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AIRLINE SIMULATION: CASE STUDY OF A REGIONAL AIRLINE COMPANY

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Abstract. *The main goal of this work is to create a tool that can be able to present results needed to analyze the economic viability of a regional airline. For this, we developed a computational simulation to study a specific case presenting the methods to its implementation and their respective results and analyzes. Created in August 2016, The Voe Minas Gerais Project was the case study of simulation and analysis in this work. The type of simulation applied was the agent-based simulation. NetLogo is an agent-based simulation software and it was chosen because its accessibility. We presented two types of simulation scenarios, the route analysis that performed the complete data analysis for each flight stretch of the airline, and the period analysis that performed a daily and weekly simulation of the airline in order to verify its actual condition. The analysis had shown that most of the flights require a full aircraft to reach a breakeven condition. In addition, daily and weekly analysis presented negative balances. Through the simulation used in this work, it was possible to indicate the routes feasibility, and to point out the variables to be improved.*

Keywords: *Simulation. Regional Airline Company. Voe Minas Gerais Project.*

1 INTRODUCTION

Over the last decades, Brazil has seen a significant increase in demand from the air transport sector. Between 2003 and 2010, there was a high growth of 118% in demand when compared to the world growth of only 40% (Anuário Estatístico Operacional, INFRAERO, 2014). In addition, aircraft operating costs have increased due to the price of fuel, labor costs, among others. Therefore, airlines have to be able to circumvent the situation and supply the demand, mainly for passenger transport.

In general, the main role of airlines is to meet the demand of fast transport of passengers between cities. However, most of the regions far from the capitals does not have this transportation in Brazil. The use of regional air transport is still small in the country, appearing only in regions such as Midwest, North, and Northeast. Although, regional airlines are able to promote regional development, encouraging regional business and tourism. The Minas Gerais Economic Development Company (CODEMIG), in partnership with the State Department of Transportation and Public Works, started the Voe Minas Gerais Project, a regional airline connecting many regions of the state of Minas Gerais with its capital, Belo Horizonte. The project aims to promote regional economic development and encourage the emergence of new regional airlines in the state.

The proposal of this work was to develop an airline simulation. From this simulation, we carried out a case study of a regional airline. We selected The Voe Minas Gerais Project as the case study thus the simulation of the project was performed to obtain data for analysis. The goal of the study was to analyze operational costs, flight time, discount policies and ticket prices.

The simulations are intended to unite the main parameters of a study and observe their behavior throughout the simulation. The type of simulation applied in this work is agent-based simulation. From the NetLogo platform, it is possible to simulate agents acting in the same environment and interacting with each other. For this work, airports and aircrafts interacted with each other performing the role of agents.

2 VOE MINAS GERAIS PROJECT

Voe Minas Gerais is a project with initiative of CODEMIG in partnership with Secretary of State for transportation and public works. Also known as the Regional Integration Project of Minas Gerais - Modal Aéreo (PIRMA), the project aims to encourage regionalized economic development. Connecting the regions of Minas Gerais through air transportation, they become more accessible, encouraging business growth and tourism. The airline started in August 2016, linking 12 cities in Minas Gerais, and the chosen hub was Pampulha airport in Belo Horizonte. Nowadays, the project is on its fourth phase connecting 17 cities. However, we developed the simulation based on the second phase of the project.

On the second phase, the project operated flights to 19 cities of Minas Gerais. Follow the Fig. 1 showing the airline map.

Figure 1. Cities attended by the Project

To implement the project, CODEMIG opened a public bidding process, in order to hire the winning company to provide the aircraft and maintenance services. Two Táxi Aéreo Ltda. won the process. According to the contract, the company must make available five Cessna Caravan 208B aircrafts approved by ANAC to carry up to nine passengers, and perform visual flights (VFR). Besides, the contract included the maintenance costs, fuel costs and crew cost. In exchange of that, the project must pay R$ 2900.00 per flight hour. Follow some specifications of the Cessna Grand Caravan:

Table 1. Specifications of Cessna Grand Caravan 208B

Seats	9 passengers, 1 Pilot and 1 Copilot
Maximum Take-off Weight	8750 lb
Fuel Weight	2224 lb
Maximum Cruise Velocity	184 kts
Power Plant	1 x PT6A-114A (Turboprop)

The Project has an electronic address (Projeto Voe Minas Gerais, 2017) in which timetables and prices can be found, as well as being the only means of acquiring tickets. All times and prices of each section are tabulated and fixed throughout the week. In addition to more affordable prices, the project offers special discounts depending on the conditions of purchase. The following discounts are offered: 10% discount for purchases made at least 30 days in advance; 20% discount on group purchases from five passengers on the same flight; in the round trip purchase, a discount of R$ 100.00 on the return ticket, regardless of the price of the chosen route.

According to CODEMIG, the project has been gradually growing. This type of project takes time to consolidate, since regional aviation is still a new initiative in this region of the country. The average aircraft occupancy rate between October 2016 and January 2017 is shown in Fig. 2.

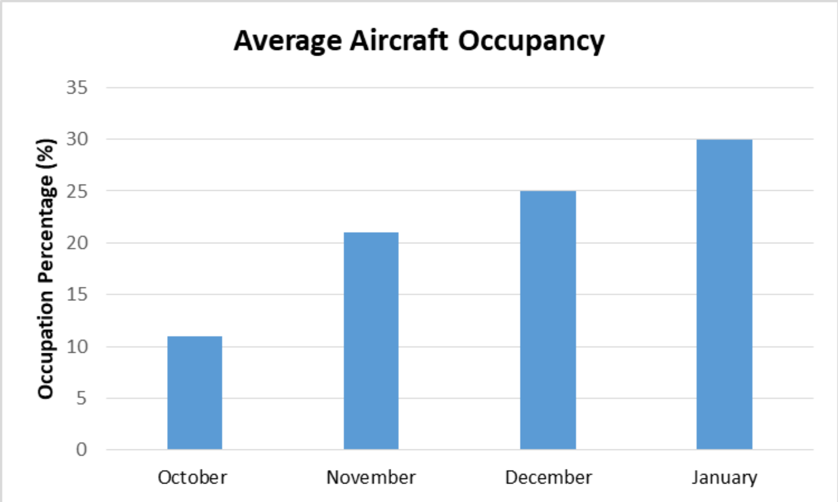

Figure 2. Average Aircraft Occupancy of the Project

3 AGENT-BASED SIMULATION

Computational simulation is a computational model based on systems that are present in reality or are desired to be implemented in the future. Through simulations it becomes possible to observe the behavior of complex systems, being able to test different conditions without having to bring this system to the real world. Many situations and subsystems can be characterized by the presence of autonomous entities in which their behavior (actions and interactions) determine (in a non-trivial way) the evolution of the system as a whole (Binii, Manzoni, VIZZARI, 2009). For these situations, agent-based simulation should be implemented. In Agent-based Systems we study mechanisms of interaction between agents and the effects of these interactions (SICHMAN, 2003).

We selected NetLogo as the platform to perform the simulation because of its accessibility. Netlogo is a software where you can generate simulations from various areas, from environmental to socioeconomic phenomena. Hundreds and thousands of agents can be created and operate independently making decisions according to the environment of NetLogo. Netlogo has its own language and its modeling is all agent-based. There are four types of agents: turtles, patches, links and the observer.

The code structure is all performed with procedures, which can be classified as functions in the most common language. These procedures can be called at any time in the code, and may or may not have input variables. You can also configure buttons on the simulation interface to perform only the desired procedures. Variables can be classified as global, agent-related or local. Global variables can be called at any time in the simulation and assume a single value. The agent-related variables are always linked to the agents, that is, they can only be called in the actions of the agents, and each agent can assume a different value for the variable. Finally, local variables are considered temporary, and can be called as input to a procedure or through a procedure.

In NetLogo, time passes through steps called ticks. These steps can be configured so that the simulation happens faster or slower. In addition, ticks can be used as a condition to perform commands and it can sort the commands throughout the simulation.

4 SIMULATION METHODOLOGY

We created a model of simulation based on agents according to the methodology of NetLogo. This model simulated a system as similar as possible from a regional airline. For this, the model is composed of agents acting in an environment. The agents follow procedures that calculate the output variables using the input variables. With this, a set of procedures can simulate a specific scenario. The agents, variables, procedures and scenarios created for Voe Minas Gerais Project simulation are described below.

4.1 Agents

We created two types of agents for the airline simulation: Airplanes and Airports.

Airplanes are agents who move on the environment collecting data and running procedures of calculation. There are four airplanes acting on the simulation following the model of the Voe Minas Gerais Project.

Airports are agents positioned according to their geographical location on the actual map and their position are fixed on the environment. Following the Project, we created 19 airports according to a scale of 6 to 1 to adapt real world to the environment of NetLogo.

4.2 Procedures and Variables

The simulation procedures are the functions that delegate the behavior of the agents and calculate the necessary variables for analysis. These functions may have temporary input variables or permanent input variables used by all code. In addition, the procedures can be called within another procedure, facilitating their organization. The main procedures that determine the progress of the simulation are listed.

Setup

This procedure has the function of providing all initial data, and must always be read by the program before starting the simulation. Among the initial functions are:

1. declare all program agents, and their respective numbers, colors, position, format. When creating the agents it is necessary that the variables related to the agents are declared with the initial values;

2. declare the input variables referring to the Time extension, such as the ratio of seconds and ticks, date and time at which the simulation will start and flight scheduling times for each airplane;
3. declare values for all global variables, and these values remained constant during the simulation.

Positioning

It has the function of positioning the aircraft at the initial departure airport. It has a temporary input variable called Initial, in which it assumes the number of the airport to position the aircraft. It can be called at the beginning of any simulation scenario.

Fly

It has the function of moving the aircraft, carrying out flights. It has a condition attached to the auxiliary variable Fly, so that whenever this variable is equal to one, the aircraft in question moves. The average speed of aircraft movement is determined by an input variable called Speed that is calculated in the Average Speed procedure.

Average Speed

It has the function of calculating the average speed that the airplane will move in each stretch. The average velocity, in patches / tick, is calculated according to Eq. 1 and 2.

$$Speed = \frac{D_{airports}}{\Delta ticks} \tag{1}$$

$$\Delta ticks = \frac{Flight\ Time}{TimeTick} \tag{2}$$

$D_{aiports}$ is the flight distance, Flight Time is the flight time calculated on procedure Cruise and TimeTick is the time per tick set on the procedure Setup.

Flight Level

It has the function of determining the cruising altitude of each flight. Several variables are present in this choice, such as flight distance, flight direction, direction of the winds, availability of the route, among others. For this simulation, only distance and direction factors are considered, since the other variables depend on conditions that are not simulated in this program.

Cessna Grand Caravan aircraft only performs visual flight (VFR) on the Project as stipulated in the contract. According to the National Civil Aviation Agency (ANAC), visual flights can be carried out at a maximum cruising altitude of 15,000 ft. Table 2 shows the flight level according to the flight direction, following ANAC rules.

Table 2. Cruising Altitude for Visual Flights

Flight Direction	180° to 359°	0° to 179°
Cruising Altitude (feet)	6500	5500
	8500	7500
	10500	9500
	12500	11500
	14500	13500

For simulation, cruising altitudes range from 6500 ft to 14500 ft. The choice of level is based on Table 2 and the distance between airports. The distance-based choice is made as follows:

1. A scale of 0 to 10 is calculated based on the distance of the longer flight. The flight between Belo Horizonte and Almenara is the longest of the project. This scale is calculated through Eq. 3 below.

$$FL = \frac{(D_{BH-AL} - D_{flight}).10}{D_{BH-AL}} \tag{3}$$

FL is a scale of 0 to 10, D_{BH-AL} is the distance between Belo Horizonte and Almenara and D_{flight} is the distance of the current flight.

2. FL scale is separated for even and odd altitudes, and is divided into equal parts, so that the smaller the scale the greater the altitude and vice versa. Table 3 and Table 4 show the scales and their respective altitudes.

Table 3. FL scale for even altitudes

FL Scale	8 to 10	6 to 8	4 to 6	2 to 4	0 to 2
Even Altitude (ft)	6500	8500	10500	12500	14500

Table 4. FL scale for odd altitudes

FL Scale	7.5 to 10	5 to 7.5	2.5 to 5	0 to 2.5
Odd Altitude (ft)	7500	9500	11500	13500

3. The choice of altitude is random but based on the FL scale. A command in NetLogo that randomly chooses a value based on the normal distribution and the standard deviation is applied. Thus, a normal distribution with mean FL and standard deviation of 2 is chosen for even altitudes and 2.5 for odd altitudes.

Cruise Calculation

It has the function of separating the flight in three stages: climb, cruise and descent. For each stage, time, fuel consumption and distance are determined. With this, it is possible to find important variables such as total flight time and fuel spent in the stretch. To perform these calculations, we used the Cessna Grand Caravan 208B Pilots Operating Handbook (POH) as the basis. The POH provides cruise, climb and descent flight data according to altitude, aircraft weight, engine speed, external ambient temperature. The following are the three flight stages and their respective data and calculation methods:

Climb and descent stages: For the present case, we chose the condition of maximum climb rate and descent rate of 800 ft/min. In addition, the take-off weight of 7800 lbs and the standard atmospheric temperature was selected for climb stage. In descent condition, the POH provides data only for condition of 8750 lbs of takeoff weight. As we desired to simulate the 7800 lbs condition, the descent data for weight of 8750 lbs was used conservatively. From the POH data, it was possible to trace a trend curve of distance and time as a function of altitude. Follow the charts for climb and descent stages.

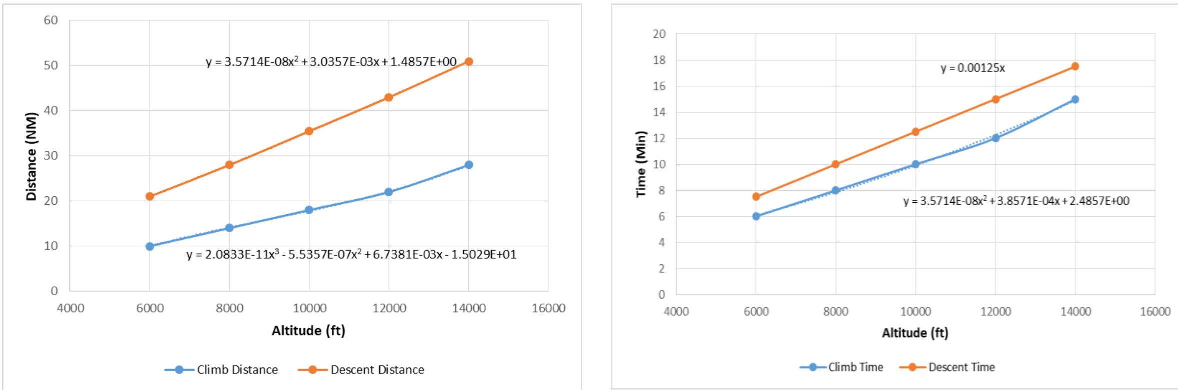

Figure 3. Distance and time charts for climb and descent stages

Cruise Stage: The POH provides data only for condition of 8750 lbs of takeoff weight. As the climb conditions are for a takeoff weight of 7800 lbs, cruise data will be conservative, since at 8750 lbs more fuel is needed. Follow the chart of the cruise speed with data referring to cruising stage for engine rotation of 1750 RPM and standard atmospheric temperature.

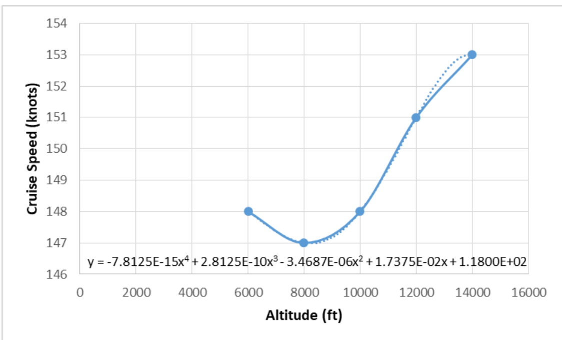

Figure 4. Cruise speed chart as function of altitude

From the charts of Fig. 3 and Fig. 4, total distance of the flight and altitude of the airports, the equations of cruise distance and time for each flight can be assembled:

$$D_{Cruise} = D_{total} - \left(D_{total\ climb} - D_{airport\ climb}\right) - (D_{total\ descent} - D_{airport\ descent}) \quad (4)$$

D_{cruise} is the distance in cruise flight, D_{total} is the total distance of the flight, $D_{total\ climb}$ is the flight distance to climb from sea level to cruising altitude, $D_{Airport\ climb}$ is the flight distance to climb from sea level to the altitude of the airport. $D_{Total\ descent}$ is the distance to descent from the cruising altitude to sea level and $D_{Airport\ descent}$ is the flight distance to descent from the altitude of the airport to sea level.

$$T_{Cruise} = \frac{D_{cruise}}{V_{cruise}} \quad (5)$$

T_{cruise} is the time spent in cruise flight. D_{cruise} is calculated in Eq. (4) and V_{cruise} is the cruise speed determined in Fig. 4. From Eq. (5) and Fig. 3, it is possible to determine the total flight time. Follows the Eq. (6) to calculate the total flight time.

$$T_{total} = T_{cruise} + T_{climb} + T_{descent} \quad (6)$$

T_{total} is the total time of flight. T_{cruise} is the time in cruise flight. T_{climb} is the time in climb flight from the altitude of the airport of departure to the cruise altitude. $T_{descent}$ is the time in descent flight from the cruise altitude to the altitude of the airport of destination.

Passengers, Tickets and Discounts

This procedure has the function of calculating the number of passengers and the ticket revenue by applying the respective discounts offered by the company for each flight. The calculation of passengers for each flight is carried out based on the average airline occupancy which is an entry variable of the program. We have Eq. (7):

$$Pax = N°_{Seats} \cdot \frac{Occupancy_{Average\%}}{100} \quad (7)$$

Pax is the number of passengers on the flight if it were with the average occupancy of the airline, $N°_{Seats}$ is the total number of seats of the aircraft and $Occupancy_{Average\%}$ is average occupancy of the project in percentage.

From Eq. (7), the program chooses a random number of passengers based on a Poisson distribution with mean Pax. We chose the Poisson distribution because the events are independent and with constant mean and constant interval. With the number of passengers on the flight, it becomes possible to calculate the discounts and the total revenue acquired with the tickets of each flight. The Voe Minas Gerais project has three types of discount. The calculations for each discount are shown below.

Discount type 1 offers a discount of $ 100.00 for customers who purchase round trip tickets. We calculated according to Eq. (8).

$$Q_{D1} = Pax.\frac{\%Pax_{D1}}{100}.D_1 \tag{8}$$

Q_{D1} is the value, in Reais, of the discount type 1 applied on each flight, % Pax_{D1} is the input variable that determines the average percentage of passengers per flight that purchase tickets according to the discount type 1 conditions and D_1 is the value, in Reais, of the discount type 1 per person (R$ 100,00). We determined that only for flights with more than one passenger the discount type 1 are applied, in order to apply the discount when the sample space is larger.

Discount type 2 offers a discount of 10% on the value of tickets purchased at least one month in advance. We calculated according to Eq. (9).

$$Q_{D2} = Pax.\frac{\%Pax_{D2}}{100}.\frac{D_2}{100}.P_{Ticket} \tag{9}$$

Q_{D2} is the value, in Reais, of the discount type 2 applied on each flight. % Pax_{D2} is the input variable that determines the average percentage of passengers per flight that purchase tickets at least one month in advance. D_2 is the discount percentage applied for each ticket and P_{Ticket} is the price, in Reais, of each ticket for the flight.

Discount type 3 offers a discount of 20% in the tickets price for groups of at least 5 people buying tickets on the same flight. We calculated according to Eq. (10).

$$Q_{D3} = Pax.\frac{\%Pax_{D3}}{100}.\frac{D_3}{100}.P_{Ticket} \tag{10}$$

Q_{D3} is the value, in Reais, of the discount type 3 applied on each flight. %Pax_{D3} is the input variable that determines the average percentage of passengers per flight that are in groups of five people and bought together. D_3 is the discount percentage applied for each ticket and P_{Ticket} is the price, in Reais, of each ticket for the flight. We determined that only for flights with more than five passengers the discount type 3 are applied, in order to restrict the discount to flights with at least a group of five people.

From the values of Q_{D1}, Q_{D2} and Q_{D3} the total discount value applied for a given flight is calculated, making it possible to calculate the total revenue of each flight through Eq. (11).

$$R_{total} = Pax.P_{Ticket} - (Q_{D1}+Q_{D2} + Q_{D3}) \tag{11}$$

Aircraft Rental and Balance

It has the function of calculating the amount paid with the rent of the aircraft and the amount of the aircraft balance of expenses, that is, the profit. The Voe Minas Gerais Project pays a value of R$ 2900.00 for each hour flown. Thus, this procedure simply multiplies the flight time by the flight hour value, obtaining the total cost with the aircraft for each flight. From this cost, it is possible to subtract from the total revenue and obtain the company's profit for each flight.

4.3 Simulations Scenarios

The simulation scenarios are composed by a group of procedures that can simulates a specific case of the airline. We created two types of scenarios: Route-Analysis and Period-Analysis.

Route-Analysis

It has the function of issuing a complete analysis of the airline simulated. In this analysis, the aircraft sweeps all stretches offered by the airline, performing all calculation procedures for all altitudes possible for each stretch. In addition, the breakeven for each route, that is, the number of passengers in which the transition between revenue and costs occurs, is also calculated. With this routine, it is possible to perform the analysis of the airline in a punctual way, that is, each flight is analyzed separately, and after that analysis check which points can be changed in order to financially improve the company as a whole.

Period-Analysis

We performed a simulation of the Voe Minas Gerais Project for daily or weekly analysis. As a company has a weekly schedule of constant values throughout the month, it was not necessary to perform monthly simulations. As daily flights vary, each day of the week was simulated and analyzed separately. The weekly simulations are intended to generate data for both weekly and monthly analysis.

5 RESULTS AND ANALYSIS

5.1 Route-Analysis

The Voe Minas Gerais project, in its second phase, serves 35 stretches in its weekly air network. For a more organized analysis, we divided airports into groups according to geographical location and the connection between them by flights. As can be seen in Fig. 1, the air network can be divided into five distinct groups, all of which groups have the Pampulha airport in common, since it is the hub of the project. The following topics show the cities that make up each group:

Group 1: Patos de Minas, Araxá, Passos, Divinópolis and Belo Horizonte;

Group 2: Curvelo, Diamantina, Almenara, Teófilo Otoni and Belo Horizonte;

Group 3: Muriaé, Viçosa, Ponte Nova, Manhuaçu and Belo Horizonte;

Group 4: São João Del Rei, Juiz de Fora, Ubá and Belo Horizonte;

Group 5: Pouso Alegre, Varginha, Lavras and Belo Horizonte.

For each stretch, all altitudes are applied. Despite the condition presented on Table 2, each stretch represents two flights, the round trip, one possible at odd altitudes and another at even altitudes, so for each stretch there is the possibility of any altitude. According to the latest CODEMIG report on the project, in January 2017, the average aircraft occupancy rate was 30%. Therefore, we used this value in the input variable $Occupancy_{average\%}$, in order to approximate the maximum of the current situation of the project. In addition, it is necessary to enter input values for the estimation of passengers per flight which are in the conditions of discounts type 1, 2 and 3. For this, we chose the values of 25% for type 1, 20% for type 2 and 10% for type 3. Finally, we inserted the values of the tickets that are available on the Project website. The analysis for each group are presented below.

Group 1 presents nine stretches to be analyzed. Among the stretches, only the cities of Patos de Minas and Passos do not connect directly. Araxá can be considered as a secondary hub, since it connects all cities and is located almost the same distance from all cities in the group. We observed that the stretches of this group presented profit condition only with aircraft almost full, four of which cover expenses only with full aircraft. The most profitable stretch is Pampulha - Araxá with a maximum profit of R$ 654.00 and the least profitable stretch is Pampulha - Divinópolis with a maximum profit of R$ 70.00.

Group 2 presents seven stretches to be analyzed. Among the stretches, the cities of Almenara and Curvelo, Almenara and Teófilo Otoni, Teófilo Otoni and Curvelo, do not connect directly. It is possible to consider the city of Diamantina as a secondary hub since it is the only one that connects all cities of the group. We observed that group 2 presented aircraft almost full for profit condition, five of which cover the expenses with only full aircraft. The most profitable stretch is Diamantina - Almenara with a maximum profit of R$ 971.00 and the least profitable stretch is Pampulha - Diamantina with a maximum profit of R$ 49.00. Pampulha – Dimantina presented altitude conditions in which the flight does not reach the breakeven, even with the full aircraft.

Group 3 presents seven stretches to be analyzed. Among the stretches, the cities of Muriaé and Manhuaçu, Muriaé and Ponte Nova, Viçosa and Ponte Nova, do not connect directly. As the stretches distance of this group are very small, the choice of a secondary hub does not apply. We observed that the stretches of group 3 presented aircraft almost full for profit, some of which did not even reach breakeven. The most profitable stretch is Pampulha - Muriaé with a maximum profit of R$ 401.00 and the least profitable stretch is Pampulha - Ponte Nova with a maximum profit of R$ 85.00. However, the stretch Pampulha - Ponte Nova is not a critical case. The Muriaé - Viçosa, Viçosa - Manhuaçu, Manhuaçu - Ponte Nova stretches did not reach breakeven, presenting financial loss to the company. Muriaé - Viçosa is the most critical with a loss of R$ 80.00.

Group 4 presents six stretches to be analyzed. This group has a direct connection between all cities. As distances are very close to all cities, any of them could serve as a secondary hub, requiring a demand analysis for that choice. We observed that the stretches of group 4 presented almost full aircraft conditions for profit, four of which cover the expenses with only full aircraft. The most profitable stretch is Pampulha - Juiz de Fora with a maximum profit of R$ 502.00 and the least profitable stretch is Juiz de Fora - Ubá with a maximum profit of R$ 2.00. Juiz de Fora - Ubá may present altitude conditions in which the flight does not reaches breakeven even with the full aircraft.

Group 5 presents six sections to be analyzed. This group has a direct connection between all cities. Varginha can be chosen as secondary hub, being the closest to the other cities. We observed that stretches of group 5 presented aircraft almost full for profit condition, some of which did not even reach breakeven. The most profitable stretch is Pampulha - Pouso Alegre with a maximum profit of R$ 603.00 and the least profitable stretch is Varginha - Pouso Alegre with a maximum profit of R$ 39.00. However, the Varginha - Pouso Alegre stretch is not a critical case. The Varginha - Lavras stretch did not reach breakeven, with a loss of R$ 39.00 for the company. The following is the map of the air network with the stretches highlighted according to their profit. The stretches in red presented a condition of financial loss and the green stretches was the most profitable.

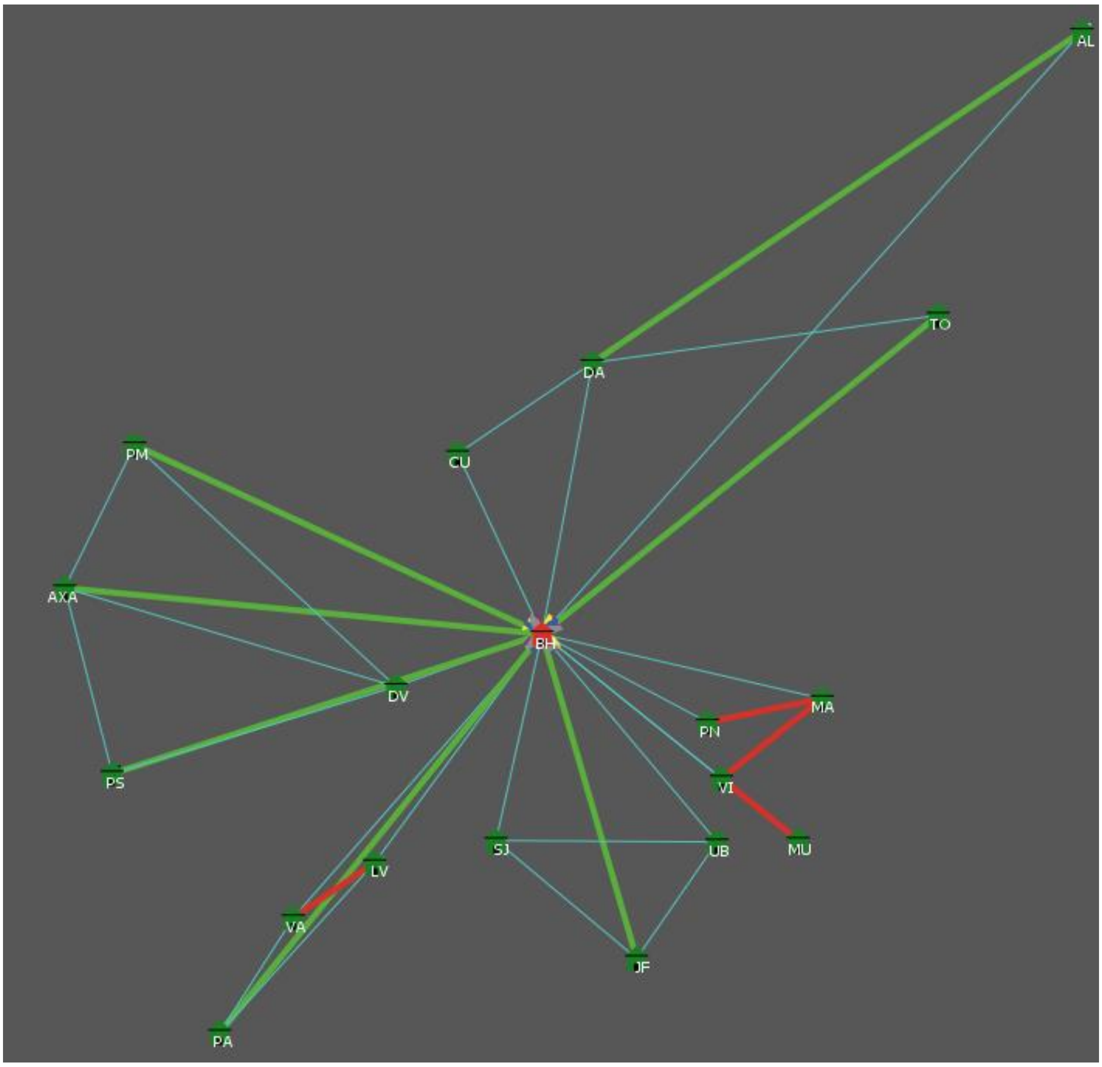

Figure 5. Project network map highlighted according to the profit

For the tickets price analysis, the average aircraft occupancy was set at 30%, 50%, 75% and 100%, letting the ticket prices vary until breakeven was reached. Fig. 6 shows the chart of tickets price according to the flight distance for the four cases of average occupancy and the actual tickets price of the project.

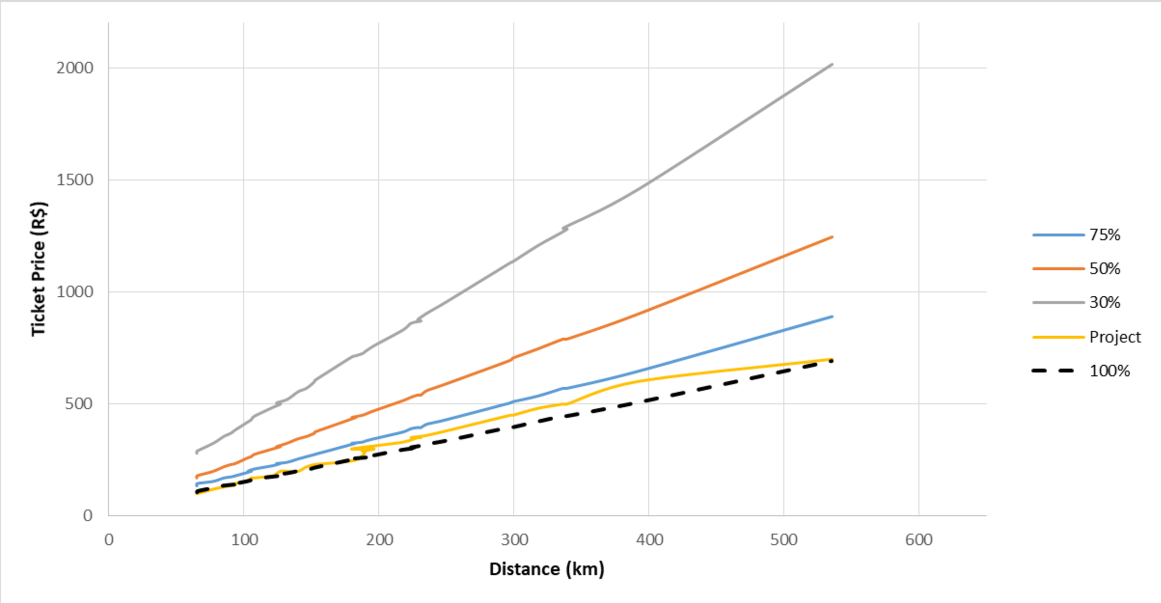

Figure 6. Chart of tickets price according to the distance of the stretch

The curves of Fig. 6 represent the minimum ticket price according to the distance that the project should have to obtain profit. In order to obtain profit from the variation in average aircraft occupancy, it is necessary that the tickets price present themselves below the curve of the respective average occupancy rate. For example, for the Pampulha - Teofilo Otoni stretch of 336 km distance, if the company had an average occupancy rate of 30%, the minimum ticket value would have to be $ 1285.00 to obtain profit. The Project curve shows that the current average occupancy of the Project should be between 75% and 100% to obtain profit. However, for stretches with distances below 180 km the project presented a condition of loss even with full aircraft.

5.2 Period-Analysis

To simulate the project, as it really is, the period analysis takes into account flight schedules, chooses the number of passengers based on the data collected, the flight altitude and the discounts. With this, it tries to get as close as possible to the current situation of the project. The Voe Minas Gerais project network has a different configuration for each day of the week, so each day is presented separately, as well as its analysis. For all simulations, we chose the value of 30% average occupancy according to the last report from CODEMIG. In addition, we chose the percentages for the use of the discounts of 25% for type 1, 20% for type 2 and 10% for type 3. Follow the data and analysis for each day.

Monday

This day presents 35 flights in total, being carried out by the four aircraft of the project, and one remains in reserve at Pampulha airport. Three cities are not served that day: Curvelo, Varginha and Muriaé. Table 5 shows the total distance, time, number of passengers, discounts and balance for Monday flights.

Table 5. Total distance, time, number of passengers, discounts and balance for flights on Monday

Distance (km)	Time (min)	N° Pax	Discounts (R$)	Balance (R$)
6956.97	1524.73	107	4059.00	-48634.00

All aircrafts presented financial loss on Monday. Monday was the weekday with the greatest financial loss and the greatest number of passengers transported.

Tuesday

This day presents 23 flights in total, being carried out by two aircraft of the project, and one is held at Pampulha airport. Four cities are not served that day: Manhuaçu, Ponte Nova, Almenara and Pouso Alegre. Table 6 shows the total distance, time, number of passengers, discounts and balance for Tuesday flights.

Table 6. Total distance, time, number of passengers, discounts and balance for flights on Tuesday

Distance (km)	Time (min)	N° Pax	Discounts (R$)	Balance (R$)
3994.89	878.07	62	2304.00	-29314.00

All aircrafts presented financial loss on Tuesday. Tuesday was the weekday with the least number of aircrafts operating.

Wednesday

This day presents 17 flights in total, being carried out by two aircraft of the project, and one is held at Pampulha airport. Five cities are not served that day: Muriaé, Viçosa, Varginha, Ubá and Passos. Table 7 shows the total distance, time, number of passengers, discounts and balance for Wednesday flights.

Table 7. Total distance, time, number of passengers, discounts and balance for flights on Wednesday

Distance (km)	Time (min)	N° Pax	Discounts (R$)	Balance (R$)
3616.81	787.49	46	1848.00	-24799.00

All aircrafts presented financial loss on Wednesday. Wednesday was the weekday with the smallest financial loss and the smallest number of passengers transported.

Thursday

This day presents 23 flights in total, being carried out by three aircraft of the project, and one is held at Pampulha airport. Six cities are not served that day: Muriaé, Viçosa, Patos de Minas, Manhuaçu, Ponte Nova and Lavras. Table 8 shows the total distance, time, number of passengers, discounts and balance for Thursday flights.

Table 8. Total distance, time, number of passengers, discounts and balance for flights on Thursday

Distance (km)	Time (min)	N° Pax	Discounts (R$)	Balance (R$)
4780.77	1045.47	61	2700.00	-32851.00

All aircrafts presented financial loss on Thursday. Thursday was the weekday with the smallest number of cities served.

Friday

This day presents 34 flights in total, being carried out by the four aircraft of the project, and one is held at Pampulha airport. Only one city is not served that day: Lavras. Table 9 shows the total distance, time, number of passengers, discounts and balance for Friday flights.

Table 9. Total distance, time, number of passengers, discounts and balance for flights on Friday

Distance (km)	Time (min)	N° Pax	Discounts (R$)	Balance (R$)
7074.62	1546.91	99	4017.00	-44375.00

All aircrafts presented financial loss on Friday. Friday was the weekday with the greatest distance flight and the greatest number of cities served.

Week

The Voe Minas Gerais project carries out 133 flights per week. Monday and Friday are the days with more flights due to demand. Follow the chart showing the financial balance per kilometer flown comparing every day of the week.

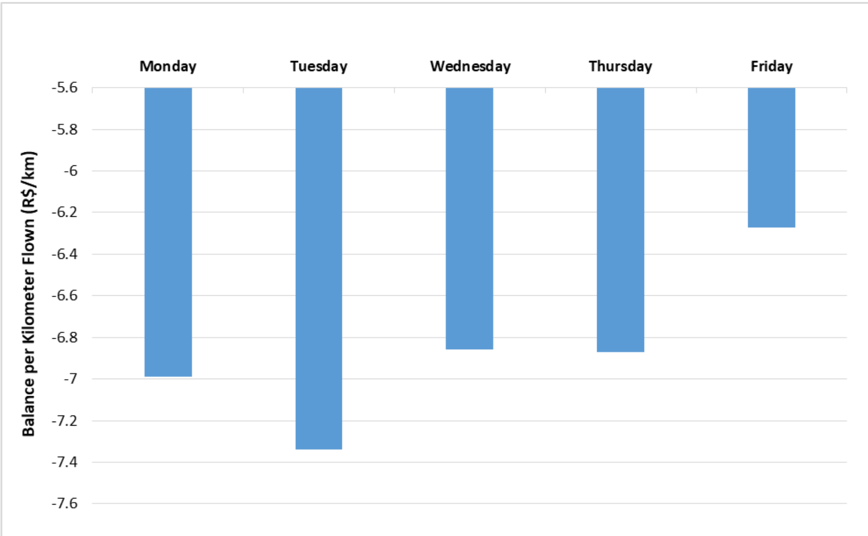

Figure 7 . Chart of the financial balance per Kilometer flown

Observing Fig. 7, we concluded that the day with the best balance per kilometer flown was Friday with a loss of R$ 6.27/km and a critical case was Tuesday that shows a loss of R$ 7.34/km.

Follow the chart showing the financial balance per passenger transported comparing every day of the week.

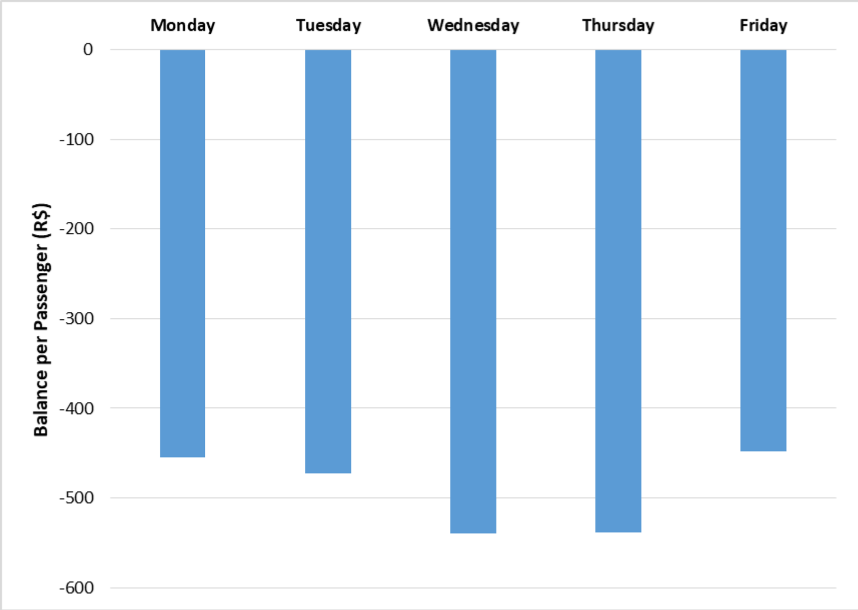

Figure 8. Chart of the financial balance per Passenger transported

Observing Fig. 8, we concluded that the day with the best balance per passenger transported was Friday with a loss of R$ 448.23/passenger and a critical case was Wednesday that presented a loss of R$ 539.11/passenger.

In addition, we performed the simulation varying the average occupancy rate, in order to estimate at which point its balance would become positive. For this, we performed the simulation ten times for each case of average occupancy rate, and then calculated the average balance for each case. Table 10 presents the average balance for various occupancy rates.

Table 10. The average week balance for various occupancy rates

Average Occupancy	Average Week Balance (R$)
50 %	-124148.00
70 %	-63158.00
80 %	-42868.00
90 %	-21754.00
100 %	-1018.00

Observing Table 10, we observed that for the conditions simulated, even with 100% occupancy the project balance would not become positive but the value was very close to that.

6 CONCLUSION

The goal of this work was to develop an airline simulation model to be applied in the regional airline sector. Much of this work had as its focus the creation of a simulation program and presentation of the data generated by it. The data generated and analyzed were aimed at the financial viability of the airline, but in order to reach this data it was necessary to know in detail the airline's network and the aircraft that performs the flights.

Despite the great level of detail of the simulation developed, the work had some limitations and simplifications. The Voe Minas Gerais project, as well as the small airline taxi companies of the country, also carries cargo transport. As a result, the financial revenue from the flights can reach values higher than expected by the simulation. Since the project has a low average occupancy rate, there is more availability for this type of transportation. In addition, the flight altitude prediction of the simulation had uncertainties because it did not take into account factors such as climatic conditions and the condition of the local airspace. Another issue was that some input variables were statistical data, such as the average occupation of aircraft and the use of discounts offered, therefore always presented average and not exact data.

The results generated by the simulations are consistent. It is advisable to carry out a statistical study of the occupancy rates and the use of the discounts, in order to obtain results that are closer to the actual situation of the airline. The average occupancy rate used in this study is chosen based on information from CODEMIG and the rates of use of discounts were chosen by the author.

The data from the route analysis simulation presented very important conclusions to make specific modifications in the company. For the Voe Minas Gerais project, we concluded that in order to reach the balance between expenses and revenue, the aircraft must carry out the stretches, practically full. That condition is far from where the project is currently. The stretches Varginha - Lavras, Manhuaçu - Ponte Nova, Manhuaçu - Viçosa and Viçosa - Muriaé were not feasible even with the full aircraft, requiring changes. The most profitable stretches were Diamantina - Almenara, Pampulha - Patos de Minas and Pampulha - Araxá. Therefore, the value of the tickets is below the required when compared to the amount demanded by the rent of the aircraft. This condition demands a balance between the less and the most profitable stretches in order to make the company feasible. In addition, monitoring the use of the project's discount policies is of great importance for cost control. A possible modification would be to change the discounts according to the percentages of use, in order not to have so many financial changes. However, the project had not made any changes to its discounts policy since the beginning of operations.

It is worth remembering that the project has the intention of encouraging regional flight, encouraging the population to adopt this type of transportation, thus allowing the appearance of new airline companies. Therefore, the policy of discounts and flight tickets below the price demanded are valid until the consolidation of the project.

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