CSE 6730 Project 2 Report

Advanced Airport Simulation

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***Abstract*—This report details the key design improvements of the airport simulation implemented in first assignment. The main improvements include the following: a fuel property added to the airplane class, the arriving airplane queue is now a priority queue based on an airplane's remaining fuel, created an Airline class, revenue and cost for each airplane is calculated to generate the final profit statistics for each airline; the turn time (time on the ground) of an airplane is modified according to the number of passengers and time to refuel, an additional runway allows for landing and departing from two different runways and a GUI allows for user input to the program which includes visualizations after each simulation is finished.**

Keywords—Simulation, Airport, Airplane, Queue, Passengers, Cost, Revenue, Turn Time, Airline

I. Introduction

The purpose of this report is to describe the details of the changes we made to our Project 1 Airport Simulator. We fulfilled all ideas given in our project proposal which are: Adding a fuel property (fuel gauge), adding an Airline property to each airplane (also added a Airline Class), Modifying an airplane's time on ground as a function of passengers, Implement an economic model with outputs, and creating a GUI. Our report is organized by Design Considerations, Results, Future Work and Conclusion.

II. Design Considerations

A. Airplane Fuel-Remaining Property

Besides the existing properties of the Airplane class (e.g. passengers, time on the ground, and speed), we added a fuel property to simulate the fuel usage of real airplanes.

Although the fuel price is a parameter that the user can set when launching the simulation, the default fuel price parameter is set to $1.58 per gallon. This is the current price for Jet Fuel A, the typical fuel type used by passenger airlines [6].

The *m_maxfuel* property is the maximum amount of fuel each airplane has for one ride, and it is set by a construction function. The *m_fuel* property is the amount of fuel each airplane at any given time. It updates according to the flight trip distance and changes at each time step. An average fuel mileage per gallon statistic was found and was determined to be approximately 5 gallons of fuel per mile (12 liters per kilometer) [5].

Due to the addition of the fuel status property, we modified the airplane landing queue from a first in first out (FIFO) queue to a priority queue. The the new queue prioritizes airplanes with the least amount of fuel remaining to ensure that the airplanes do not run out of fuel while circling and waiting to land. Since each plane is refueled on the ground to maximum capacity we did not modify the departing FIFO queue.. The added current fuel remaining property of each airplane also is used in calculating the time an airplane takes on ground (for refueling) and the economic cost of running each; both are discussed in later sections.

B. Airline Class

We also created an Airline class for each airline we record its' name (e.g. United), total revenue, and total cost calculated from the flights associated with each airline. We chose to compare three airlines: "Delta", "Southwest" and "Spirit". Each airplane instance also includes a company name property so that for each flight an airplane is associated with one of these three airlines.

Every airplane added to the model is assigned to an airline according to a probability ratio of 0.6: 0.35: 0.05 for Delta, Southwest and Spirit respectively. This probability was chosen based on the size of each airlines' airplane fleets and dividing by the total. The airplane fleet sizes are 1280, 724 and 101 airplanes for Delta, Southwest and Spirit respectively [11]. After each airplane is assigned to an airline, the airplane is then randomly assigned with equal probability for each (⅓ chance) as one of the following models: Airbus A380, Boeing 777 and Airbus A320.

C. Modified Time on Ground Parameter

Unlike in Project 1 when the time on the ground variable was constant, we chose to more realistically simulate an airplane's turn around time. We chose to modify the time on the ground according to the number of passengers on a given flight and the amount of fuel to refill. Such a model is built on the assumption that the time for passengers to board and deboard the plane are proportional to the number of passengers as well as that the time for the airplane to refuel is proportional to the amount of fuel needed.

Therefore, we use the following mathematical model to calculate the total time on the ground for each airplane:

TimeonGound = *m_TimeonGround* + 0.1**numofPassengers* + 0.01*(*maxFuel* - *fuel*)

The *m_TimeonGround* parameter is a constant across each airline/airplane and was chosen to be 30 minutes after a careful review of online literature [10]. The variables: number of passengers and fuel refuel time were chosen to be 5 minutes to refuel and 30 minutes for 300 passengers to board and deboard. *maxFuel* varies depending on the type of airplane and was found through a quick survey of references for type [2][3][4].

D. Additional Runway for Each Airport

We added an additional runway to each airport for a total of two. One is the runway for landing planes, which is related to the landing priority queue. The other one is the runway for all departing planes, which is related to the departing queue. Each runway has a flag to denote its status.

E. Generate Random Airports

In this project, 50 airports are generated with the user option to generate more or less. Unlike project 1, which uses five realistic domestic airports, the properties of these airports are generated randomly this includes the runway time to land and runway time to depart for each airport are also randomly generated. We assume each airport has a direct flight to and from all others, the distance matrix with airport distance pairs is generated using a random number generator bound between the 500 and 5,000 miles. Based on 2016 flight data 86% of all domestic flights from Delta, Southwest and Spirit airlines were between 500 and 5,000 miles apart [1]. All initial instantiated airplanes are set to be in the air, and then are allocated to arrive at a random airports.

F. Economic Model for Each Airline and Airport

We also built an economic model for our airplane simulation. For each flight, the revenue is calculated and then added to the airline that owns the airplane. The cost calculation contains two parts: the fuel cost for flying and the fee paid at the arriving airport. Therefore, for each flight, we calculated the revenue and cost for the airline it belongs. Finally, each airline's profit is calculated by taking the difference between cost and revenue. Calculations are as follows:

*Revenue = Revenue_perpassenger_permile * NumOfPassengers * Miles*

*Cost = fuel_price * fuelcost_permile * miles + airport_fee + Casm_perpassenger_permile * NumOfPassengers * Miles*

Profit = Revenue - Cost

We found the above parameters, such as *Revenue_perpassenger_permile*, for each airline through extensive research.

The airport landing fees were calculated as follows. Sample fees for Los Angeles International Airport (LAX) were found and used for every airport to simplify the model. At LAX the landing fees are "$4.50 per thousand pounds of maximum gross landed weight" [7]. This combined with the knowledge that the average airplane maximum landing weight is 140,000 pounds [8], gave the following equation of airport fees per landing:

airport charge = $4.50/(1000 *lbs*) *(140,000 *lbs*) = $630

The following revenue statistics given in *dollars /(passenger-mile)* were found and implemented in the simulation to calculate the revenue per flight. In the following table, RASM is the revenue per passenger-mile [9]:

	RASM (CENTS)	CASM (CENTS)	MARGIN (CENTS)	MARGIN
Alaska	12.7	9.7	3.1	24.0%
Spirit	10.6	8.3	2.3	22.1%
Southwest	13.9	11.0	3.0	21.4%
Delta	15.0	11.9	3.1	20.9%
Frontier	10.6	8.6	2.1	19.4%
Allegiant	10.0	8.4	1.6	15.8%
JetBlue	12.8	10.9	2.0	15.5%
Virgin	12.2	10.4	1.8	15.1%
American	13.8	11.8	2.0	14.2%
Hawaiian	12.3	10.6	1.7	13.7%
United	13.3	12.2	1.1	8.5%

Fig. 1. Revenue Per Passenger-Mile

Similarly, the cost statistics given in *dollars/(passenger-mile)* were found and implemented in the simulation to calculate the cost per flight. We added together the labor cost per passenger-mile and other cost per passenger-mile to calculate our *Casm_perpassenger_permile* parameter. We exclude the fuel cost because we calculate the the fuel cost within our model based on the input fuel value. In the following table, CASM is the cost per passenger-mile [9]:

AIRLINE	YEAR	CASM	LABOR	FUEL	OTHER	CHANGE	%
Alaska	2014	11.4	3.3	3.9	4.3	0.1	0.7%
	2015	9.7	3.2	1.9	4.6	-1.7	-14.9%
Hawaiian	2014	12.6	2.8	4.1	5.6	0.5	4.0%
	2015	11.2	3.1	2.5	5.6	-1.4	-10.8%
United	2014	13.6	4.2	4.1	5.3	0.4	2.9%
	2015	12.4	4.6	2.7	5.1	-1.2	-9.1%
American	2014	13.8	3.6	4.5	5.7	0.4	3.0%
	2015	11.8	3.8	2.7	5.3	-2.0	-14.3%
Delta	2014	15.6	5.1	4.4	6.1	0.4	2.4%
	2015	13.3	4.3	3.8	5.2	-2.4	-15.0%
Spirit	2014	9.9	1.6	3.7	4.5	-0.2	-1.9%
	2015	8.4	1.7	2.3	4.4	-1.6	-15.8%
Allegiant	2014	10.2	2.3	4.6	3.3	0.2	2.4%
	2015	8.4	2.2	3.0	3.3	-1.8	-17.2%
Virgin America	2014	10.9	1.9	3.8	5.3	0.3	2.5%
	2015	10.4	2.2	2.5	5.8	-0.6	-5.1%
Frontier	2014	11.3	2.2	4.0	5.1	-0.5	-4.1%
	2015	8.9	1.8	2.4	4.8	-2.4	-21.3%
Southwest	2014	12.5	4.2	4.1	4.2	0.1	0.7%
	2015	11.1	4.5	2.7	3.9	-1.4	-10.9%
JetBlue	2014	12.3	3.0	4.4	4.9	0.6	5.3%
	2015	11.2	3.3	3.0	5.0	-1.1	-9.0%

Fig. 2. Cost Per Passenger-Mile

G. *Input GUI to Run Simulation and Produce Outputs*

We used NetBeans IDE to create the input and output graphical user interface (GUI) code. We decided to use the Swing package as opposed to the built in AWT package because Swing is dramatically more visually appealing. We also use the JFreeCharts package to implement the visualizations because this package is free and easy to implement.

Despite setting the structure with NetBeans, a lot of modification was still needed to set action events for each button and check the field input. For example, if a user clicks the “Profit” button in the output GUI, then the class had to be hardcoded to output bar graphs of profitability statistics per airline.

With the input GUI, the user sets the parameters needed for the simulation, and once he/she clicks “Run Simulation”, the simulation starts. The parameters the user can choose are: the number of airports, the number of airplanes, fuel cost and simulation length.

The input GUI allows the user to choose the output statistics desired which are broken down by airline. The simulation is only implemented with 3 airlines as mentioned above: Spirit, Delta, and Southwest. The possible output statistics are profit, revenue, cost and passengers.

III. Results

Our simulation is started by running the InputGUI class, which launches a GUI that takes the input of number of airports, price of fuel and simulation length. Once clicking “Run Simulation” in the input GUI, the actual simulation is launched and after this simulation ends the output GUI is generated.

A. *Input GUI*

The picture below shows the input GUI for our system. The default parameters are set to model a realistic situation for the three airlines we chose (Delta, SouthWest, Spirit). We recommend the default values as follows: the total number of airplanes is set to 2000, the number of airports is set to 50, the simulation time is set to 365 and the fuel cost is set to $1.58 per gallon.

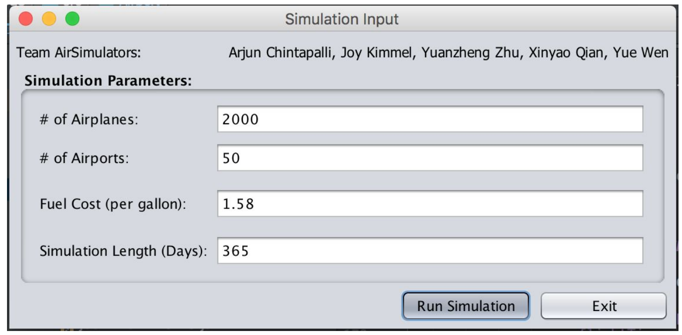

Fig. 3. Input GUI panel

B. *Output GUI*

In the output GUI, a user can select the statistics they want to view: the profit, the revenue, the cost and number of passengers carried for each airline. Since the simulation time is one year we can compare the total final profits for each airline with the financial statistics we found.

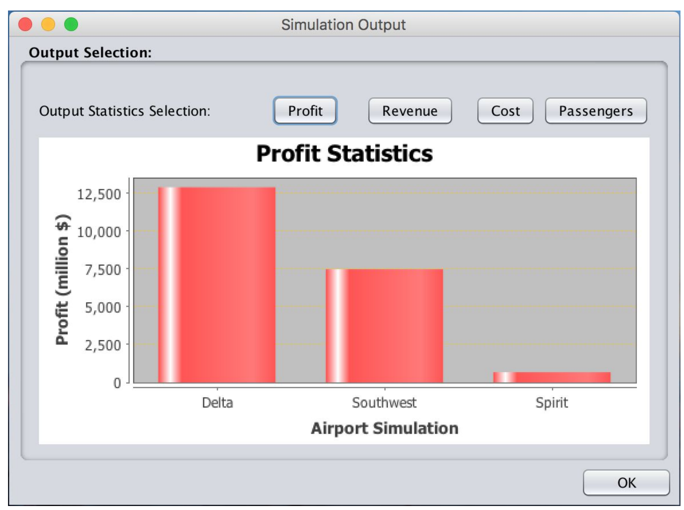

Fig. 4. Profit statistics for different airlines

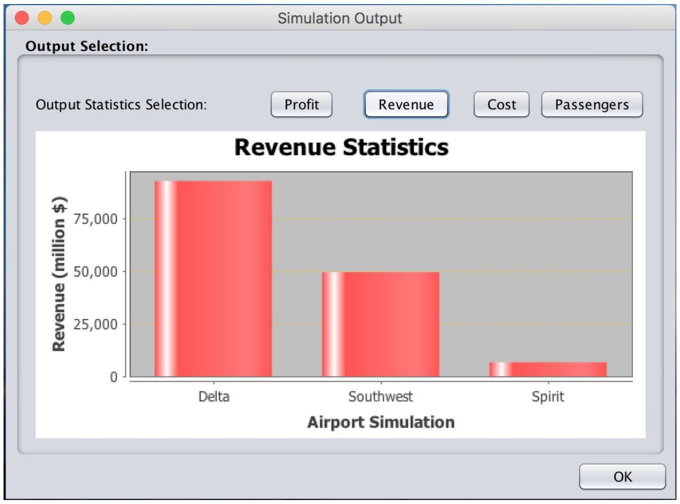

Fig. 5. Revenue statistics for different airlines

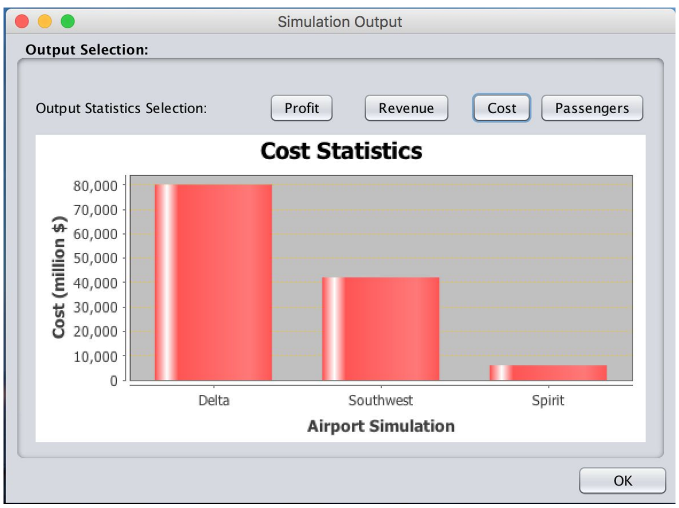

Fig. 6. Cost statistics for different airlines

C. *Validation*

The following real-world profitability statistics were found for comparison to validate the model.

Rank	Airline	Net Income	Operating Profit or Loss	Operating Revenue	Revenue from Fares	Percent of Revenue from Fares (%)
1	AA-US Combined	7,895	6,189	41,084	29,173	0.71
2	Delta	4539	7,845	40,816	28,437	0.70
3	United	7,301	5,167	37,864	26,333	0.70
4	Southwest	2181	4,117	19,820	18,347	0.93
5	JetBlue	677	1,198	6,416	5,907	0.92
6	Alaska	829	1,291	5,594	3,961	0.71
7	Hawaiian	193	431	2,313	2,015	0.87
8	Spirit	331	509	2,142	1,267	0.59
9	SkyWest	113	216	1,932	1,876	0.97
10	Frontier	146	276	1,604	1,277	0.80
10-Carrier Total		24,204	27,239	159,585	118,592	0.74
All Passenger Airlines		25,596	27,993	168,874	126,880	0.75

Fig. 7. Real-World Profitability Statistics

Our results show similar trends as the the real world revenue and profitability statistics for the chosen airlines [12]. For example, the simulation profit and revenue for Delta was ~$12.5 billion and ~$80 billion, compared to real world values of ~$7.845 billion and ~$40 billion.

Our simulation output is on the same order and magnitude as real world values however, does have some discrepancy.

IV. *Future Work*

We expect that the discrepancy noted between the simulation and real world statistics are due to exogenous factors that aren't accounted for in the simulation such as maintenance time, weather cancellations, delayed flights (average flight delay is 2.58 min) and emergency situations [13].

These factors above would explain why the simulated revenue is drastically larger than the real world revenue but are difficult to factor into the simulation because these factors are more or less random events. Although in the future these events could be modelled and added to the simulation to make it more accurate and realistic. Other improvements could be made to the boarding / deboarding / fueling statistics as all of that differs by method of boarding (e.g. a Southwest first in first seated method or Delta a customer service centric model where different zones are seated with priority). 2016 domestic flight data is available and in a future iteration of this model could be used as an input probability for distances between airports so that the random generator for the 50 +/- airports could be as realistic as possible. We also could include an option for some airports not to have direct flights or include simulate flights where only some passengers de-board the plane (connecting flights).

V. *Conclusion*

With our additional modifications we found the importance of making educated assumptions and focusing on the purpose of the model. For our model we focused on the economic impact of passengers and fuel. Similar models to our simulator could be very useful for airline companies to predict the effects of fuel price, and passenger behavior on their business plans at a big picture level.

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