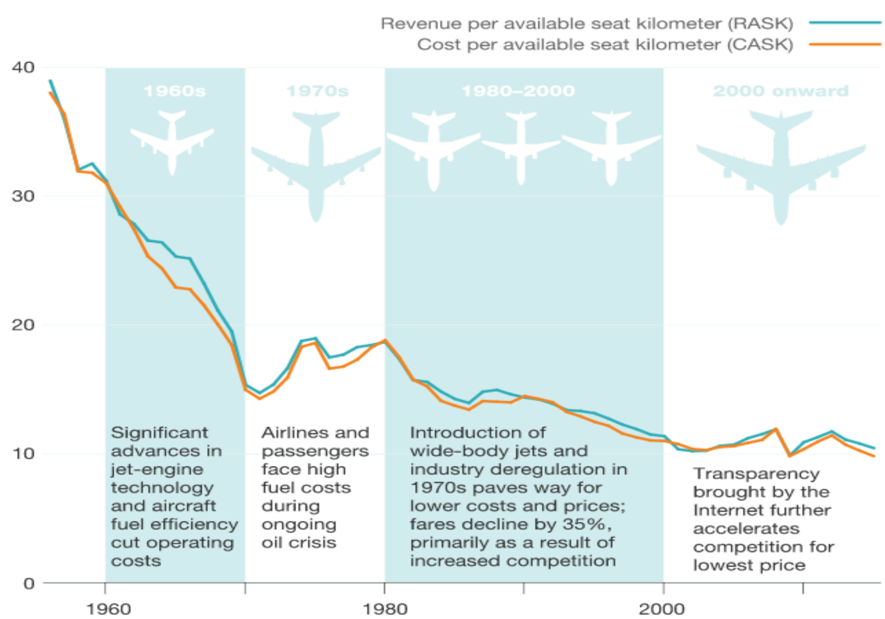


Figure 2.5. A history of the airline industry's revenues and costs, in 2015 US cents. (Saxon & Weber, n.d.).

Saxon and Weber (n.d.) opened their article "A better approach to airline costs," citing how ticket price has been decreasing. According to figure 2.5, they affirmed that on average, the price declines two percent every year over the past 20 years. One key element that drove this change is operational efficiency.

Figure 2.6 exposed how closely RASK and CASK evolve together. Also, the links between changes in the aviation scenario, the revenues, and cost per seat in the US market. Figure 2.6 presents a correlation of 0.958, which is a strong correlation between CASK and RASK in the Brazilian market (ANAC, 2018).

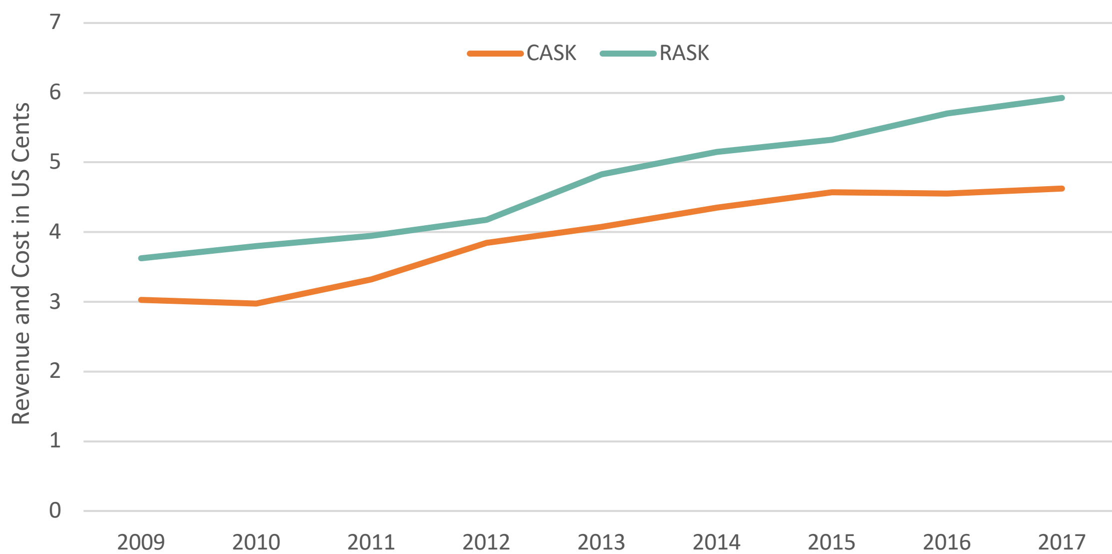


Figure 2.6. CASK vs. RASK in the Brazilian Airline Market between 2009 and 2017 (ANAC, 2018)

Vasigh et al. (2018) also commented that after deregulation, the industry in the US had a negative net income in 23 out of 26 years, which reaffirms how dependable the sector is in the economy and the level of competition.

There is no doubt that it is crucial to control costs. The most import indicator of cost for the airlines is cost available seat mile (CASM). According to Belobaba et al. (2009), CASM is the ratio between total operating costs by available seat miles (ASM).

The more spare aircraft an airline has, the higher is their CASM, which decreases their productivity and profitability. Therefore, find ways to reduce cost and increase aircraft productivity, such as optimized ground times, network flights, and fleet utilization, is crucial to surviving in this environment.

Cost Efficiency

There is another emerging market niche in the industry that is born with this focus on cost management, rather than the traditional service quality, the Low-Cost Carrier (LCC). The operational cost management is one of the strongest points of any successful incoming LCC. Schlumberger & Weisskopf (2014) affirmed that one facto of LCC model success is the high level of aircraft utilization. By having spare planes, a legacy airline is going in the opposite direction. According to the MIT Airline Data Project (n.d.), aircraft utilization is the aircraft block hours divided by the number of aircraft days assigned to service on air carriers. The Key Performance Indicator (KPI) of aircraft utilization usually is measured in block hours per day.

Concerning the aviation industry, Vasigh et al. (2018) cited higher aircraft productivity due to higher aircraft utilization as one of the essential sources for the economies of scale. Having that in mind, airlines had been assigning more flights for a plane to maximize their productivity. Which, in the case of an AOG, it makes it harder to absorb the effects of the lack of an aircraft. A significant change in the passenger travel schedule results in a high level of complaints, compensations, and possible lawsuits costs. Those schedule changes impact how the passenger perceives the company, making them less likely to recommend the airline. It happens because of the low level of satisfaction of the passenger.

In the Brazilian aviation market, there is an extra challenge due to the currency variation to control and reduce operational costs. Regarding the drop in international oil prices, ABEAR (2016) acknowledged that in Brazil, the airlines could not get its benefits. The devaluation of the Real, the Brazilian currency, against the dollar between 2011 and 2015 off-sets the international oil price gains. The fuel cost represented a large proportion of overall Brazilian airlines cost ABEAR (2016).

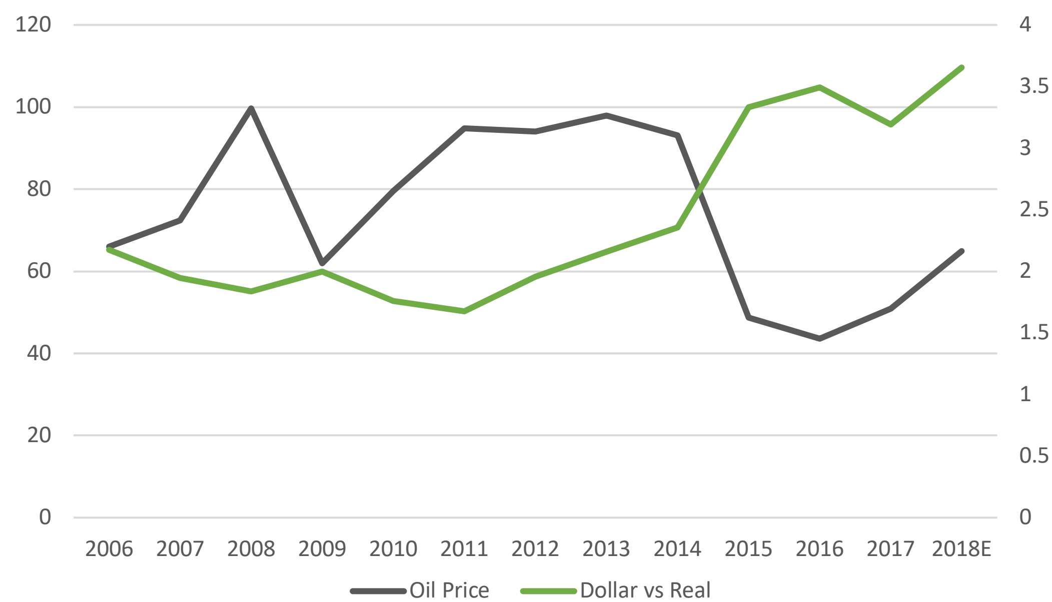


Figure 2.7. The variation between 2006 and 2018 (estimated) of International Oil Price and US Dollar exchange rate in Brazil. Data from international oil price from "Crude Oil Prices - 70 Year Historical Chart" and the dollar rate in Brazil from IPEA (2019)

Figure 2.7 showed exactly how oil price interacts with dollar vs. real. As Brazilian airlines are strongly reliant on these external macroeconomic variables when one is more favorable, another has a significant increase and vice versa. Therefore, they were unlikely to benefit from lower operating costs, which depends on the US dollar and aviation oil.

Another aggravating factor in the Brazilian industry was the impressive jet fuel cost in airports when compared with other countries. The reason is the high product taxations and logistical costs.

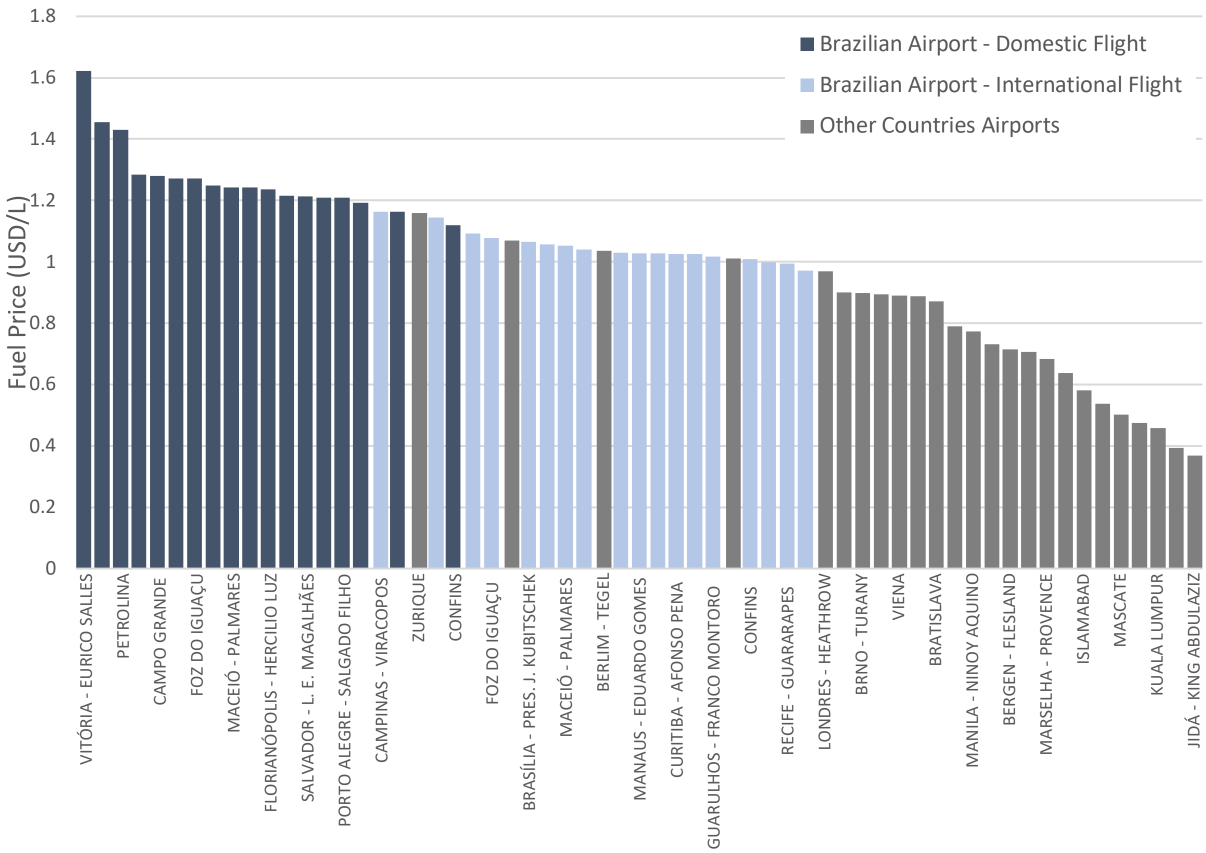


Figure 2.8. Comparison of Aviation Fuel Price in Brazilian Airports and other countries in 2016 (ABEAR, 2016)

Figure 2.8 presented the comparison of aviation fuel prices in Brazilian airports. It is possible to realize that in the Brazilians airports, domestic and international ones have a much higher fuel price average when compared with other countries.

Besides that, in the same report, ABEAR (2016) presented that there are additional dollar-based costs that affect the airlines in Brazil, such as leasing, maintenance, and aircraft depreciation. This significant increase in the participation of every cost happened due to the weakness of the Brazilian currency. The same report reinforced that countries with stronger currency such as Dollar (U$), Euro (€), and Pound Sterling (£/GBP) are not affected. They have more options to manage their fares and be more competitive in the market.

Spare aircraft

Establish the necessity of acquiring extra resources and how to use it is fundamental for the operating strategy. Irrgang (2000) suggests targeting slack in the region of one to three percent of aircraft. Another scenario the researchers studied is to have one extra resource unit available.

Spare aircraft are commonly used in airlines worldwide. It is part of each airline strategy, balancing cost, and customer satisfaction. Inside the Brazilian environment, all major airlines have additional aircraft located in their hubs to cover contingency situations during the day. The main reason is due to the costs related to customer compensations and regulations in the country that weight heavily on companies' final decisions. In order to be useful in more situations, some airlines that use more than one type of aircraft would have more than one aircraft type as spare aircraft. For example, it is necessary to have long- and short-range aircraft in strategic locations. The quantity of spare aircraft of each airline is part of the strategy of each airline. Because of that, it is sensitive information that the airlines do not provide or publish.

Having a spare aircraft is a way for airlines to ensure a regular operation. If the turnaround time becomes too short due to an aircraft delay, a spare aircraft can be used to not cause consequent delays in the network (Barnhart & Smith2011). By interrupting the delays cascade during the operations, the airline can avoid cancelations and also keep a higher OTP.

Cancellation sometimes is unavoidable. If the canceled flight is a round trip from a hub, it will sacrifice the first aircraft assignment. This action creates a temporary or virtual spare aircraft (Barnhart & Smith, 2011). By doing so, this aircraft can accomplish other flights to minimize the impact on the overall schedule.

Zhang (2010) defends the use of spare aircraft when maintenance is required. By having a slack aircraft, the airline improves its maintenance strategy.

There are a few ways to use a spare aircraft

The spare aircraft usually replace another airplane due to an issue and will not be able to fulfill its flight schedule. The most common reasons for this are due to maintenance or bad weather condition. For example, the maintenance team identifies in one aircraft, that is assigned to perform a flight, a maintenance issue. Those maintenance labor hours would result in the cancelation of the flight assigned to the aircraft in maintenance. However, if there is a spare aircraft in the airport where the aircraft with maintenance issue is, it can be replaced by the spare aircraft. In this case, the spare aircraft prevents the flights from been canceled. Even if the location of the spare aircraft is at a different airport (commonly left on the hub airport, where is most likely to be needed), it is possible to transfer the aircraft to the affected airport, in order to cover the impaired flight.

Another possible scenario is a bad weather condition. For instance, if there is an aircraft that will perform the following flights in this sequence:

- Flight 1: Airport A to B
- Flight 2: Airport B to C

Before the departure of flight 1, airport A is closed due to bad weather conditions, preventing the aircraft from departure. This flight will be cancelled and will generate a lack of an aircraft at airport B. The lack of aircraft will prevent flight 2 from being operated. In this scenario, if there is a spare aircraft in airport B, it will replace the aircraft that is stuck at airport A and prevent flight 2 from being canceled.

In these two scenarios, the spare aircraft prevents flights from canceling, which saves money with compensations and improves passenger satisfaction. Additionally, in order to make possible the operation of spare aircraft, it is necessary to have a crew available to perform it. Therefore, the flight planning department of an airline must consider the aircraft and crew availability to cover an impaired aircraft.

Where to place the Spare aircraft?

The spare aircraft needs to be at the airport where the flight will be performed to prevent it from canceling — assuming that the likelihood of maintenance issue occurrence is equal in every flight. The more flights an airport performs, the higher is the probability of having an issue that the spare aircraft can be used.

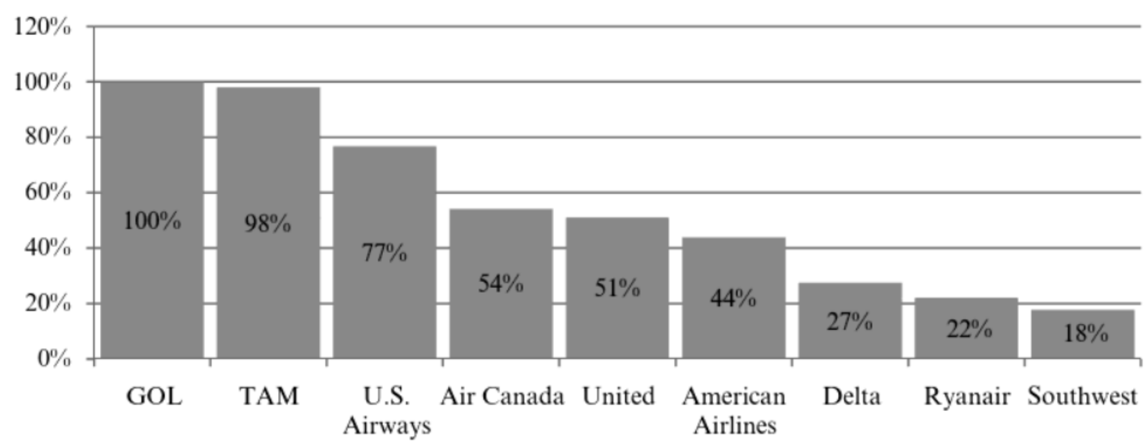
Another factor that needs to be evaluated in this decision is the proximity to other airports. That is important because the aircraft can be translated to a different airport to perform a flight that had an issue with an aircraft, preventing it from canceling.

The third requirement is crew availability. Having flexibility and, therefore, crew availability to be used on a spare aircraft is crucial for effective operation.

By evaluating these three factors, the best option and widely used by airlines is the hub airport. These locations, besides having a higher number of flights, thus more likely to require a spare aircraft, also have fast accessibility to any other destination that requires aircraft support.

Aircraft Leasing

According to O'Connor (2001), it is not a common practice for an airline to buy an aircraft with its resources, which is when the leasing option comes in hand. Currently, more than two-fifth of the current global fleet, and more than half of the new deliveries are leased (Guzhva, Raghavan, D'Agostino, 2018). Kaplan (2017) affirmed that today, 40% of the global aircraft fleet is leased, and in the '90s, it was only 15%. And, forty years ago, this percentage was less than two (Kaplan, 2017). A leasing contract is usually a long-term contract and sometimes includes a right to purchase a clause (O'Connor, 2001). According to Vasigh, Taleghani & Jenkins (2012), the leasing is a favorable alternative for the airlines, once they are in a business with low margins and volatile demand. The lease shields the airline balance sheets (Vasigh, Taleghani & Jenkins, 2012).



Vasigh, Taleghani & Jenkins (2012), cites a Brazilian example of GOL airlines, where almost all of 100 fleet aircraft are being leased. According to figure 2.9, it is possible to see that leasing is a popular option among Brazilian airlines. GOL and TAM present a high percentage of leased fleet, GOL has 100% of aircraft leased and TAM 98%.

Figure 2.9. Percentage of leased fleet (Vasigh, Taleghani & Jenkins, 2012).

Because of that, the researchers considered in the study the spare aircraft as being leased, as a dry leasing condition.

Dry leasing differs from a Wet leasing operation type. In the wet-leasing, the services, such as maintenance, crew, and others, are provided by the lessor. While in the Dry-type services are provided only to the aircraft (Guzhva, Raghavan, D'Agostino, 2018).

400 Resolution

Another characteristic of the Brazilian market that also affects any airline CASM is the compensation for an injured passenger. Since 2016, ANAC published a regulation named "Resolução 400" (400 Resolution) to establish the mandatory compensations for passengers in national territory regarding delays longer than one hour, flight cancelations, and overbooking. The regulation dictates that the passenger receives compensations that provide communication, food, transportation, and hotel when applicable. This initiative has generated a considerable increase in terms of direct costs for Brazilian airlines in recent years. It is important to mention that even in meteorological or infrastructure issues that are factors not under airline control, the airline still needs to compensate its passengers. Unlike the U.S. Department of Transportation (2017), there is no obligation for any air passenger carrier to provide any of those forms of compensations. In the United States, it is up to the airline established policy on flight delays and cancelations.

In this context, it is essential to mention the regulation established for the following compensations rules:

- On a delay over one hour, the airline in Brazil must provide communication assistance. If the delay is expected or effectively gets longer than two hours, the airline is obligated to provide food following the time the passenger is at the airport.
- If the original itinerary of the passenger changes over four hours, during night time, the airline must provide hotel accommodation for customers who do not live in the city where the airport is in addition to transportation to and from the hotel. Those passengers who live in the town, they have to receive transportation. The accommodation for a traveler with special needs, according to the legislation, must be given even during the day.

Lawsuits costs on Brazilian Aviation

A study conducted by the Board of Representatives of International Airlines of Brazil (JUCAIB - Junta dos Representantes das Companhias Aéreas Internacionais do Brasil) using data from ANAC in 2017, shows how high is the level of judicialization in the aviation sector in Brazil. Court convictions due to lawsuits filed by passengers represented approximately 1% of the operational cost of the Brazilian airlines. That 1% is the equivalent of U$ 78MM, which is the result of more than 60,000 lawsuits (Fenelon, Catanant, & Alencar, 2019). This effect is mainly supported by recent ANAC regulation (Resolução 400), which lay more demanding rights from passengers to the airlines.

That is alarming news. For 2019, IATA foresaw a net profit of U$200MM for all airlines in Latin American (IATA, 2019). The cost of those court convictions is 39% of all the foreseen profit for the region. To exemplify how high is the judicialization in Brazil, Fenelon, Catanant, & Alencar (2019) shared that an airline company operates around 5,000 flights daily in the United States and five in Brazil. In one year, they had 130 lawsuits filled in the USA and 1,200 filled in Brazil. The airline flew a thousand times more in the USA but had ten times more lawsuits in Brazil.

This topic was very relevant for this current project because the lack of a spare aircraft can result in flight delays or cancellations. The decision-making process of having or not a spare aircraft must consider the direct and indirect costs related to lawsuit costs in case of delays and cancelations.

Optimization applied in aviation

Many optimization models can be solved using linear programming (Bazargan, 2010). Companies like Jeppesen and Sabre sell tools to optimize operations. One example is the Jeppesen Tail Assignment software, a three percent higher aircraft utilization can be achieved by optimizing flights and maintenance together. It also takes into consideration operational costs and constraints (Jeppesen, 2019).

Sabre (2019) AirVision Fleet Manager assigns airline demand to the appropriate fleet type. This optimization maximizes revenue and lowers the company's operational costs.

Optimization and its capabilities

Optimization model analysis is part of the Operational Research (OP) field. OP uses mathematics and scientific methods to provide support for decision making. This field had its origin during the wartime, the 1930s. What started with a military purpose was extended to other uses (Dodge, 2008).

Usually, optimization problems are a compound of (Reeb, Leavengood, 1998):

- The variables: are the resources.
- An objective function: it is a function that will be maximized or minimized.
- A set of constraints: defines the limits of the variables.

According to Dodge (2008), mathematical programming (which includes linear programming and other problem-solving methods) appeared in the 1930s in the economics, with excellent contributions of John Von Neumann. Another very significant contributor to the field was George. Dantzing, the father of the simplex method, which is one of the most popular ways to solve linear programming (Shamir, 1987). The simplex method is an algorithm method of Linear Programming (LP) solution, which means that, with a set of rules and steps, it is possible to find the optimal value (Reeb & Leavengood, 1998). The Simplex method and graphical methods are ways to solve LP that can be applied even without the use of computers. An example of the use of this technique in airline settings is to stipulate the ground time of an aircraft. With a set of variables and restrictions, such as aircraft size, amount of passenger and baggage handling, and airport infrastructure limitations, it is possible to find an optimal ground time to be standardized for the referred airport.

Regarding Linear Programming, Sharmir (1987) also affirmed that it is the most commonly used optimization model. LP is an easy and powerful optimizing tool. Fourer, Gay, & Kernighan (2003) also affirmed that it does not matter how many variables or constraints there is. If it is possible to formulate the problem in linear programming, undoubtedly, the optimum solution will be found.

Sharmir (1987) cited allocation and scheduling problems as one of the strengths of the LP. The model intends to suggest optimized scheduling and flight allocation in the face of lack of aircraft, make sense to use LP to find an optimal solution.

Summary

In a highly competitive market, the legacy airlines have only one option to survive, which is to keep well balanced the cost challenges and customer service level. Focusing on operational efficiency, the airline must also consider its development variables like the economy as well as all other externalities, such as wars, diseases, and terrorism. These variables reduce the airline's net profit.

As aggravating, in Brazil, there is a recent strong regulation in favor of the customer, that defines that in cases of cancelations and some delays passenger must be compensated. This regulation increased the cost for airlines due to irregular operations. Besides that, the high judicialization in Brazil leads to cost with court convictions due to lawsuits filed by passengers. That information was very relevant for this project because it showed the impact on the traveler schedule and how it is linked to direct operational costs.

The optimization model based on linear programming provided the optimal fleet size. From that value, and combined with the airline network, it was possible to compare the impacts on passengers and operation in a scenario with an extra airplane with a scenario without an additional airplane.

Chapter III

Methodology

This project estimated the compensation costs of a Brazilian legacy airline and compared it with the cost of having a spare aircraft. The researchers used linear programming software to provide the optimal fleet domestic flight network. The researchers evaluated the impact on flight cancelation for the unavailability of an airplane in two scenarios. The first with no spare aircraft and then with one spare aircraft. This project used mostly public data. Since the analysis focused on domestic flights, the researchers removed the international flights. There were too many flights so that the model could fit in the researchers' LINDO Version. The researchers also removed overnight flights. As a result, the network fits in one day. By removing those flights, the researchers generated gaps in the schedule, so the researchers added flights to fill those gaps. With all those changes, the researchers kept the airline in which the network the researchers based their study on could be kept anonymous.

Research Question

This project intended to answer whether or not the passenger compensation cost, according to ANAC 400 resolution, justify, financially, the cost of an extra aircraft to prevent flight cancelation for a Brazilian Airline.

As the null hypothesis (H_0), the researchers have that a spare aircraft, seated in a hub airport, brings saving by improving the regularity rate (the percentage of planed flights that the airline performed) for a legacy airline in Brazil. On the other hand, the alternative hypothesis (H_a) states that the savings gained with a spare aircraft, reducing flight cancelation, does not cover the spare aircraft cost.

Flight Schedule

The researchers obtained the flight data from Diio (Business Intelligence for the Aviation Industry - https://www.diio.net/), which is a BI tool for aviation. This BI source provides information about all scheduled flights that any airline offers. To narrow down the project, the researchers have chosen the network of a Brazilian airline that had less than 800 flights. This is the maximum number of variables that the LINDO™ Classic student version could process. It is essential to notice that LINDO also offers other paid versions. The range of computational power varies from hundreds of variables to unlimited capacity (LINDO systems INC, n.d.). Of course, the larger the capability of the version more costly it is.

The researchers looked-up on data of august of 2018. To have a schedule to work with, the researchers have selected the network of one of the days of the month with the most number of flights. The researchers selected August 2th of 2018. Due to the LINDO™ Classic student version limitation, the researchers made a few changes to the original flight schedule. Those changes focused on generating a representative network for the Brazilian Market. For the study, the researchers wanted to evaluate a domestic flight network. So the researchers removed international flights. This removal created gaps in the network, so other adjustments were made that included new domestic flights. The researchers select those flights were randomly along with the network, and the only constraint was that the flight time was lower than the gaps created by the removal of the international flights. The researchers made another adjustment regarding the visualization of the results; the researchers made all flights fit into 24 hours schedule. So there are no overnight flights. Flights started and finished on the same day.

The mentioned changes in the schedule had two reasons. Even though the flight schedule is public information, the researchers have changed the flight numbers. The researchers wanted to make the airline anonymous so the study could be generalized and used by any airline. And secondly, to address the restriction of the LINDO™ Classic variable restriction, which the researchers used almost to its limit. LINDO™ Classic student version can process 800 variables; the researchers used 772 variables. It is worthy of signalizing that other paid versions options allow Lindo to process larger models. In this upgraded software, other variables like different aircraft models or types could be used, also maintenance restrictions, airport curfew, and even aircraft performance.

The network the researchers studied had 253 domestic flights in 27 airports. Another adjustment the researchers made was to simplify the operation by using only one aircraft, a narrow-body Airbus A320. That can be replicated by any airline that would want to perform a similar study with their information. The complete schedule of flights in the dataset can be viewed in Appendix A.

Optimization Model to verify the optimal number of aircraft

The researchers created an optimization model to run on the LINDO™ Classic student version. Based on that network, the researchers formulated the set of constraints and the objective function to find the optimal fleet size. The objective function is very straight forward. The objective is to minimize the number of aircraft needed. To achieve that, the researchers created variables that represent the number of overnight aircraft parked at every airport the airline operates. These aircraft stay at the airport overnight and are available to perform the flights at the beginning of the day. The network does not perform flights overnight, which means that it starts in one day and finishes at the other day.

Variables

The variables the researchers created represents the number of aircraft parked in each airport as followed:

- AJU0001: Number of overnight aircraft parked at AJU airport
- BEL0001: Number of overnight aircraft parked at BEL airport
- BSB0001: Number of overnight aircraft parked at BSB airport
- CGB0001: Number of overnight aircraft parked at CGB airport
- CGH0001: Number of overnight aircraft parked at CGH airport
- CGR0001: Number of overnight aircraft parked at CGR airport
- CNF0001: Number of overnight aircraft parked at CNF airport
- CWB0001: Number of overnight aircraft parked at CWB airport
- FLN0001: Number of overnight aircraft parked at FLN airport
- FOR0001: Number of overnight aircraft parked at FOR airport
- GIG0001: Number of overnight aircraft parked at GIG airport
- GRU0001: Number of overnight aircraft parked at GRU airport
- GYN0001: Number of overnight aircraft parked at GYN airport
- IGU0001: Number of overnight aircraft parked at IGU airport

- IOS0001: Number of overnight aircraft parked at IOS airport
- JDO0001: Number of overnight aircraft parked at JDO airport
- JPA0001: Number of overnight aircraft parked at JPA airport
- MCZ0001: Number of overnight aircraft parked at MCZ airport
- NAT0001: Number of overnight aircraft parked at NAT airport
- NVT0001: Number of overnight aircraft parked at NVT airport
- PNZ0001: Number of overnight aircraft parked at PNZ airport
- POA0001: Number of overnight aircraft parked at POA airport
- REC0001: Number of overnight aircraft parked at REC airport
- SDU0001: Number of overnight aircraft parked at SDU airport
- SSA0001: Number of overnight aircraft parked at SSA airport
- VIX0001: Number of overnight aircraft parked at VIX airport
- XAP0001: Number of overnight aircraft parked at XAP airport

The sum of all those variables will be the total number of aircraft needed to execute that network. This function will work because at the beginning of the day; there will not be any airplane flying because there is no overnight flight. The Objective Function is: Min:AJU0001+BEL0001+BSB0001+CGB0001+CGH0001+CGR0001+CNF0001+CWB0001+FLN0001+FOR0001+GIG0001+GRU0001+GYN0001+IGU0001+IOS0001+JDO0001+JPA0001+MCZ0001+NAT0001+NVT0001+PNZ0001+POA0001+REC0001+SDU0001+SSA0001+VIX0001+XAP0001

Regarding the constraints, there are two types of variables. The flight is the flight number (i.e., XX4000) and the number of aircraft at the airport at a specific time (i.e., AJU0530, which represents the number of aircraft at AJU airport at 05h30). There were two types of constraints:

1) The number of aircraft at the beginning of the day must be the same as the number of aircraft at the end of the operation day.

$$\mathrm{AJU0001} - \mathrm{AJU2359} = 0 \;\; => \;\; \mathrm{AJU0001} = \mathrm{AJU2359}$$

Where:

- AJU0001 is the number of aircraft at the beginning of the day.
- AJU2359 is the number of aircraft at the airport at the end of the day.

2) There must be at least one aircraft available to assume the flight planned. This means that at the time the flight occurs, there must be one less flight from the prior moment if it is a departure. In case of an arrival flight, it is added to the number of aircraft.

$$\mathrm{AJU0530} - \mathrm{AJU0001} + \mathrm{XX4225} = 0 \;\; => \;\; \mathrm{AJU0530} = \mathrm{AJU0001} - \mathrm{XX4225}$$

Where:

- AJU0530 is the quantity of aircraft at AJU airport at 05:30.
- AJU0001 is the quantity of aircraft at AJU airport before the DEP of flight XX4225.
- XX4225 is the flight that DEP at 05:30.

3) Every flight must have an aircraft assigned, which is every flight receives the value of one.

$$\mathrm{XX4225} = 1$$

This model generated 772 integer variables; because of that, the researchers finished the model with END GIN772. The complete model is presented in Appendix B. The result of this model is presented in the outcome chapter.

Comparison between LINDO™ Classic vs. AirVision® Planning and Scheduling

Another interesting comparison was generated by LINDO™ Classic versus the results generated by another airline tool of optimization of flight schedule, the AirVision® Planning, and Scheduling. Besides, the AirVision® Planning and Scheduling also provided a visualization of the network, which was essential for the study. This comparison aimed to evaluate how the result of the optimization model is coherent with the result of a tool applied by the airlines.

To perform the analysis on the AirVision® Planning and Scheduling, the researchers uploaded the data on the software and ordered the software to optimize considering First in First out (FIFO). Using FIFO rule makes the ground time longer, which helps the airline team to perform the various process they need to take care of during a Turn-Around. The other rules set on the system are actually what is used in the day-by-day by real airlines in Brazil. Because of that, details cannot be provided. However, the fact that it would be a result that a real airline would get makes the result very significative.

This tool is a potent one. It also has much functionality that not everybody knows how to use, mainly because some of those functionalities are made for specific studies of function in the airline business.

Cost factor involved in the cost of a spare aircraft

The researchers hypothesize that the cost with passenger compensation, according to the Brazilian Laws, could justify having a spare aircraft. So there is a reduction in cost by avoiding flight cancelation. That took us to estimate the cost of having a spare aircraft, which involves:

- Leasing
- Maintenance Reserve
- Parking Fees

The insurance was not taken into consideration since the operator usually pays for a pack, and one extra aircraft would not change it.

Aircraft Leasing Cost

To estimate the airline cost, the researchers used the leasing cost of an Airbus A320 since more than one-third of the world's commercial fleet is leased (Gomes, Fonseca, & Queiroz, 2013). Also, the leasing has become a common practice for airlines to “acquire” a new plane (Gomes, Fonseca, & Queiroz, 2013). It brings an advantage for the airline to maintain its capital, and keep its capacity close to its demand (O'Connor, 2001).

In this project, instead of using a multi equipment fleet, the researchers have used only one aircraft type fleet. It is a fleet of Airbus A320. In this project, instead of using a multi equipment fleet, the researchers used only one aircraft type fleet. It is a fleet of Airbus A320. Recently the International Bureau of Aviation (IBA) and the International Society of Transport Aircraft Trading published the current leasing costs for the A320ceo as

U$330k and the A320neo as U$370k monthly (Martins, 2019). In the study, the researchers considered the dry lease of A320ceo, which costs U$330k monthly.

Maintenance Cost Reserve

Based on the detailed explanation provided by the MRO provider Sofema (2017), the researchers were able to find out that the maintenance reserve cost for an A320 is U$157k monthly. In their example, Sofema (2017) assumed that the aircraft flies 150 flights per month. From that cost, U$120k is regarding engine maintenance, which is programmed based on the number of cycles or flying hours (Sofema, 2017).

The researchers studied the cost of one spare aircraft. Because of that, it would fly way less than 150 flights per month, actually less than 50 flights per month, one-third. So the cost with the engine should be reduced proportionally, to U$40k, and the other costs stay unchanged. The maintenance reserve cost results in U$77k monthly. This cost involves maintenance and checks planned on the life cycle of the aircraft. Another assumption was that this is a twelve years leasing contract (Sofema, 2017).

Parking Costs

The A320 has a Maximum Take-Off Weight (MTOW) of 75.5 tons (Airbus, 2019). To have the parking cost, the researchers used the Guarulhos Airport (GRU) as a reference, as the GRU airport is the hub of the network, and where the spare aircraft would be. According to the contract of airport concession (ANAC, 2018b) in combination with the MTOW of the A320, there are two parking fees at GRU:

- At the terminal or near terminal locations: R$147.40 per hour.

- More remote locations: R$31.30 per hour.

The researchers considered the worst-case scenario, in which the airplane stays parked for 24h per day, 22 hours on the on remote locations and two hours near or at the terminal. This scenario is not realistic, once the aircraft would be in use, but assuming a conservative perspective is the better way to compare the costs.

$$Monthly\ Parking\ cost = 30 * (22 * 31{,}30 + 2 * 147{,}40)$$

$$Monthly\ Parking\ cost = R\$\ 29{,}486.69$$

Considering an exchange rate of four reais for one dollar, the parking cost per month is U$7,371.70, which is conservative since the researchers considered that the spare aircraft is always on the ground.

$$Monthly\ Parking\ cost\ (U\$) = \frac{U\$\ 1}{R\$\ 4} * R\$\ 29{,}486.69 = \text{ U\$7,371.70}$$

It is essential to state that a spare aircraft is only useful if there is a crew to perform the flight at the airport. That is another reason that the aircraft is placed in the airport hub, where the airline also allocates the recovery crew. Because of that, the researchers did not consider the extra cost with an additional crew. If a crew had to be assigned for a reserve at the airport, the hour cost would be the same as if they were in an actual flight.

$$Spare\ Aircraft\ Cost/month = \text{Leasing Cost} + \text{Maintence reserve} + \text{Parking Cost}$$

$$Spare\ Aircraft\ Cost/month = 330{,}000 + 77{,}375 + 7{,}372$$

$$Spare\ Aircraft\ Cost/month = U\$\ 414{,}747$$

400 Resolution: Passenger compensation Cost

The cost with passenger compensation established in 400 resolution is the counterpart to evaluate the financial benefits of having a spare aircraft. To create a formula or equation of passenger compensation, the researchers need to have the cost of each service the airline is obligated to provide in a flight delay or cancelation. The researchers were able to evaluate historical data of a Legacy Brazilian airline, which helped us to generate table 3.1.

Service	Applicable when	The average cost per passenger
Communication	Delays longer than 60 minutes, and flight cancelation	zero
Meal	Delays longer than 120 minutes, and flight cancelation	50 BRL
Transportation	Delays longer than four hours, and flight cancelation	115 BRL
Hotel Accommodation	Delays longer than four hours on night period or flight cancelation	205 BRL

Table 3.1. 400 resolution passenger compensation rights and the average cost per passenger affected according to each irregular operation scenario.

Since those services are provided at or near the airport, the airlines usually share the same provider, so the unit costs are practically the same for all of them.

The compensation cost will be obtained by analyzing Resolution 400, the average costs of each service provided so that the researchers could have a compensation cost equation for flight cancelation. The first step was to calculate the Load Factor. The Load Factor helped us to have an estimated number of travelers per flight based on the number of seats on the airplane.

The average load factor is crucial information. The National Civil Aviation Agency - ANAC makes historical data available of all flights performed in Brazil and by Brazilian airlines. It shows the data of each airline on the route and month level (ANAC, 2019a). The relevant information for this project in the database are:

- ASK, which represents the seat availability;
- RPK, which represents passenger demand;

The researchers gathered the data of RPK and ASK for the airline; the researchers obtained the network for a whole year, 2018. With this data, it was possible to calculate the load factor, which is the RPK divided by ASK. The formula and values observed were:

$$L.F\ for\ the\ whole\ Year._{2018} = \frac{RPK_{2018}}{ASK_{2018}} = \frac{12{,}822{,}383{,}974}{15{,}185{,}076{,}926} = 84\%$$

An example of a specific calculation based on month:

$$L.F.\,for\ the\ month_{Aug} = \frac{RPK_{Aug}}{ASK_{Aug}} = \frac{1{,}090{,}946{,}314}{1{,}298{,}822{,}295} = 84\%$$

MONTH	ASK	RPK	LOAD FACTOR
January	1,326,661,890	1,183,179,373	89%
February	1,160,254,533	1,003,880,727	87%
March	1,260,591,132	1,071,340,203	85%
April	1,261,601,325	1,047,085,059	83%
May	1,305,374,713	1,027,025,052	79%
June	1,246,733,724	1,000,412,049	80%
July	1,350,996,024	1,174,960,877	87%
August	1,298,822,295	1,090,946,314	84%

September	1,235,636,439	1,034,605,905	84%
October	1,298,128,467	1,086,026,168	84%
November	1,198,944,481	1,017,969,591	85%
December	1,241,331,903	1,084,952,656	87%
YEAR	**15,185,076,926**	**12,822,383,974**	**84%**

Table 3.2. ASK, RPK, and Load Factor of the airline, the researchers evaluated the network.

As presented in table 3.2, the Load Factor calculation gave us 84% of occupation, both in the analyzed month, as well in the whole year of 2018. Another relevant information is how many passengers the airline transported in the period, august of 2018 because the data is on the month level, not on the day level. The A320 has a configuration of 162 passengers in coach class. By having 84% load factor, and a 162 capacity, the researchers learned that on average, every flight has 136 passengers. That number of average affected passengers is part of the passenger compensation cost equation.

$$Number\ of\ Passenger\ per\ flight = L.F.* Acft\ Capacity = 84\% * 162 = \mathbf{136\ Pax}$$

There were a few details that needed to be analyzed to estimate the compensation costs:

- <u>% of PAX that lives in the city of the airport</u>: if the passenger lives in the city of the airport, they do not need hotel accommodation.
- <u>% of PAX in connection</u>: if in the passenger lose a connection flight, they may the accommodated in a flight on another day, which will require hotel accommodation.

- <u>% of PAX that would file a lawsuit</u>: that is quite expensive per the lawsuit, and the focus is on flight delay longer than two hours and flight cancelation.

After having all those percentages, it allowed us to formulate a generic equation for cancelation flights.

Limitation to evaluate the total cost of a flight cancelation

Flight cancelation involves many costs. Some of those costs are directly related to the 400 resolution, and some of them are related to the situation the cancelation generates.

- Passenger compensations in money
- Passenger compensations in miles
- Cost with PAX accommodation in another airline flight
- Material Catering loss
- Airport tax
- Ground handling team overtime cost
- Airport team overtime cost
- Crew team overtime cost
- Lawsuits filed by passengers
- Hotel Accommodation
- Transportation
- Food

Most of those costs are confidential, and to put it on a paper would not be approved by any airline. Because of that, the researchers restricted their analysis on flight cancelation cost to the data available, which was the "Resolution 400" and the lawsuits. Because of that, the researchers can affirm that the overall cost of a flight cancelation if higher than the cost that the fulfillment of the "Resolution 400" generates to an airline in Brazil. The cost with "Resolution 400" will be a generalization; because of that, the researchers needed a few assumptions.

Assumptions to evaluate the "Resolução 400" cost of a flight cancelation

Communication tools that send e-mails and SMS are essential to prevent passengers from canceled flights to go to the airport. However, most flight cancelations that would be prevented by a spare aircraft would have very little anticipation. Another issue is that a large part of the passengers does not buy their tickets directly with the airline. So the airline does not have the passenger phone or e-mail to reach them. So the researchers assumed that the communication tools with the passenger are a little effective. So when the flight is canceled the chance of the passenger came to the airport is quite high.

According to ABEAR (2016c), the connections in the Brazilian market represent 15% to 20% of total transported passengers. The total transported passenger is the sum of all passengers in each flight, so if a passenger has a connection flight, he or she will be counted twice. In other words, 15% to 20% of the passengers being counted at least twice.

To calculate the cost with a flight cancelation, the researchers need to know the percentage of passengers on connecting flights. Once the ABEAR (2016c) study says the connection is between 15% and 20%, the researchers used the average value, 17%. The math to identify the percentage of travelers in connecting flight was quite simple, considering a universe of 100 passengers, the researchers assumed that the customer in connection has only one connection.

$$Number\ of\ Pax\ CNX\ =\ 100 * 17\%\ =\ 17\ passenger$$

Since they were in connecting flights, those 17 passengers are counted twice because the same passenger is counted in the inbound flight and also counted in the outbound flight. So the total passenger is 100 - 17, which is 83. Now the researchers found-out the total number of passengers, 83, and once 17 have a connection, which means that 21% of transported passengers have a connection.

$$\%\ \text{of passengers in connection} = \frac{17}{83}\ =\ 21\%$$

The researchers already know that 21% of passengers were in connecting flights. The researchers needed to identify if 79% of other passengers would need or not hotel accommodation. This necessity is determined if they live in a city close to the airport, cases in which is only provided transportation. The information is not public. Because of that, no database could help us determine the proportion of passengers that departures from an airport near their house, who would not need hotel accommodation. So rational calculation will be very straight forward. Once every trip has an origin and a destination, the researchers assumed that in one end of that is where the passenger lives. That would take us to half of the passengers have their home address near the airport. So, from the rest 79% of passengers, for half of them, the airport is close to their home, so they do not need a hotel, and the other half does.

$$\%\ \text{Boarding in out of their home city} = \frac{79\%}{2}\ =\ 39.5\%$$

$$\%\ \text{Boarding in their home city} = \frac{79\%}{2}\ =\ 39.5\%$$

Litigation Costs

Brazil is a very litigious country. This affects airlines profoundly. It is common for passengers who suffer adverse changes on their travel itinerary to sue the airline. Based on the data of a Brazilian airline, it was possible to identify the percentage of passengers that suffer a flight delay or cancelation that file a lawsuit against the airline. To find this value, the researchers were able to evaluate real data from a Brazilian Airline from 2016, 2017, and 2018.

When it comes to canceled flights, the subject is more explicit. All of those flight cancelations presents a significant impact on the traveler itinerary. The researchers obtained the number of lawsuits due to flight delay and cancelation during 2016, 2017, and 2018 — and the number of passengers that suffered sudden and significant changes in their itinerary. With those two pieces of information, it was possible to verify the percentage of travelers that sue airlines when they suffer significant IROPs.

$$\% = \frac{\text{Number of Filed Lawsuits}}{\text{Total number of Passenger affected}}$$

Airport Name	2016	2017	2018	Over All
% Of PAX that had their flight canceled that filed lawsuit	2,7%	3,0%	3,1%	3,0%
% Of PAX that had their flight delay longer than 2h that filed a lawsuit.	1,5%	2,3%	3,4%	2,5%

Table 3.3. % of passengers that suffer significant changes in itinerary file lawsuit against the airline.

Table 3.3 presents the % of passengers affected by delays or cancelation that filled lawsuits. A similar analysis was conducted to calculate the average value paid for cancelation and flight delay.

1) The researchers summed all the lawsuits paid among 2016, 2017, and 2018.
2) The researchers counted the number of lawsuits paid in the same period.

$$Average\ Cost\ = \frac{\text{Cost of Filed Lawsuits}}{\text{Number of Lawsuits}}$$

As a result, the researchers had for the delays, the average cost is R$3,800.00 and for the canceled flights is R$4,400.00

How much cost the passenger compensation?

After finding the percentage of each condition, the researchers created table 3.4. It is comprehensive and presents how the researchers formulated the general equation.

Passenger affected by each scenario	Short Form	% of total passenger affected per flight	Associated Cost (Short Form)	Cost per Passenger (BRL)
Boarding in their home city	%BIHC	39.5	Ground Transportation (GT)	115
Boarding out of their home city	%BOHC	39.5	Hotel accommodation (HA) Ground Transportation (GT) Meal (FD)	205 115 50
Connection Flights		21.0	Hotel accommodation (HA)	205

	%CNX		Ground Transportation (GT) Meal (FD)	115 50
File Lawsuit	%FLS	3.0	Lawsuit cost (LC)	4,400

Table 3.4 Calculation of cost per passenger by scenario

By combining the scenario in table 3.4 and the average quantity of passenger per flight, it was possible to formulate the equation canceled flight cost (CFC):

CFC= QP*[%BIHC*GTC+%BOHC*(HA+CTC+FD)+%CNX*(HA+CTC+FD)+%FLS*(LC)]

Where: QP is the average number of passengers per flight, which is 136, in the study.

CFC= 136*[39.5%*115+39.5%*(205+115+50)+21%*(205+115+50)+3%*(4400)]

$$\text{CFC (R\$)} = \text{R\$ } 54{,}573.40$$

$$\text{CFC (U\$)} = \frac{U\$\ 1}{R\$\ 4} * \text{R\$ } 54{,}573.40 \Rightarrow \text{CFC (U\$)} = U\$13{,}643.35$$

The researchers multiplied the equation with Q, so the researchers could have a cost function on Q, which represents the number of flights canceled prevented by the spare aircraft.

$$f(Q) = Flight\ Cancelation\ Cost * \#Flight\ Calletion\ Prevented$$

$$f(Q) = U\$13{,}643.35 * Q$$

This function provided us the break-even point that is presented in the outcome chapter.

What is the principal analysis of this project?

The researchers identified the costs related to passenger compensation due to flight cancelation, which generates missing flight connection and longer stopovers on the passenger travel itinerary. The researchers also have the cost of having a spare aircraft. The objective was to find the break-even point of how many flights the spare aircraft has to prevent flight canceling. So the cost from the prevented flight cancelation would pay the cost of an extra aircraft. And, that demonstrates how economically viable and recommended this alternative is or not. There will be two scenarios that will be evaluated.

1) The researchers will run the flight schedule with the optimal number of aircraft that the optimization model run in LINDO Classic suggested.
2) Another aircraft will be placed in Guarulhos airport (GRU). This hub airport was selected for two reasons. According to the schedule, GRU hosts more flights than other airports (24% of the network departures are from GRU). So the probability of having a canceled flight in GRU is higher than other airports. The second reason, once GRU is a hub airport, there are extra crews at the airport. Because of that, it does not create incremental cost with an additional crew as it would happen in an airport other than a hub.

Summary

Anyone who wants to determine the cost with a flight cancelation needs to evaluate many sources of costs. It is a complex analysis that could involve various departments of an airline. It involves confidential data. Because of it, this project focused on the compensation cost with the Brazilian regulation “Resolução 400”.

The researchers also calculated the cost of having an extra aircraft. Moreover, in the next chapter, the researchers compared these two values to evaluate when it is positive to have a spare aircraft.

Chapter IV

Outcomes

Optimal fleet size

The researchers have got 40 aircraft as the optimal number of aircraft to perform the network. The complete LINDO output is available in Appendix C. The 40 airplanes were distributed in 20 airports before the beginning of the operation, as presented in table 4.1. Another important information is that GRU is the airport with most airplanes, eight, which represents 20% of all fleet. Other than that, 61 flight departures from GRU, which represents 25% of all flights of the domestic network.

AJU	BSB	CGB	CGH	CGR	CNF	CWB	FOR	GIG	GRU
1	1	1	5	2	1	2	3	1	8
GYN	**JPA**	**MCZ**	**NAT**	**PNZ**	**POA**	**REC**	**SDU**	**SSA**	**XAP**
1	1	1	1	1	1	3	3	2	1

Table 4.1. The number of aircraft of overnight parking by airports.

There are several optimization tools applied to airlines' schedule building. The researchers used one of them, AirVision® Planning and Scheduling, to compare with the result of the linear programming using Lindo. The AirVision® Planning and Scheduling outcome was the same provided by LINDO, 40 aircraft. This number is exclusive to perform the scheduled flights. It reinforces the capability of the model and also presents a real example of optimization in the use of airlines.

At figure 4.1, it is possible to see the result of the AirVision® Planning and Scheduling. The tool provided a visualization of the distribution of the schedule flights over the 40 aircraft. By doing that, it makes it possible to visualize the ground time, which presents how short are the ground time.

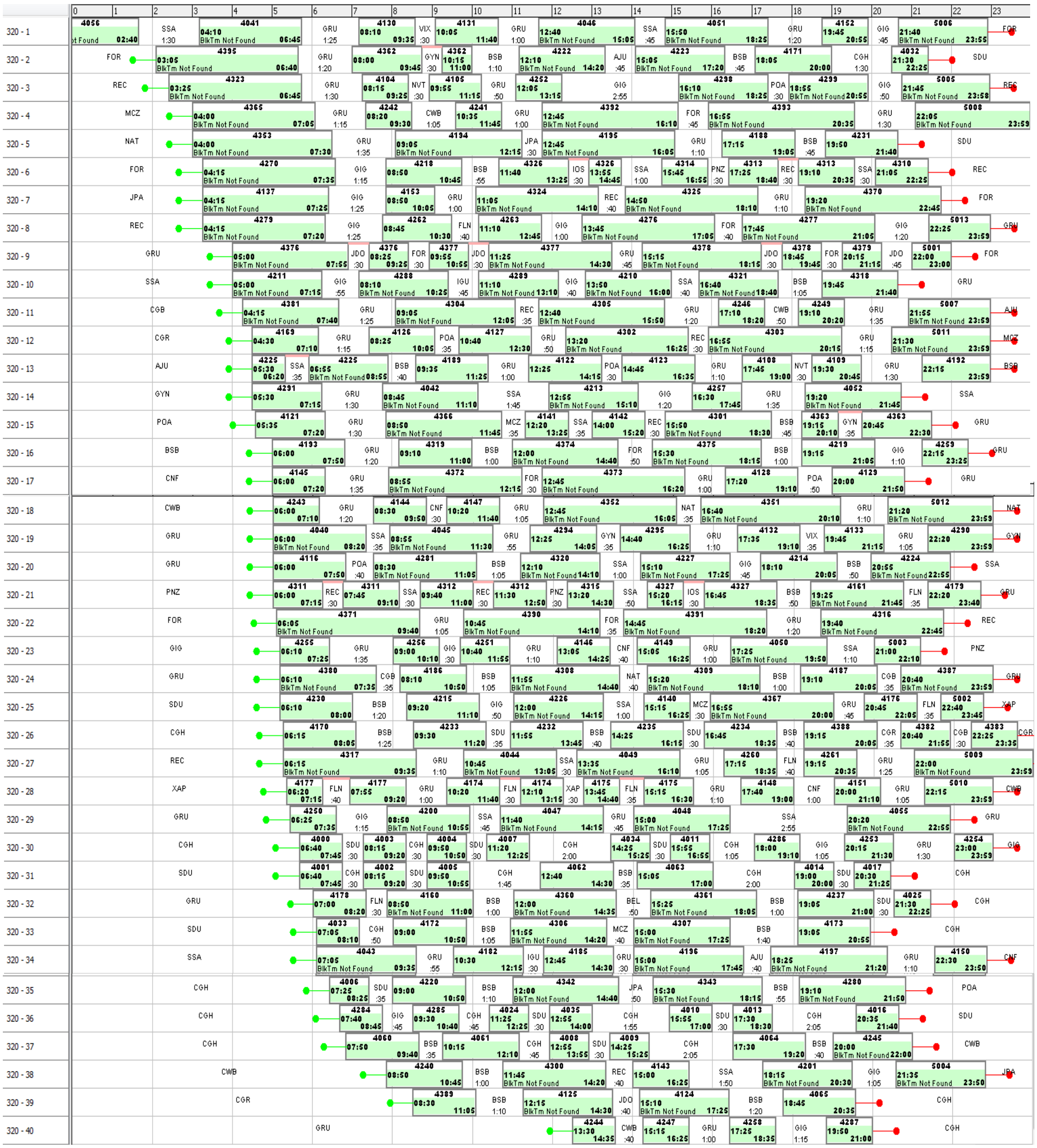


Figure 4.1. Visual distribution of 253 flights into 40 aircraft from AirVision® Planning and Scheduling.

The impacts on the airline regularity

To make any understanding from the scenario with an extra aircraft, it is necessary to begging to calculate how much time the network demanded. Which is the sum of every Hour Block Time of every flight planned. Hour Block Time (HBT) is the planned time between the push-back on the origin airport and the parking at the gate (Dyer, 2015).

$$Amount\ of\ flight\ demand\ hours = \sum_{i=1}^{n} HBT_i$$

As a result, all 253 flights demand 482 hours of flying hours. When taking into account that the turnaround is a productive activity for the flight execution, the aircraft demand hours is 657. Knowing that the airline has 40 airplanes, it was possible to obtain the average of flying hours per aircraft per day, and demand hours.

$$Aircraft\ average\ flying\ hours = \frac{\sum_{i=1}^{n} HBT_i}{\text{Qnt Acft}} = \frac{482}{40} = 12h$$

Every aircraft flies 12hours per day. Another interesting data is the average of HBT. The network evaluated had 253 flights.

$$Average\ flight\ HBT = \frac{\sum_{i=1}^{n} HBT_i}{\text{Qty Flights}} = \frac{482}{253} = 1h54$$

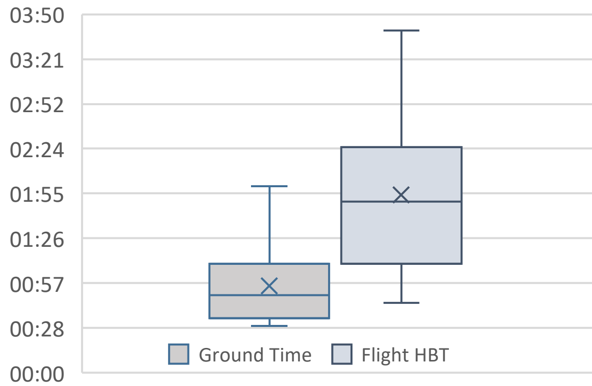


Figure 4.2. Boxplot of ground time and flight HBT.

The HBT of the data set on average is 1h54min. Brazil is a vast country; because of that, the flight length can vary significantly from route to route. Some flights take only 45 min like GYN to BSB and others that may take 3h45 from GRU to BEL. Figure 4.2 shows that the mean is 1h50min; it is worth mentioning that it has a standard deviation of 0.0330. For the ground time, there is a variation between 30min to 2h55min, the mean is 50 minutes, and the standard deviation is 0.0209.

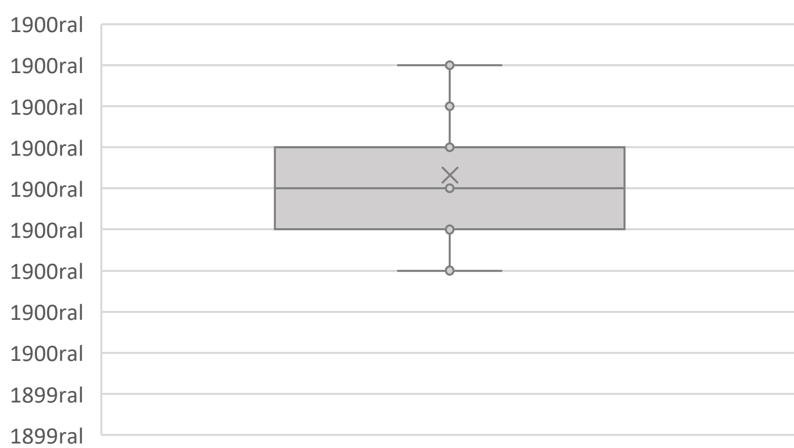


Figure 4.3. Boxplot of flight distribution per aircraft.

The 253 flights were distributed between 40 aircraft. The distribution of flights between the aircraft represents a standard deviation of 1.068, with a mean and average of six flights per aircraft, although there is one aircraft with nine flights assigned in one day.

Figure 4.3 shows the boxplot of the number of aircraft assigned per aircraft. It is clear how the majority of aircraft perform between five and seven flights daily. Moreover, the mean value is six flights performed by one aircraft per day.

Another pertinent aspect is how the network of the airline could absorb the flights of the AOG aircraft. The average flight time is around two hours (1h54min to be more precise). To evaluate the impact of including a new flight, it is necessary to evaluate the intervals between one flight and another assigned on the same aircraft.

By analyzing the data of arrival and departure flights, the researchers created table 4.2 to show the percentage ground time based on the time range.

Ground Time	≤45min	46 to 60min	61 to 90min	91 to 120min	>120min
% of flight	48%	17%	27%	6%	2%

Table 4.2. % of the range of flight ground time.

Table 4.2 tells us how low is the likelihood of success of including a flight from an AOG airplane to another one without a significant impact on passenger itinerary.

Impact of an additional aircraft on aircraft utilization

One extra aircraft may be used in two ways. The aircraft can be parked at one airport, probably at a hub. Once there is a lack of aircraft, the spare aircraft can be used to perform the flight. Secondly, the extra aircraft can be added to the operating fleet. This second scenario provides longer ground time and more rotation points. In both ways, there is more flexibility to absorb and reduce negative impacts on passenger flying experience.

In the study, the researchers used the first scenario where they placed the aircraft in Guarulhos airport (GRU).

By adding one aircraft, there is a reduction in the aircraft utilization rate. The aircraft utilization reduces from 12h to 11h45min.

$$Aircraft\ average\ flying\ hours = \frac{\sum_{i=1}^{n} HBT_i}{\text{Qnt Acft}} = \frac{482}{41} = 11h45min$$

The breakeven point

The first outcome from this study worth mentioning is the breakeven point between the investment on a spare aircraft and the cost with passenger compensation according to resolution 400.

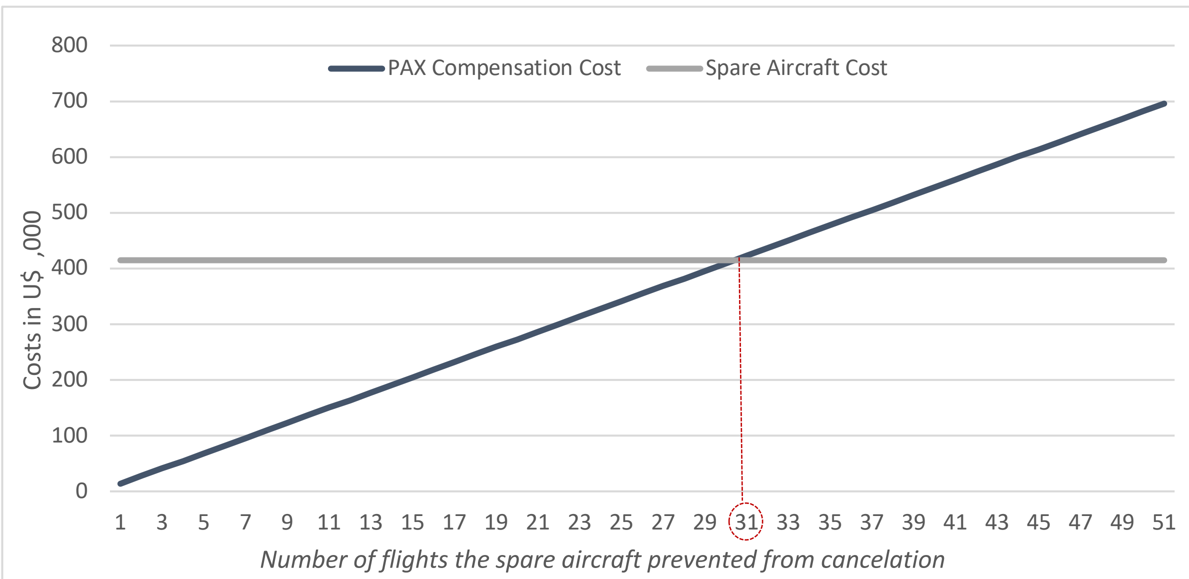


Figure 4.4. Breakeven point of the number of flights cancelation vs. cost with an aircraft spare in one month.

On figure 4.4, it is possible to see that the investment with spare aircraft, which is U$ 414,747.00. It also shows the saving according to the number of flight cancelation. To pay it back, the spare aircraft need to successful prevent, in one month, 31 flight cancelation, which costs U$13,643.35. The schedule has 253 flights daily, considering a

30 day month, it results in 7.590 flights. Thirty-one flights represent 0.4% of month planed flights.

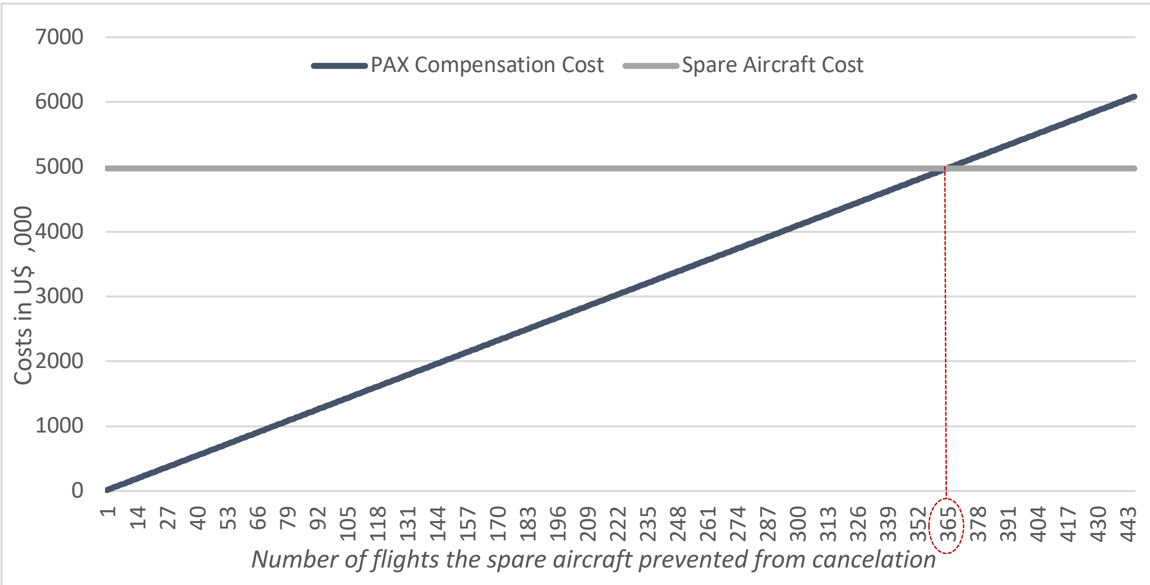


Figure 4.5. Breakeven point of the number of flights cancelation vs. cost with an aircraft spare in one year.

In Figure 4.5, the researchers presented the same perspective as the figure 4.5 but considering a more extended period, a whole year. It is essential to have this perspective due to seasonality, which may affect the likelihood of canceling a flight. During colder periods, there is a higher probability of having fog at the airport, which could retain the flight departure. Depending on how long the airport is closed, the next flight assigned to the aircraft retained due to weather will be canceled due to the lack of aircraft at the airport.

For example, if there is an aircraft to perform a morning flight from IGU airport to GRU airport. If IGU has a weather condition that retains the departures for too long, it will generate a lack of aircraft in GRU airport to perform the scheduled flights, which may result in the flight cancelation. The fog condition usually happens during winter. By evaluating the whole year is possible to measure the cost properly, considering peaks and valleys of flight cancelation due to external factors. Figure 4.6 shows the seasonality of bird strike, which affects the availability of aircraft substantially. Both examples reinforce that a one-year payback is a better way to evaluate the saving with passenger compensation in comparison with the annual cost of a spare aircraft.

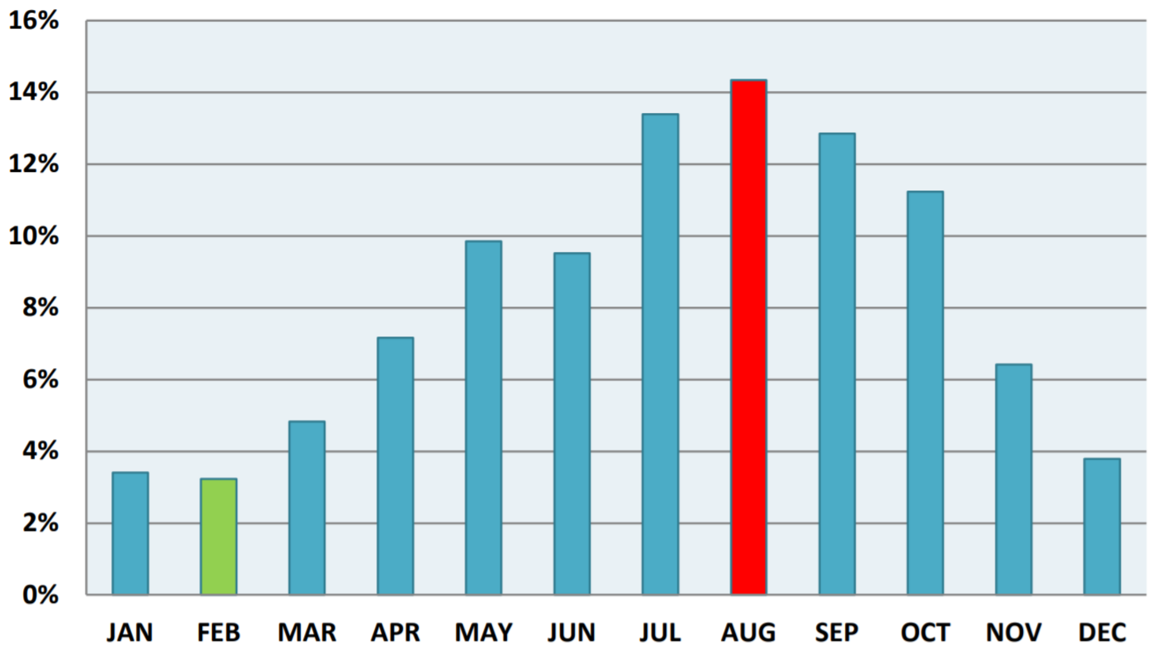


Figure 4.6. Month of occurrence of bird-strike (2008-2015) in Northern Hemisphere (ICAO, 2017)

So if a spare aircraft prevents 365 flights from cancelation, the saving with passenger compensation would pay back the investment the extra aircraft. The network the researchers studied has 253 flights per day. The saving with flight compensation would pay back the investment if spare aircraft could prevent 0.4% of the s scheduled flight from canceling.

Summary

The extra aircraft reduces the aircraft utilization rate. It usually is an indicator of productivity, which may lead to the impression of increment of cost, once one airline has more aircraft per flying hours in comparison with other companies. However, that extra cost with aircraft may result in even higher savings with passenger compensations. If the researchers take operational costs into account, such as over hours of the crew, and airport team, airport taxes, and fines, the investment becomes even more beneficial.

If the spare aircraft is capable of preventing 365 flights from canceling, the saving with passenger compensation justifies its investment. In the next chapter, the researchers talk about their conclusions.

Chapter V

Conclusions, Recommendations, and Limitations

Overview of Research

In this study, the researchers were able to estimate the costs with passenger compensation according to the Brazilian regulation. The researchers also could estimate the cost of a spare aircraft in the airline fleet. Focusing on only executing the scheduled flight, not counting aircraft to cover check-C or check-D maintenance routines, the researchers calculated the optimal number of aircraft to perform the schedule of 253 flights in one day. There are additional costs related to a spare aircraft, but there are significant benefits too. It gets even more impressive when there is in place austere regulations that strictly establishes how passengers must be compensated in cases of flight delay and cancelation.

According to FlightStas data, between the three larger airlines in Brazil, LATAM, GOL, and AZUL the airline with less flight cancelation had around 1,250 in 2018. Once in our study, every flight cancelation costs US$13,643 in passenger compensation and lawsuit. Each of those airlines in Brazil had spent more than U$17,053,750 in passenger compensation due to flight cancelation. This cost is equivalent to more than three spare aircraft. The idea of having a spare aircraft in Brazil is promising. The decision to have an extra resource can result in an improvement of passenger satisfaction and cost reduction.

Summary of Results

If the researchers only consider the cost with passenger compensation, which is just a fraction of the total cost of a flight cancelation, the cost of 365 flight canceled is equivalent to having an extra aircraft for one year. It is essential to emphasize the fact that in Brazil, the airline is responsible for providing meals, transportation, and hotel accommodation for any flight canceled situations. It differs from other countries, where it is up to the airline to decide how to compensate or care about the passengers that have their flight canceled or significantly delayed. There is a regulation that defines how passengers should be taken care of during irregular operations. That fact may increase the cost for the airline with passenger compensation inside the Brazilian industry.

Cost management is imperative for the airline to keep itself profitable, as well as choosing wisely the better investment options that maximize the indirect benefits for the airline. The increment of an aircraft on the airline fleet affects the aircraft utilization indication. But, the benefits of investing in an extra aircraft are substantially higher than spending on passenger compensation, considering the break-even point was achieved.

In the study, which resulted in 40 airplanes as an optimal fleet to perform the schedule, the reduction on aircraft utilization rate is quite small, from 12h without a spare aircraft to 11h45min with an extra aircraft, which sum 41. It is a 2.1% variation, which is small, and should not be a warning of not investing in a spare aircraft.

This trade-off brings excellent advantages for the passengers; it also provides revenue and operational gains. For instance, by not canceling or delaying a flight with cargo, the deadlines are met, and there is no risk of revenue loss. The spare aircraft may also increase rotation points, which is especially useful in cases that the aircraft arrives late at its destination. The more rotation points there are, the better are the chances to revert late arrival of the aircraft, preventing or reducing delay.

Information Gained from the Study

The most relevant information was the breakeven point between the cost with passenger compensation according to 400 Resolution and the cost of a spare aircraft in one year. The passenger compensation cost is very relevant in the cases of flight cancelation. It happens due to established laws in Brazil. As a result of that analysis, the researchers have found out that if the spare aircraft can prevent 365 flight cancelation per year, the cost of passenger compensation would pay its annual investment. The researchers have also learned that the annually based analysis is more coherent than a monthly based because it takes into account seasonality. Seasonality such as the occurrence of bird-strike, but also involves weather and the volume of passengers.

The present study provided an understanding of how optimization and cost efficiency go together in the aviation business. It also provided learnings on how a local regulation may create scenarios so different from another region, which can affect the strategy of the local airline.

Conceptual Implications

The goal of the study was to find out if having a spare aircraft is financially beneficial. It would be necessary to provide some confidential data to evaluate that. That was a problem because they are strategic for any airline. Instead of doing that, the researchers aim to evaluate the cost of complying with the Brazilian regulation on passenger compensation. Another challenge to the initial goal of the project was to obtain the number of cancelation due to the lack of aircraft there are.

Another data that the researchers were not able to obtain was the number of flight cancelations that could happen due to the lack of aircraft, without the effects of spare aircraft in place. Most airlines have spare aircraft, so the cancelations already suffer the effect of having an extra resource. The researchers researched Operational Reliability KPI, but in that number, delays, even smaller ones, are counted. The researchers could not find any rate that could tell how many flight cancelation should expect concerning the number of flights or flight hours.

There are also non-financial benefits that are not possible to put in numbers, although the airline must take into consideration before making the decision. The passenger experience, the brand impact, and how the airline is perceived is very important and need to be taken into consideration as well. It is especially important for the business traveler, who usually choose their flight based on the flight schedule. The business traveler is responsible for most revenue of the airlines, so caring about their perception is very important for the airline.

Future Implications

Just considering the cost with the local regulation, the cost of 365 flight cancelation would justify the annual investment of having a spare aircraft. That should drive every airline to deep dive into their costs, and frequency of cancelation due to lack of aircraft. Once without increasing cost, it is possible to offer a more reliable and on-time operation to the passenger. Considering the business traveler, those are factors very relevant to their decision making.

This study provides information on the relevance of preventing cost with flight cancelation. Moreover, it also raises a discussion about maximizing indirect benefits. Even if the investment with an extra aircraft cost as much as the 365 canceled flights, by choosing to spend on the aircraft brings more benefits. The spare aircraft in that scenario provides better indirect benefits.

The researchers suggest that every airline should conduct a cross-department evaluation of the cost involved with flight cancelation and delays. This kind of assessment is even more relevant in countries where there is an obligation to provide passenger compensations. A comprehensive assessment would involve the airport, operations, OCC, schedule, maintenance, finances, legal, and fleet department. Indeed if the analysis involves all costs and department if the result of the spare aircraft and the cancelations and delays, it is very likely to be approved the spare aircraft investment. It is so because all stakeholders are involved, and the cost with aircraft can be understood as an investment, that makes the passenger experience better. While the cancelations e delays make passengers angry and unhappy. Those kinds of occurrences generate complaints on twitter, Instagram, and Facebook, which affects the airline's image. Although, as mentioned before, even if there is not a saving, the investment may be worthy, once there are many other benefits such as:

- Increment on the on-time performance
- Better regularity.
- Fulfillment of cargo deadlines.

Fewer flight delays and cancelation makes the passenger perceive the brand as more reliable. That also brings an increment on passenger satisfaction, which can result in revenue gains, once the business travelers are those more interested in the fulfillment of the flight schedule.

A future research topic is to evaluate historical data regarding a specific airline or fleet. It could provide a rate of AOG per cycle or flights, which can show depending on the airline schedule if it is beneficial to have a spare aircraft, and how effective the spare aircraft is. For a future academic study, there could be a simulation of the effectiveness of the spare aircraft on preventing flights from delay or cancelation. Choosing a real day of operation and simulate the operation with one extra aircraft. Another scenario to be evaluated is having the spare aircraft added to the operational fleet instead of staying parked at the ground. That is, the flight network structured with more time buffers between its flights.

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APPENDIX A

Flight Schedule Data Set

Flight	DEP	ARR	STD	STA
XX4000	CGH	SDU	0640	0745
XX4001	SDU	CGH	0640	0745
XX4002	CGH	SDU	0815	0920
XX4003	SDU	CGH	0815	0920
XX4004	CGH	SDU	0950	1050
XX4005	SDU	CGH	0950	1055
XX4006	CGH	SDU	0725	0825
XX4007	SDU	CGH	1120	1225
XX4008	CGH	SDU	1255	1355
XX4009	SDU	CGH	1425	1525
XX4010	CGH	SDU	1555	1700
XX4011	SDU	CGH	1555	1655
XX4013	SDU	CGH	1730	1830
XX4014	CGH	SDU	1900	2000
XX4016	CGH	SDU	2035	2140
XX4017	SDU	CGH	2030	2125
XX4024	CGH	SDU	1125	1225
XX4025	SDU	CGH	2130	2225
XX4032	CGH	SDU	2130	2225
XX4033	SDU	CGH	0705	0810
XX4034	CGH	SDU	1425	1525
XX4035	SDU	CGH	1255	1400
XX4040	GRU	SSA	0600	0820
XX4041	SSA	GRU	0410	0645
XX4042	GRU	SSA	0845	1110
XX4043	SSA	GRU	0705	0935
XX4044	GRU	SSA	1045	1305
XX4045	SSA	GRU	0855	1130
XX4046	GRU	SSA	1240	1505
XX4047	SSA	GRU	1140	1415
XX4048	GRU	SSA	1500	1725
XX4049	SSA	GRU	1335	1610
XX4050	GRU	SSA	1725	1950
XX4051	SSA	GRU	1550	1825
XX4052	GRU	SSA	1920	2145
XX4055	SSA	GRU	2020	2255
XX4056	GRU	SSA	0015	0240
XX4060	CGH	BSB	0750	0940
XX4061	BSB	CGH	1015	1210
XX4062	CGH	BSB	1240	1430
XX4063	BSB	CGH	1505	1700
XX5007	GRU	AJU	2155	2359
XX5013	GIG	GRU	2225	2359

Flight	DEP	ARR	STD	STA
XX4064	CGH	BSB	1730	1920
XX4065	BSB	CGH	1845	2035
XX4104	GRU	NVT	0815	0925
XX4105	NVT	GRU	0955	1115
XX4108	GRU	NVT	1745	1900
XX4109	NVT	GRU	1930	2045
XX4116	GRU	POA	0600	0750
XX4121	POA	GRU	0535	0720
XX4122	GRU	POA	1225	1415
XX4123	POA	GRU	1445	1635
XX4124	JDO	BSB	1510	1725
XX4125	BSB	JDO	1215	1430
XX4126	GRU	POA	0825	1005
XX4127	POA	GRU	1040	1230
XX4128	GRU	POA	1720	1910
XX4129	POA	GRU	2000	2150
XX4130	GRU	VIX	0810	0935
XX4131	VIX	GRU	1005	1140
XX4132	GRU	VIX	1735	1910
XX4133	VIX	GRU	1945	2115
XX4137	JPA	GIG	0415	0725
XX4140	SSA	MCZ	1515	1625
XX4141	MCZ	SSA	1220	1325
XX4142	SSA	REC	1400	1520
XX4143	REC	SSA	1500	1625
XX4144	GRU	CNF	0830	0950
XX4145	CNF	GRU	0600	0720
XX4146	GRU	CNF	1305	1425
XX4147	CNF	GRU	1020	1140
XX4148	GRU	CNF	1740	1900
XX4149	CNF	GRU	1505	1625
XX4150	GRU	CNF	2230	2350
XX4151	CNF	GRU	2000	2110
XX4152	GRU	GIG	1945	2055
XX4153	GIG	GRU	0850	1005
XX4160	FLN	BSB	0850	1100
XX4161	BSB	FLN	1925	2145
XX4169	CGR	GRU	0430	0710
XX4171	BSB	CGH	1805	2000
XX4172	CGH	BSB	0900	1050
XX4173	BSB	CGH	1905	2055
XX5008	GRU	CGB	2205	2359

Flight	DEP	ARR	STD	STA
XX4174	FLN	XAP	1210	1315
XX4174	GRU	FLN	1020	1140
XX4175	FLN	GRU	1515	1630
XX4175	XAP	FLN	1345	1440
XX4176	GRU	FLN	2045	2205
XX4177	FLN	GRU	0755	0920
XX4177	XAP	FLN	0620	0715
XX4178	GRU	FLN	0700	0820
XX4179	FLN	GRU	2220	2340
XX4182	GRU	IGU	1030	1215
XX4185	IGU	GRU	1245	1430
XX4186	CGB	BSB	0810	1050
XX4187	BSB	CGB	1910	2005
XX4188	GRU	BSB	1715	1905
XX4189	BSB	GRU	0935	1125
XX4192	GRU	BSB	2215	2359
XX4193	BSB	GRU	0600	0750
XX4194	GRU	JPA	0905	1215
XX4195	JPA	GRU	1245	1605
XX4196	GRU	AJU	1500	1745
XX4197	AJU	GRU	1825	2120
XX4200	GIG	SSA	0850	1055
XX4201	SSA	GIG	1815	2030
XX4210	GIG	SSA	1350	1600
XX4211	SSA	GIG	0500	0715
XX4213	SSA	GIG	1255	1510
XX4214	GIG	BSB	1810	2005
XX4215	BSB	GIG	0920	1110
XX4218	GIG	BSB	0850	1045
XX4219	BSB	GIG	1915	2105
XX4220	SDU	BSB	0900	1050
XX4222	BSB	AJU	1210	1420
XX4223	AJU	BSB	1505	1720
XX4224	BSB	SSA	2055	2255
XX4225	AJU	SSA	0530	0620
XX4225	SSA	BSB	0655	0855
XX4226	GIG	SSA	1200	1415
XX4227	SSA	GIG	1510	1725
XX4230	SDU	BSB	0610	0800
XX4231	BSB	SDU	1950	2140
XX4232	SDU	BSB	1155	1345
XX5009	GRU	CGR	2200	2359

Table A.1. Data set schedule flight part 1

Flight	DEP	ARR	STD	STA
XX4233	BSB	SDU	0930	1120
XX4234	SDU	BSB	1645	1835
XX4235	BSB	SDU	1425	1615
XX4237	BSB	SDU	1905	2100
XX4240	CWB	BSB	0850	1045
XX4241	CWB	GRU	1035	1145
XX4242	GRU	CWB	0820	0930
XX4243	CWB	GRU	0600	0710
XX4244	GRU	CWB	1330	1435
XX4245	BSB	CWB	2000	2200
XX4246	GRU	CWB	1710	1820
XX4247	CWB	GRU	1515	1625
XX4249	CWB	GRU	1910	2020
XX4250	GRU	GIG	0625	0735
XX4251	GIG	GRU	1040	1155
XX4252	GRU	GIG	1205	1315
XX4253	GIG	GRU	2015	2130
XX4254	GRU	GIG	2300	2359
XX4255	GIG	GRU	0610	0725
XX4256	GRU	GIG	0900	1010
XX4257	GIG	GRU	1630	1745
XX4258	GRU	GIG	1725	1835
XX4259	GIG	GRU	2215	2325
XX4260	GRU	FLN	1715	1835
XX4261	FLN	GRU	1915	2035
XX4262	GIG	FLN	0845	1030
XX4263	FLN	GIG	1110	1245
XX4270	FOR	GIG	0415	0735
XX4276	GIG	FOR	1345	1705
XX4277	FOR	GIG	1745	2105
XX4279	REC	GIG	0415	0720
XX4280	BSB	POA	1910	2150
XX4281	POA	BSB	0830	1105
XX4284	CGH	GIG	0740	0845
XX4285	GIG	CGH	0930	1040
XX4286	CGH	GIG	1800	1910
XX4287	GIG	CGH	1950	2100
XX4288	GIG	IGU	0810	1025
XX4289	IGU	GIG	1110	1310
XX4290	GRU	GYN	2220	2359
XX4291	GYN	GRU	0530	0715
XX5010	GRU	CWB	2215	2359

Flight	DEP	ARR	STD	STA
XX4294	GRU	GYN	1225	1405
XX4295	GYN	GRU	1440	1625
XX4298	GIG	POA	1610	1825
XX4299	POA	GIG	1855	2055
XX4300	BSB	REC	1145	1420
XX4301	REC	BSB	1550	1830
XX4302	GRU	REC	1320	1625
XX4303	REC	GRU	1655	2015
XX4304	GRU	REC	0905	1205
XX4305	REC	GRU	1240	1550
XX4306	BSB	MCZ	1155	1420
XX4307	MCZ	BSB	1500	1725
XX4308	BSB	NAT	1155	1440
XX4309	NAT	BSB	1520	1810
XX4310	SSA	REC	2105	2225
XX4311	PNZ	REC	0600	0715
XX4311	REC	SSA	0745	0910
XX4312	REC	PNZ	1130	1250
XX4312	SSA	REC	0940	1100
XX4313	PNZ	REC	1725	1840
XX4313	REC	SSA	1910	2035
XX4314	SSA	PNZ	1545	1655
XX4315	PNZ	SSA	1320	1430
XX4316	GRU	REC	1940	2245
XX4317	REC	GRU	0615	0935
XX4318	BSB	GRU	1945	2140
XX4319	GRU	BSB	0910	1100
XX4320	BSB	SSA	1210	1410
XX4321	SSA	BSB	1640	1840
XX4323	REC	GRU	0325	0645
XX4324	GRU	REC	1105	1410
XX4325	REC	GRU	1450	1810
XX4326	BSB	IOS	1140	1325
XX4326	IOS	SSA	1355	1445
XX4327	IOS	BSB	1645	1835
XX4327	SSA	IOS	1520	1615
XX4342	BSB	JPA	1200	1440
XX4343	JPA	BSB	1530	1815
XX4351	NAT	GRU	1640	2010
XX4352	GRU	NAT	1245	1605
XX4353	NAT	GRU	0400	0730
XX5011	GRU	MCZ	2130	2359

Flight	DEP	ARR	STD	STA
XX4360	BSB	BEL	1200	1435
XX4361	BEL	BSB	1525	1805
XX4362	GRU	GYN	0800	0945
XX4362	GYN	BSB	1015	1100
XX4363	BSB	GYN	1915	2010
XX4363	GYN	GRU	2045	2230
XX4365	MCZ	GRU	0400	0705
XX4366	GRU	MCZ	0850	1145
XX4367	MCZ	GRU	1655	2000
XX4370	GRU	FOR	1920	2245
XX4371	FOR	GRU	0605	0940
XX4372	GRU	FOR	0855	1215
XX4373	FOR	GRU	1245	1620
XX4374	BSB	FOR	1200	1440
XX4375	FOR	BSB	1530	1815
XX4376	GRU	JDO	0500	0755
XX4376	JDO	FOR	0825	0925
XX4377	FOR	JDO	0955	1055
XX4377	JDO	GRU	1125	1430
XX4378	GRU	JDO	1515	1815
XX4378	JDO	FOR	1845	1945
XX4379	FOR	JDO	2015	2115
XX4380	GRU	CGB	0610	0735
XX4381	CGB	GRU	0415	0740
XX4382	CGR	CGB	2040	2155
XX4383	CGB	CGR	2225	2335
XX4387	CGB	GRU	2040	2359
XX4388	BSB	CGR	1915	2005
XX4389	CGR	BSB	0830	1105
XX4390	GRU	FOR	1045	1410
XX4391	FOR	GRU	1445	1820
XX4392	GRU	FOR	1245	1610
XX4393	FOR	GRU	1655	2035
XX4395	FOR	GRU	0305	0640
XX4170	CGH	BSB	0615	0805
XX5001	JDO	FOR	2200	2300
XX5002	FLN	XAP	2240	2345
XX5003	SSA	PNZ	2100	2210
XX5004	GIG	JPA	2135	2350
XX5005	GIG	REC	2145	2358
XX5006	GIG	FOR	2140	2355
XX5012	GRU	NAT	2120	2359

Table A.2. Data set schedule flight part 2

APPENDIX B

Linear Programming Optimization Model – Optimal Number of Aircraft

Min

AJU0001+BEL0001+BSB0001+CGB0001+CGH0001+CGR0001+CNF0001+CWB0001+FLN0001+FOR0001+GIG0001+GRU0001+GYN0001+IGU0001+IOS0001+JDO0001+JPA0001+MCZ0001+NAT0001+NVT0001+PNZ0001+POA0001+REC0001+SDU0001+SSA0001+VIX0001+XAP0001

SUBJECT TO

!AJU

AJU0001-AJU2359=0

AJU0530-AJU0001+XX4225=0

AJU1420-AJU0530-XX4222=0

AJU1505-AJU1420+XX4223=0

AJU1745-AJU1505-XX4196=0

AJU1825-AJU1745+XX4197=0

AJU2359-AJU1825-XX5007=0

!BEL

BEL0001-BEL1525=0

BEL1435-BEL0001-XX4360=0

BEL1525-BEL1435+XX4361=0

!BSB

BSB0001-BSB2359=0

BSB0600-BSB0001+XX4193=0

BSB0800-BSB0600-XX4230=0

BSB0805-BSB0800-XX4170=0

BSB0855-BSB0805-XX4225=0

BSB0920-BSB0855+XX4215=0

BSB0930-BSB0920+XX4233=0

BSB0935-BSB0930+XX4189=0

BSB0940-BSB0935-XX4060=0

BSB1015-BSB0940+XX4061=0

BSB1044-BSB1015-XX4218=0

BSB1045-BSB1044-XX4240=0

BSB1048-BSB1045-XX4172=0

BSB1049-BSB1048-XX4186=0

BSB1050-BSB1049-XX4220=0

BSB1098-BSB1050-XX4160=0

BSB1099-BSB1098-XX4319=0

BSB1100-BSB1099-XX4362=0

BSB1104-BSB1100-XX4281=0

BSB1105-BSB1104-XX4389=0

BSB1140-BSB1105+XX4326=0

BSB1145-BSB1140+XX4300=0

BSB1154-BSB1145+XX4306=0

BSB1155-BSB1154+XX4308=0

BSB1198-BSB1155+XX4342=0

BSB1199-BSB1198+XX4360=0

BSB1200-BSB1199+XX4374=0

BSB1209-BSB1200+XX4222=0

BSB1210-BSB1209+XX4320=0

BSB1215-BSB1210+XX4125=0

BSB1345-BSB1215-XX4232=0

BSB1425-BSB1345+XX4235=0

BSB1430-BSB1425-XX4062=0

BSB1505-BSB1430+XX4063=0

BSB1720-BSB1505-XX4223=0

BSB1724-BSB1720-XX4124=0

BSB1725-BSB1724-XX4307=0

BSB1804-BSB1725+XX4171=0

BSB1805-BSB1804-XX4361=0

BSB1810-BSB1805-XX4309=0

BSB1814-BSB1810-XX4343=0

BSB1815-BSB1814-XX4375=0

BSB1830-BSB1815-XX4301=0

BSB1834-BSB1830-XX4234=0

BSB1835-BSB1834-XX4327=0

BSB1840-BSB1835-XX4321=0

BSB1845-BSB1840+XX4065=0

BSB1903-BSB1845+XX4173=0

BSB1904-BSB1903-XX4188=0

BSB1905-BSB1904+XX4237=0

BSB1909-BSB1905+XX4187=0

BSB1910-BSB1909+XX4280=0

BSB1913-BSB1910+XX4219=0

BSB1914-BSB1913+XX4363=0

BSB1915-BSB1914+XX4388=0

BSB1920-BSB1915-XX4064=0

BSB1925-BSB1920+XX4161=0

BSB1945-BSB1925+XX4318=0

BSB1950-BSB1945+XX4231=0

BSB2000-BSB1950+XX4245=0

BSB2005-BSB2000-XX4214=0

BSB2055-BSB2005+XX4224=0

BSB2359-BSB2055-XX4192=0

!CGB

CGB0001-CGB2359=0

CGB0415-CGB0001+XX4381=0

CGB0735-CGB0415-XX4380=0

CGB0810-CGB0735+XX4186=0

CGB2005-CGB0810-XX4187=0

CGB2040-CGB2005+XX4387=0

CGB2155-CGB2040-XX4382=0

CGB2225-CGB2155+XX4383=0

CGB2359-CGB2225-XX5008=0

!CGH

CGH0001-CGH2225=0

CGH0615-CGH0001+XX4170=0

CGH0640-CGH0615+XX4000=0

CGH0725-CGH0640+XX4006=0

CGH0740-CGH0725+XX4284=0

CGH0745-CGH0740-XX4001=0

CGH0750-CGH0745+XX4060=0

CGH0810-CGH0750-XX4033=0

CGH0815-CGH0810+XX4002=0

CGH0900-CGH0815+XX4172=0

CGH0920-CGH0900-XX4003=0

CGH0950-CGH0920+XX4004=0

CGH1040-CGH0950-XX4285=0

CGH1055-CGH1040-XX4005=0

CGH1125-CGH1055+XX4024=0

CGH1210-CGH1125-XX4061=0

CGH1225-CGH1210-XX4007=0

CGH1240-CGH1225+XX4062=0

CGH1255-CGH1240+XX4008=0

CGH1400-CGH1255-XX4035=0

CGH1425-CGH1400+XX4034=0

CGH1525-CGH1425-XX4009=0

CGH1555-CGH1525+XX4010=0

CGH1655-CGH1555-XX4011=0

CGH1700-CGH1655-XX4063=0

CGH1730-CGH1700+XX4064=0

CGH1800-CGH1730+XX4286=0

CGH1830-CGH1800-XX4013=0

CGH1900-CGH1830+XX4014=0

CGH2000-CGH1900-XX4171=0

CGH2034-CGH2000+XX4016=0

CGH2035-CGH2034-XX4065=0

CGH2055-CGH2035-XX4173=0

CGH2100-CGH2055-XX4287=0

CGH2125-CGH2100-XX4017=0

CGH2130-CGH2125+XX4032=0

CGH2225-CGH2130-XX4025=0

!CGR

CGR0001-CGR2359=0

CGR0430-CGR0001+XX4169=0

CGR0830-CGR0430+XX4389=0

CGR2005-CGR0830-XX4388=0

CGR2040-CGR2005+XX4382=0

CGR2335-CGR2040-XX4383=0

CGR2359-CGR2335-XX5009=0

!CNF

CNF0001-CNF2350=0

CNF0600-CNF0001+XX4145=0

CNF0950-CNF0600-XX4144=0

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NAT2359-NAT1640-XX5012=0

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NVT0955-NVT0925+XX4105=0

NVT1900-NVT0955-XX4108=0

NVT1930-NVT1900+XX4109=0

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POA0830-POA0750+XX4281=0

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XX4376=1	XX4382=1	XX4395=1	XX5009=1
XX4376=1	XX4383=1	XX5001=1	XX5010=1
XX4377=1	XX4387=1	XX5002=1	XX5011=1
XX4377=1	XX4388=1	XX5003=1	XX5012=1
XX4378=1	XX4389=1	XX5004=1	XX5013=1
XX4378=1	XX4390=1	XX5005=1	
XX4379=1	XX4391=1	XX5006=1	
XX4380=1	XX4392=1	XX5007=1	

End

GIN 772

APPENDIX C

Linear Programming Optimization Model Result – Optimal Number of Aircraft

LP OPTIMUM FOUND AT STEP 59

OBJECTIVE FUNCTION VALUE

1) 40.00000

Variable	Value	Reduced Cost
AJU0001	1.000000	0.000000
BEL0001	0.000000	0.000000
BSB0001	1.000000	0.000000
CGB0001	1.000000	0.000000
CGH0001	5.000000	0.000000
CGR0001	2.000000	0.000000
CNF0001	1.000000	0.000000
CWB0001	2.000000	0.000000
FLN0001	0.000000	0.000000
FOR0001	3.000000	0.000000
GIG0001	1.000000	0.000000
GRU0001	8.000000	0.000000
GYN0001	1.000000	0.000000
IGU0001	0.000000	0.000000
IOS0001	0.000000	1.000000
JDO0001	0.000000	1.000000
JPA0001	1.000000	0.000000
MCZ0001	1.000000	0.000000
NAT0001	1.000000	0.000000
NVT0001	0.000000	1.000000
PNZ0001	1.000000	0.000000
POA0001	1.000000	0.000000
REC0001	3.000000	0.000000
SDU0001	3.000000	0.000000
SSA0001	2.000000	0.000000
VIX0001	0.000000	0.000000
XAP0001	1.000000	0.000000
AJU0530	0.000000	1.000000
XX4225	1.000000	0.000000
AJU1420	1.000000	0.000000
XX4222	1.000000	0.000000
AJU1505	0.000000	0.000000
XX4223	1.000000	0.000000
AJU1745	1.000000	0.000000
XX4196	1.000000	0.000000

AJU1825	0.000000	0.000000	BSB1044	1.000000	0.000000
XX4197	1.000000	0.000000	XX4218	1.000000	0.000000
BEL1435	1.000000	0.000000	BSB1045	2.000000	0.000000
XX4360	1.000000	0.000000	XX4240	1.000000	0.000000
BEL1525	0.000000	1.000000	BSB1048	3.000000	0.000000
XX4361	1.000000	0.000000	XX4172	1.000000	0.000000
BSB0600	0.000000	1.000000	BSB1049	4.000000	0.000000
XX4193	1.000000	0.000000	XX4186	1.000000	0.000000
BSB0800	1.000000	0.000000	BSB1050	5.000000	0.000000
XX4230	1.000000	0.000000	XX4220	1.000000	0.000000
BSB0805	2.000000	0.000000	BSB1098	6.000000	0.000000
XX4170	1.000000	0.000000	XX4160	1.000000	0.000000
BSB0855	3.000000	0.000000	BSB1099	7.000000	0.000000
BSB0920	2.000000	0.000000	XX4319	1.000000	0.000000
XX4215	1.000000	0.000000	BSB1100	8.000000	0.000000
BSB0930	1.000000	0.000000	XX4362	1.000000	0.000000
XX4233	1.000000	0.000000	BSB1104	9.000000	0.000000
BSB0935	0.000000	0.000000	XX4281	1.000000	0.000000
XX4189	1.000000	0.000000	BSB1105	10.000000	0.000000
BSB0940	1.000000	0.000000	XX4389	1.000000	0.000000
XX4060	1.000000	0.000000	BSB1140	9.000000	0.000000
BSB1015	0.000000	0.000000	XX4326	1.000000	0.000000
XX4061	1.000000	0.000000	BSB1145	8.000000	0.000000

XX4300	1.000000	0.000000	XX4124	1.000000	0.000000
BSB1154	7.000000	0.000000	BSB1725	4.000000	0.000000
XX4306	1.000000	0.000000	XX4307	1.000000	0.000000
BSB1155	6.000000	0.000000	BSB1804	3.000000	0.000000
XX4308	1.000000	0.000000	XX4171	1.000000	0.000000
BSB1198	5.000000	0.000000	BSB1805	4.000000	0.000000
XX4342	1.000000	0.000000	BSB1810	5.000000	0.000000
BSB1199	4.000000	0.000000	XX4309	1.000000	0.000000
BSB1200	3.000000	0.000000	BSB1814	6.000000	0.000000
XX4374	1.000000	0.000000	XX4343	1.000000	0.000000
BSB1209	2.000000	0.000000	BSB1815	7.000000	0.000000
BSB1210	1.000000	0.000000	XX4375	1.000000	0.000000
XX4320	1.000000	0.000000	BSB1830	8.000000	0.000000
BSB1215	0.000000	0.000000	XX4301	1.000000	0.000000
XX4125	1.000000	0.000000	BSB1834	9.000000	0.000000
BSB1345	1.000000	0.000000	XX4234	1.000000	0.000000
XX4232	1.000000	0.000000	BSB1835	10.000000	0.000000
BSB1425	0.000000	0.000000	XX4327	1.000000	0.000000
XX4235	1.000000	0.000000	BSB1840	11.000000	0.000000
BSB1430	1.000000	0.000000	XX4321	1.000000	0.000000
XX4062	1.000000	0.000000	BSB1845	10.000000	0.000000
BSB1720	2.000000	0.000000	XX4065	1.000000	0.000000
BSB1724	3.000000	0.000000	BSB1903	9.000000	0.000000

XX4173	1.000000	0.000000	BSB2000	1.000000	0.000000
BSB1904	10.000000	0.000000	XX4245	1.000000	0.000000
XX4188	1.000000	0.000000	BSB2005	2.000000	0.000000
BSB1905	9.000000	0.000000	XX4214	1.000000	0.000000
XX4237	1.000000	0.000000	BSB2055	1.000000	0.000000
BSB1909	8.000000	0.000000	XX4224	1.000000	0.000000
XX4187	1.000000	0.000000	BSB2359	2.000000	0.000000
BSB1910	7.000000	0.000000	XX4192	1.000000	0.000000
XX4280	1.000000	0.000000	CGB0415	0.000000	1.000000
BSB1913	6.000000	0.000000	XX4381	1.000000	0.000000
XX4219	1.000000	0.000000	CGB0735	1.000000	0.000000
BSB1914	5.000000	0.000000	XX4380	1.000000	0.000000
XX4363	1.000000	0.000000	CGB0810	0.000000	0.000000
BSB1915	4.000000	0.000000	CGB2005	1.000000	0.000000
XX4388	1.000000	0.000000	CGB2040	0.000000	0.000000
BSB1920	5.000000	0.000000	XX4387	1.000000	0.000000
XX4064	1.000000	0.000000	CGB2155	1.000000	0.000000
BSB1925	4.000000	0.000000	XX4382	1.000000	0.000000
XX4161	1.000000	0.000000	CGB2225	0.000000	0.000000
BSB1945	3.000000	0.000000	XX4383	1.000000	0.000000
XX4318	1.000000	0.000000	CGH0615	4.000000	0.000000
BSB1950	2.000000	0.000000	CGH0640	3.000000	0.000000
XX4231	1.000000	0.000000	XX4000	1.000000	0.000000

CGH0725	2.000000	0.000000	CGH1225	3.000000	0.000000
XX4006	1.000000	0.000000	XX4007	1.000000	0.000000
CGH0740	1.000000	0.000000	CGH1240	2.000000	0.000000
XX4284	1.000000	0.000000	CGH1255	1.000000	0.000000
CGH0745	2.000000	0.000000	XX4008	1.000000	0.000000
XX4001	1.000000	0.000000	CGH1400	2.000000	0.000000
CGH0750	1.000000	0.000000	XX4035	1.000000	0.000000
CGH0810	2.000000	0.000000	CGH1425	1.000000	0.000000
XX4033	1.000000	0.000000	XX4034	1.000000	0.000000
CGH0815	1.000000	0.000000	CGH1525	2.000000	0.000000
XX4002	1.000000	0.000000	XX4009	1.000000	0.000000
CGH0900	0.000000	1.000000	CGH1555	1.000000	0.000000
CGH0920	1.000000	0.000000	XX4010	1.000000	0.000000
XX4003	1.000000	0.000000	CGH1655	2.000000	0.000000
CGH0950	0.000000	0.000000	XX4011	1.000000	0.000000
XX4004	1.000000	0.000000	CGH1730	1.000000	0.000000
CGH1040	1.000000	0.000000	CGH1800	0.000000	0.000000
XX4285	1.000000	0.000000	XX4286	1.000000	0.000000
CGH1055	2.000000	0.000000	CGH1830	1.000000	0.000000
XX4005	1.000000	0.000000	XX4013	1.000000	0.000000
CGH1125	1.000000	0.000000	CGH1900	0.000000	0.000000
XX4024	1.000000	0.000000	XX4014	1.000000	0.000000
CGH1210	2.000000	0.000000	CGH2000	1.000000	0.000000

CGH2034	0.000000	0.000000
XX4016	1.000000	0.000000
CGH2035	1.000000	0.000000
CGH2055	2.000000	0.000000
CGH2100	3.000000	0.000000
XX4287	1.000000	0.000000
CGH2125	4.000000	0.000000
XX4017	1.000000	0.000000
CGH2130	3.000000	0.000000
XX4032	1.000000	0.000000
CGH2225	4.000000	0.000000
XX4025	1.000000	0.000000
CGR0430	1.000000	0.000000
XX4169	1.000000	0.000000
CGR0830	0.000000	0.000000
CGR2005	1.000000	0.000000
CGR2040	0.000000	1.000000
CGR2335	1.000000	0.000000
CNF0600	0.000000	1.000000
XX4145	1.000000	0.000000
CNF0950	1.000000	0.000000
XX4144	1.000000	0.000000
CNF1020	0.000000	0.000000
XX4147	1.000000	0.000000
CNF1425	1.000000	0.000000
XX4146	1.000000	0.000000
CNF1505	0.000000	0.000000
XX4149	1.000000	0.000000
CNF1900	1.000000	0.000000
XX4148	1.000000	0.000000
CNF2000	0.000000	0.000000
XX4151	1.000000	0.000000
CNF2350	1.000000	0.000000
XX4150	1.000000	0.000000
CWB0600	1.000000	0.000000
XX4243	1.000000	0.000000
CWB0850	0.000000	1.000000
CWB0930	1.000000	0.000000
XX4242	1.000000	0.000000
CWB1035	0.000000	0.000000
XX4241	1.000000	0.000000
CWB1435	1.000000	0.000000
XX4244	1.000000	0.000000
CWB1515	0.000000	0.000000
XX4247	1.000000	0.000000
CWB1820	1.000000	0.000000

XX4246	1.000000	0.000000	XX4261	1.000000	0.000000
CWB1910	0.000000	0.000000	FLN2145	1.000000	0.000000
XX4249	1.000000	0.000000	FLN2220	0.000000	0.000000
CWB2200	1.000000	0.000000	XX4179	1.000000	0.000000
FLN0715	1.000000	0.000000	FLN2315	1.000000	0.000000
XX4177	1.000000	0.000000	XX4176	1.000000	0.000000
FLN0755	0.000000	1.000000	FOR0305	2.000000	0.000000
FLN0820	1.000000	0.000000	XX4395	1.000000	0.000000
XX4178	1.000000	0.000000	FOR0415	1.000000	0.000000
FLN0850	0.000000	0.000000	XX4270	1.000000	0.000000
FLN1030	1.000000	0.000000	FOR0605	0.000000	1.000000
XX4262	1.000000	0.000000	XX4371	1.000000	0.000000
FLN1110	0.000000	0.000000	FOR0925	1.000000	0.000000
XX4263	1.000000	0.000000	XX4376	1.000000	0.000000
FLN1140	1.000000	0.000000	FOR0955	0.000000	0.000000
XX4174	1.000000	0.000000	XX4377	1.000000	0.000000
FLN1210	0.000000	0.000000	FOR1215	1.000000	0.000000
FLN1440	1.000000	0.000000	XX4372	1.000000	0.000000
XX4175	1.000000	0.000000	FOR1245	0.000000	0.000000
FLN1515	0.000000	0.000000	XX4373	1.000000	0.000000
FLN1835	1.000000	0.000000	FOR1410	1.000000	0.000000
XX4260	1.000000	0.000000	XX4390	1.000000	0.000000
FLN1915	0.000000	0.000000	FOR1440	2.000000	0.000000

FOR1445	1.000000	0.000000
XX4391	1.000000	0.000000
FOR1530	0.000000	0.000000
FOR1610	1.000000	0.000000
XX4392	1.000000	0.000000
FOR1655	0.000000	0.000000
XX4393	1.000000	0.000000
FOR1705	1.000000	0.000000
XX4276	1.000000	0.000000
FOR1745	0.000000	0.000000
XX4277	1.000000	0.000000
FOR1945	1.000000	0.000000
XX4378	1.000000	0.000000
FOR2015	0.000000	0.000000
XX4379	1.000000	0.000000
FOR2245	1.000000	0.000000
XX4370	1.000000	0.000000
GIG0610	0.000000	1.000000
XX4255	1.000000	0.000000
GIG0715	1.000000	0.000000
XX4211	1.000000	0.000000
GIG0720	2.000000	0.000000
XX4279	1.000000	0.000000
GIG0725	3.000000	0.000000
XX4137	1.000000	0.000000
GIG0734	4.000000	0.000000
XX4250	1.000000	0.000000
GIG0735	5.000000	0.000000
GIG0810	4.000000	0.000000
XX4288	1.000000	0.000000
GIG0844	3.000000	0.000000
GIG0845	4.000000	0.000000
GIG0848	3.000000	0.000000
XX4153	1.000000	0.000000
GIG0849	2.000000	0.000000
XX4200	1.000000	0.000000
GIG0850	1.000000	0.000000
GIG0930	0.000000	0.000000
GIG1010	1.000000	0.000000
XX4256	1.000000	0.000000
GIG1040	0.000000	0.000000
XX4251	1.000000	0.000000
GIG1110	1.000000	0.000000
GIG1200	0.000000	0.000000
XX4226	1.000000	0.000000
GIG1245	1.000000	0.000000

GIG1310	2.000000	0.000000	XX4201	1.000000	0.000000
XX4289	1.000000	0.000000	GIG2054	2.000000	0.000000
GIG1315	3.000000	0.000000	XX4152	1.000000	0.000000
XX4252	1.000000	0.000000	GIG2055	3.000000	0.000000
GIG1345	2.000000	0.000000	XX4299	1.000000	0.000000
GIG1350	1.000000	0.000000	GIG2104	4.000000	0.000000
XX4210	1.000000	0.000000	GIG2105	5.000000	0.000000
GIG1510	2.000000	0.000000	GIG2215	4.000000	0.000000
XX4213	1.000000	0.000000	XX4259	1.000000	0.000000
GIG1610	1.000000	0.000000	GIG2359	5.000000	0.000000
XX4298	1.000000	0.000000	XX4254	1.000000	0.000000
GIG1630	0.000000	0.000000	GRU0015	7.000000	0.000000
XX4257	1.000000	0.000000	XX4056	1.000000	0.000000
GIG1725	1.000000	0.000000	GRU0500	6.000000	0.000000
XX4227	1.000000	0.000000	GRU0599	5.000000	0.000000
GIG1810	0.000000	0.000000	XX4040	1.000000	0.000000
GIG1835	1.000000	0.000000	GRU0600	4.000000	0.000000
XX4258	1.000000	0.000000	XX4116	1.000000	0.000000
GIG1910	2.000000	0.000000	GRU0610	3.000000	0.000000
GIG1950	1.000000	0.000000	GRU0625	2.000000	0.000000
GIG2015	0.000000	0.000000	GRU0640	3.000000	0.000000
XX4253	1.000000	0.000000	GRU0644	4.000000	0.000000
GIG2030	1.000000	0.000000	XX4041	1.000000	0.000000

GRU0645	5.000000	0.000000	GRU0825	9.000000	0.000000
XX4323	1.000000	0.000000	XX4126	1.000000	0.000000
GRU0700	4.000000	0.000000	GRU0830	8.000000	0.000000
GRU0705	5.000000	0.000000	GRU0845	7.000000	0.000000
XX4365	1.000000	0.000000	XX4042	1.000000	0.000000
GRU0709	6.000000	0.000000	GRU0850	6.000000	0.000000
GRU0710	7.000000	0.000000	XX4366	1.000000	0.000000
GRU0715	8.000000	0.000000	GRU0855	5.000000	0.000000
XX4291	1.000000	0.000000	GRU0900	4.000000	0.000000
GRU0719	9.000000	0.000000	GRU0904	3.000000	0.000000
XX4121	1.000000	0.000000	XX4194	1.000000	0.000000
GRU0720	10.000000	0.000000	GRU0905	2.000000	0.000000
GRU0725	11.000000	0.000000	XX4304	1.000000	0.000000
GRU0730	12.000000	0.000000	GRU0910	1.000000	0.000000
XX4353	1.000000	0.000000	GRU0920	2.000000	0.000000
GRU0740	13.000000	0.000000	GRU0934	3.000000	0.000000
GRU0750	14.000000	0.000000	XX4043	1.000000	0.000000
GRU0800	13.000000	0.000000	GRU0935	4.000000	0.000000
GRU0810	12.000000	0.000000	XX4317	1.000000	0.000000
XX4130	1.000000	0.000000	GRU0940	5.000000	0.000000
GRU0815	11.000000	0.000000	GRU1005	6.000000	0.000000
XX4104	1.000000	0.000000	GRU1020	5.000000	0.000000
GRU0820	10.000000	0.000000	GRU1030	4.000000	0.000000

XX4182	1.000000	0.000000
GRU1044	3.000000	0.000000
XX4044	1.000000	0.000000
GRU1045	2.000000	0.000000
GRU1105	1.000000	0.000000
XX4324	1.000000	0.000000
GRU1115	2.000000	0.000000
XX4105	1.000000	0.000000
GRU1125	3.000000	0.000000
GRU1130	4.000000	0.000000
XX4045	1.000000	0.000000
GRU1139	5.000000	0.000000
XX4131	1.000000	0.000000
GRU1140	6.000000	0.000000
GRU1145	7.000000	0.000000
GRU1155	8.000000	0.000000
GRU1205	7.000000	0.000000
GRU1224	6.000000	0.000000
XX4122	1.000000	0.000000
GRU1225	5.000000	0.000000
XX4294	1.000000	0.000000
GRU1230	6.000000	0.000000
XX4127	1.000000	0.000000
GRU1240	5.000000	0.000000
XX4046	1.000000	0.000000
GRU1244	4.000000	0.000000
XX4352	1.000000	0.000000
GRU1245	3.000000	0.000000
GRU1305	2.000000	0.000000
GRU1320	1.000000	0.000000
XX4302	1.000000	0.000000
GRU1330	0.000000	1.000000
GRU1415	1.000000	0.000000
XX4047	1.000000	0.000000
GRU1429	2.000000	0.000000
XX4185	1.000000	0.000000
GRU1430	3.000000	0.000000
GRU1499	2.000000	0.000000
XX4048	1.000000	0.000000
GRU1500	1.000000	0.000000
GRU1515	0.000000	0.000000
GRU1550	1.000000	0.000000
XX4305	1.000000	0.000000
GRU1605	2.000000	0.000000
XX4195	1.000000	0.000000
GRU1610	3.000000	0.000000

XX4049	1.000000	0.000000	GRU1810	2.000000	0.000000
GRU1620	4.000000	0.000000	XX4325	1.000000	0.000000
GRU1623	5.000000	0.000000	GRU1820	3.000000	0.000000
GRU1624	6.000000	0.000000	GRU1825	4.000000	0.000000
GRU1625	7.000000	0.000000	XX4051	1.000000	0.000000
XX4295	1.000000	0.000000	GRU1919	3.000000	0.000000
GRU1630	8.000000	0.000000	XX4052	1.000000	0.000000
GRU1635	9.000000	0.000000	GRU1920	2.000000	0.000000
XX4123	1.000000	0.000000	GRU1940	1.000000	0.000000
GRU1710	8.000000	0.000000	XX4316	1.000000	0.000000
GRU1714	7.000000	0.000000	GRU1945	0.000000	0.000000
GRU1715	6.000000	0.000000	GRU2000	1.000000	0.000000
GRU1720	5.000000	0.000000	XX4367	1.000000	0.000000
XX4128	1.000000	0.000000	GRU2010	2.000000	0.000000
GRU1724	4.000000	0.000000	XX4351	1.000000	0.000000
XX4050	1.000000	0.000000	GRU2015	3.000000	0.000000
GRU1725	3.000000	0.000000	XX4303	1.000000	0.000000
GRU1735	2.000000	0.000000	GRU2020	4.000000	0.000000
XX4132	1.000000	0.000000	GRU2034	5.000000	0.000000
GRU1740	1.000000	0.000000	GRU2035	6.000000	0.000000
GRU1744	0.000000	0.000000	GRU2045	7.000000	0.000000
XX4108	1.000000	0.000000	XX4109	1.000000	0.000000
GRU1745	1.000000	0.000000	GRU2110	8.000000	0.000000

GRU2115	9.000000	0.000000	GYN1440	0.000000	0.000000
XX4133	1.000000	0.000000	GYN2010	1.000000	0.000000
GRU2120	10.000000	0.000000	GYN2045	0.000000	0.000000
GRU2130	11.000000	0.000000	GYN2359	1.000000	0.000000
GRU2140	12.000000	0.000000	IGU1025	1.000000	0.000000
GRU2150	13.000000	0.000000	IGU1110	0.000000	1.000000
XX4129	1.000000	0.000000	IGU1215	1.000000	0.000000
GRU2155	12.000000	0.000000	IGU1245	0.000000	0.000000
GRU2215	11.000000	0.000000	IOS1325	1.000000	0.000000
GRU2220	10.000000	0.000000	IOS1355	0.000000	0.000000
XX4290	1.000000	0.000000	IOS1615	1.000000	0.000000
GRU2229	9.000000	0.000000	IOS1645	0.000000	0.000000
GRU2230	10.000000	0.000000	JDO0755	1.000000	0.000000
GRU2255	11.000000	0.000000	JDO0825	0.000000	0.000000
XX4055	1.000000	0.000000	JDO1055	1.000000	0.000000
GRU2300	10.000000	0.000000	JDO1125	0.000000	0.000000
GRU2325	11.000000	0.000000	JDO1430	1.000000	0.000000
GRU2340	12.000000	0.000000	JDO1510	0.000000	0.000000
GRU2359	13.000000	0.000000	JDO1815	1.000000	0.000000
GYN0530	0.000000	1.000000	JDO1845	0.000000	0.000000
GYN0945	1.000000	0.000000	JDO2115	1.000000	0.000000
GYN1015	0.000000	0.000000	JPA0415	0.000000	0.000000
GYN1405	1.000000	0.000000	JPA1215	1.000000	0.000000

JPA1245	0.000000	0.000000	PNZ1250	1.000000	0.000000
JPA1440	1.000000	0.000000	XX4312	1.000000	0.000000
JPA1530	0.000000	1.000000	PNZ1320	0.000000	1.000000
MCZ0400	0.000000	1.000000	XX4315	1.000000	0.000000
MCZ1145	1.000000	0.000000	PNZ1655	1.000000	0.000000
MCZ1220	0.000000	0.000000	XX4314	1.000000	0.000000
XX4141	1.000000	0.000000	PNZ1725	0.000000	0.000000
MCZ1420	1.000000	0.000000	XX4313	1.000000	0.000000
MCZ1500	0.000000	0.000000	POA0535	0.000000	1.000000
MCZ1625	1.000000	0.000000	POA0750	1.000000	0.000000
XX4140	1.000000	0.000000	POA0830	0.000000	0.000000
MCZ1655	0.000000	0.000000	POA1005	1.000000	0.000000
NAT0400	0.000000	0.000000	POA1040	0.000000	0.000000
NAT1440	1.000000	0.000000	POA1415	1.000000	0.000000
NAT1520	0.000000	1.000000	POA1445	0.000000	0.000000
NAT1605	1.000000	0.000000	POA1825	1.000000	0.000000
NAT1640	0.000000	0.000000	POA1855	0.000000	0.000000
NVT0925	1.000000	0.000000	POA1910	1.000000	0.000000
NVT0955	0.000000	0.000000	POA2000	0.000000	0.000000
NVT1900	1.000000	0.000000	POA2150	1.000000	0.000000
NVT1930	0.000000	0.000000	REC0325	2.000000	0.000000
PNZ0600	0.000000	0.000000	REC0415	1.000000	0.000000
XX4311	1.000000	0.000000	REC0615	0.000000	1.000000

REC0715	1.000000	0.000000	SDU0705	0.000000	1.000000
REC0745	0.000000	0.000000	SDU0745	1.000000	0.000000
REC1100	1.000000	0.000000	SDU0815	0.000000	0.000000
REC1130	0.000000	0.000000	SDU0825	1.000000	0.000000
REC1205	1.000000	0.000000	SDU0900	0.000000	0.000000
REC1240	0.000000	0.000000	SDU0920	1.000000	0.000000
REC1410	1.000000	0.000000	SDU0950	0.000000	0.000000
REC1420	2.000000	0.000000	SDU1050	1.000000	0.000000
REC1450	1.000000	0.000000	SDU1119	0.000000	0.000000
REC1500	0.000000	0.000000	SDU1120	1.000000	0.000000
XX4143	1.000000	0.000000	SDU1155	0.000000	0.000000
REC1520	1.000000	0.000000	SDU1225	1.000000	0.000000
XX4142	1.000000	0.000000	SDU1255	0.000000	0.000000
REC1550	0.000000	0.000000	SDU1355	1.000000	0.000000
REC1625	1.000000	0.000000	SDU1425	0.000000	0.000000
REC1655	0.000000	0.000000	SDU1525	1.000000	0.000000
REC1840	1.000000	0.000000	SDU1555	0.000000	0.000000
REC1910	0.000000	0.000000	SDU1615	1.000000	0.000000
REC2225	1.000000	0.000000	SDU1645	0.000000	0.000000
XX4310	1.000000	0.000000	SDU1700	1.000000	0.000000
REC2245	2.000000	0.000000	SDU1830	2.000000	0.000000
SDU0610	2.000000	0.000000	XX4012	1.000000	0.000000
SDU0640	1.000000	0.000000	SDU2000	3.000000	0.000000

SDU2030	2.000000	0.000000	SSA1400	0.000000	0.000000
SDU2100	3.000000	0.000000	SSA1410	1.000000	0.000000
SDU2130	2.000000	0.000000	SSA1415	2.000000	0.000000
SDU2139	3.000000	0.000000	SSA1430	3.000000	0.000000
SDU2140	4.000000	0.000000	SSA1445	4.000000	0.000000
SDU2225	5.000000	0.000000	SSA1505	5.000000	0.000000
SSA0240	3.000000	0.000000	SSA1510	4.000000	0.000000
SSA0410	2.000000	0.000000	SSA1515	3.000000	0.000000
SSA0500	1.000000	0.000000	SSA1520	2.000000	0.000000
SSA0620	2.000000	0.000000	SSA1545	1.000000	0.000000
SSA0655	1.000000	0.000000	SSA1550	0.000000	0.000000
SSA0705	0.000000	1.000000	SSA1600	1.000000	0.000000
SSA0820	1.000000	0.000000	SSA1625	2.000000	0.000000
SSA0855	0.000000	0.000000	SSA1640	1.000000	0.000000
SSA0910	1.000000	0.000000	SSA1725	2.000000	0.000000
SSA0940	0.000000	0.000000	SSA1815	1.000000	0.000000
SSA1055	1.000000	0.000000	SSA1950	2.000000	0.000000
SSA1110	2.000000	0.000000	SSA2020	1.000000	0.000000
SSA1140	1.000000	0.000000	SSA2035	2.000000	0.000000
SSA1255	0.000000	0.000000	SSA2105	1.000000	0.000000
SSA1305	1.000000	0.000000	SSA2145	2.000000	0.000000
SSA1325	2.000000	0.000000	SSA2255	3.000000	0.000000
SSA1335	1.000000	0.000000	VIX0935	1.000000	0.000000

VIX1005	0.000000	1.000000
VIX1910	1.000000	0.000000
VIX1945	0.000000	0.000000
XAP0620	0.000000	1.000000
XAP1315	1.000000	0.000000
XAP1345	0.000000	0.000000
XX4015	1.000000	0.000000
XX4063	1.000000	0.000000
XX4074	1.000000	0.000000
XX4075	1.000000	0.000000
XX4077	1.000000	0.000000
XX4102	1.000000	0.000000
XX4103	1.000000	0.000000
XX4183	1.000000	0.000000
XX4184	1.000000	0.00000

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