CSE6730 Project II: Advanced Airport Simulation

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***Abstract*—With increasing number of airport passengers, management of airport operations are becoming more and more essential. However, it could not be ignored that the delay of the flight always happens, which leads to a huge economic loss. Hence, airport operation efficiency needs further improvement. In this project, priority queues are applied to handle different airport events. New features such as multiple runways, emergency events, and graphical user interface are included to make it more applicable. How different parameters affect the arriving and departing number of passengers of an airport as well as plane circling time is analyzed.**

***Index Terms*—airport, simulation, priority queue**

I. Introduction

AIR traffic control has aroused more and more attention nowadays due to the growth of air transportation services. According to data from Federal Aviation Administration (FAA), larger airports, like Atlanta Hartsfield International (ATL) airport, need to handle more than 900000 operations every year [1]. Proper operations on runways and airplanes are usually applied based on robust modeling and simulation, which is so-called discrete event simulation.

Discrete event simulation functions by generating priority queues to handle events and taking other affecting factors into account. Previous works mainly focus on the design of airlines and passenger flow control. Caoyuan Zhong includes a set of traffic paths in the airfield network [2], and then simulates the process using different control strategies to get the best path for each plane. Julio C. Martinez performs analysis on multiple-runway operations by directly using STROBOSCOPE, which is a discrete event simulation system, to get waiting time for airplanes [3]. Other works focus on simulation to model passenger flow so as to improve check-in systems and reduce delay time [4].

In this project, the objective is to simulate four stages of the process for an airplane, and add new features to make airport operation more complicated and practical. Several aspects, such as number of planes, airplane speed, and required time on ground, are focused to figure out their relationship with the number of arriving (or departing) passengers and the plane's circling time, which is the time needed waiting to land. One hundred airports and ten thousand airplanes are picked up, each having four different categories. The whole simulation consists of enhancing the model, setting parameters, varying parameters, collecting data, and analyzing results.

II. Modeling and Analysis

A. New Features

In the previous project, four stages of the airplane process are simulated, including arriving, landed, taking off, and departing. Several new features are introduced in this project to make airport operation more applicable:

- Each airport has different number of runways, varying from 1 to 4.
- Time required on the ground are different for airports, which can be 60, 120, 180, or 240 min.
- The speed is different for airplanes, which may be 9.00, 9.35, 9.45, or 9.50 miles per min.
- The maximum capacity for passengers for each type of airplane (four types in total) is different.
- Emergency event is included with a probability of 0.1 percent when a plane arrives. It automatically has the highest priority to land.
- All the arriving queues, takeoff queues, and emergency queues are binary heaps instead of first-in-first-out queues.
- Graphical User Interface (GUI) is implemented to set parameters and display results.

Four different type of airports are used in our project. Since there can be international and domestic airports, their number of runways should be different. Each runway can be used for planes to land or take off. For the queue system design, binary-heap rather than simple linked list would be used for the queue system design. The time complexity for inserting and deleting event for binary-heap is both log(n). This means that this data structure is greater than that normal binary tree on considering the priority event.

Time required on ground is regarded as one of the most important factors to reflect the efficiency of an airport. During that time, all the things including security check and cargo shift are finished, and should also be different. The chosen of the airplane for this project are specified to Boeing (BO747 and BO787) and Airbus (A380 and A330). The Boeing airplane has a slightly higher speed, while Airbus carries more passengers. Hence, the efficiency of these four types of airplanes are also explored. Details of their speed and passenger capacity are listed in following sections.

One of the most important feature is the emergency event. Figure 1 shows our schema diagram.

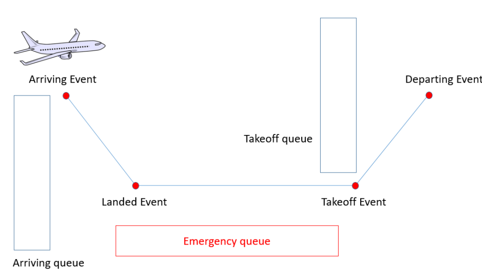

Fig. 1: Schema diagram for airport simulation

In the real world, it is quite normal that an airplane has to land as soon as possible on several reasons. For example, medical first aid, airplane mechanical malfunctions, exhaustive of oil and so on. Therefore, an emergency queue is set up for each airport. If emergency event happens when a plane arrives, it can have the highest priority to land. Figure 2 illustrates our logical schema.

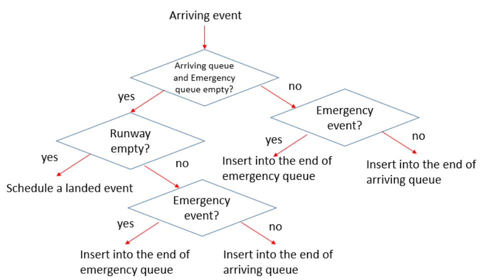

Fig. 2: Logical schema for emergency event

To show the timestamps and our results more vividly, GUI is implemented using C++. User can also set the number of planes by themselves. A snapshot of our GUI demonstration is in Fig.3.

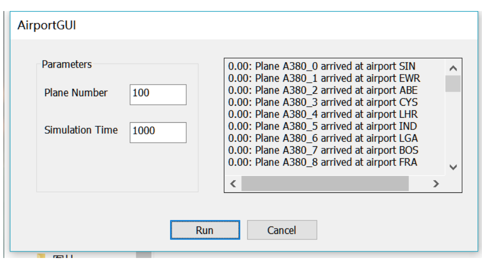

Fig. 3: Graphical user interface for the program

B. Assumptions

Before enhancing our model, following assumptions need to be clarified to simplify the problem.

- Airports are mutually connected so airplanes can fly between any two of them.
- Each airport has an arriving queue for planes waiting to land, a takeoff queue for planes waiting to take off, and an emergency queue. These queues are binary heaps arranging events according to their timestamp order.
- The probability for an arriving event to be an emergent event is 0.1 percent.
- Time required on the ground is proportional to the airport's number of runways.
- Runway time to land and takeoff time remain the same for each airport.
- Initially, the arriving airport for each plane is randomly selected.
- When the plane departs, its number of passenger is reset randomly within a certain range, which differs according to airplane type.
- When the plane departs, its destination airport is randomly selected, which is different from current airport.
- Only one plane is allowed on the runway each time. In other words, when a plane is landing, no other planes can land or take off.

C. Parameters

Necessary parameters for airports and airplanes are defined and initialized based on some research.

- $Distances$: a 100×100 matrix containing distances (in mile) from each airport to others.
- $Airplane$: Table 1 lists four types of airplanes. To make it more authentic, the number of passengers for each departing event is generated randomly within the range between 200 and the passenger capacity of each airplane.

TABLE I: Airplane parameters

	Passenger capacity	Speed (mile per min)
A380	500	9.45
BO747	400	9.50
A330	300	9.00
BO787	250	9.35

- $Airport$: Table 2 shows parameters for four types of airports.

TABLE II: Airport parameters

	Number of runways	Required time on ground (min)
Type 1	1	60
Type 2	2	120
Type 3	3	180
Type 4	4	240

- $Emergencyevent$: the probability that an arriving plane has an emergency event is set as 0.1 percent.

III. Simulator Experiment

A. Introduction

As mentioned before, we want to explore the operation efficiency of different types of airports. For airports with four multiple-runways, it could be intuitionally thought to represent the higher efficiency compared to fewer runways. However, it could not be ignored that more runways always means more complex control systems, which leads to longer waiting time. Hence, we want to explore the balance between the number of runways and waiting time on the ground. The simulator experiment is summarized as below.

B. Method

In order to avoid the randomness, we initially set 100 airports, with ratio 2:2:3:3 for 4,3,2,1 runways respectively. Also, we set different simulation time and run for several times, then take the average. Besides, there is no limit for the destination of airplanes, which means ideally, for the final results, all the airports should have almost the same arriving and departing passengers regardless of the airports type.

C. Result and Discussion

For the simulation results of airports, we take the average value of all the airports belong to one type, and the record value is Average circling time, Total arriving passengers and Total departing passengers. The results for all the time set is presented in Table 3 through Table 8. Ten thousand planes are tested.

In order to better represent the results, several graphs are plotted to visualize the data as following. Figure 4 shows the relationship between number of runways and average circling time for an airport.

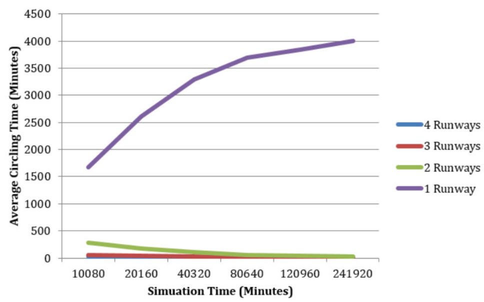

Fig. 4: Trend of average circling time

As the trend of arriving and departing passengers are almost the same, only arriving passengers are plotted here in Fig.5.

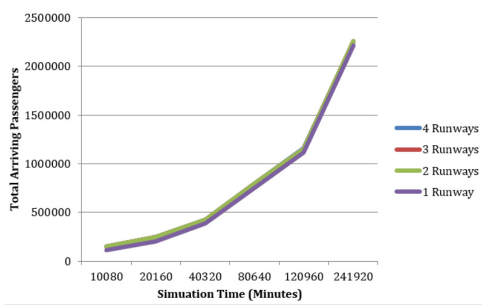

Fig. 5: Trend of total arriving passengers

Hence, from the tables and graphs presented above, it could be found that the total number of passengers arriving (departing) is almost the same, which coincides with the theory prediction results. On the other aspect, it provides the evidence that there is limited effect from the waiting time on the ground for the volume of passengers. However, there exists a huge gap between average circling time. For single runway, its average circling time is much larger than the other three types, which shows that the operation efficiency of this type is low, and too much time waste on circling also means a huge economic loss. For more details, 2-runway system performs almost the same as the other two runway systems. Therefore, on considering the construction investments for expanding runways, may be 2-runway system would be the best choice after considering all the factors.

Before drawing the final conclusion, there is another thing we have to prove, say, the results got above is not the results for fewer airplanes. We also have to test our simulator for fewer planes while making the simulation time as 120960 min. The results are presented in Table 9 through Table 12. Their columns represents the number of runways, average circling time, arriving number of passengers, and departing number of passengers.

In order to better represent the results, several graphs are plotted to visualize the data as following. Figure 6 shows the relationship between number of airplanes and the average circling time in an airport.

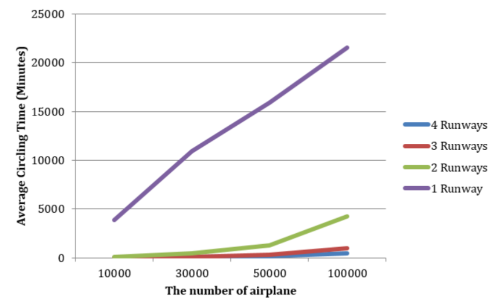

Fig. 6: Trend of average circling time

As the trend of arriving and departing passengers are almost the same, only arriving passengers are plotted here in Fig.7.

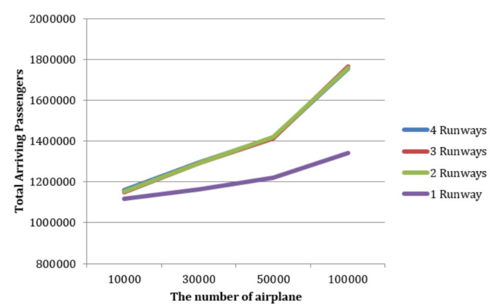

Fig. 7: Trend of total arriving passengers

Hence, it could be found that with the number of airplanes, the same conclusion could still be got, and the 1 runway performs even worse, the lag between the other three systems is reduced more. Hence, for now, we can have confidence to draw the conclusion that 2-runway system is the optimal one for the new airport construction.

IV. Future Improvement

Although this model includes detailed process of airplane from arriving to departing, many aspects are not taken into consideration since it is a simplified model. For future improvement, other factors, such as plane's arriving rate and weather conditions, need to be included. With a refined discrete event simulation, airport traffic control can be more efficient. Besides, distributed programming can be applied to each airport as a logical process to make it more efficient.

TABLE III: Results for simulation time = 10080 min

Airport type (Runway-number)	Average circling time (min)	Total arriving passengers	Total departing passengers
4	34.01	149561.80	147233.20
3	59.46	149387.30	147196.10
2	286.68	149393.57	147864.53
1	1677.98	110586.63	73682.23

TABLE IV: Results for simulation time = 20160 min

Airport type (Runway-number)	Average circling time (min)	Total arriving passengers	Total departing passengers
4	21.61	243123.45	241035.75
3	37.81	246813.80	244214.90
2	179.39	242893.40	241176.03
1	2613.13	202269.23	164886.07

TABLE V: Results for simulation time = 40320 min

Airport type (Runway-number)	Average circling time (min)	Total arriving passengers	Total departing passengers
4	12.08	420950.95	417996.60
3	20.85	424925.15	422961.75
2	105.67	420629.70	419908.17
1	3287.13	386650.83	348334.73

TABLE VI: Results for simulation time = 80640 min

Airport type (Runway-number)	Average circling time (min)	Total arriving passengers	Total departing passengers
4	6.46	795174.60	791810.50
3	12.45	794868.10	793730.90
2	55.45	792507.73	790997.73
1	3696.14	753119.07	713580.93

TABLE VII: Results for simulation time = 120960 min

Airport type (Runway-number)	Average circling time (min)	Total arriving passengers	Total departing passengers
4	4.57	1160516.55	1158854.85
3	8.21	1151291.80	1148620.15
2	42.65	1151679.97	1150487.00
1	3841.05	1118096.30	1080415.13

TABLE VIII: Results for simulation time = 241920 min

Airport type (Runway-number)	Average circling time (min)	Total arriving passengers	Total departing passengers
4	2.21	2255797.95	2253237.35
3	4.23	2257418.60	2257207.15
2	22.31	2263399.70	2261569.73
1	3998.93	2218173.73	2179042.60

TABLE IX: Results for 10000 airplanes

Runway	Avg circling time(min)	Arriving	Departing
4	4.5664735	1160516.55	1158854.85
3	8.208017	1151291.8	1148620.15
2	42.65074667	1151679.967	1150487
1	3841.045	1118096.3	1080415.133

TABLE X: Results for 30000 airplanes

Runway	Avg circling time(min)	Arriving	Departing
4	44.176425	1297592.65	1295082.5
3	99.582925	1293921.7	1291965.9
2	455.6328667	1293818.167	1292718.133
1	10911.29967	1164592.1	1038784.9

V. Conclusion

This project uses discrete event simulation to model the process of airplane along with airport traffic control. Several aspects, including the number of planes, required time on ground, and the number of runways are analyzed to figure out their relationship with arriving (or departing) number of passengers in an airport and the circling time. Increasing number of airplanes, decreasing required time on ground,

TABLE XI: Results for 50000 airplanes

Runway	Avg circling time(min)	Arriving	Departing
4	121.579105	1417808.3	1417242.4
3	277.32225	1414852.5	1412886.55
2	1253.703133	1420652.167	1419488.4
1	15911.06667	1221299.933	984132.5333

TABLE XII: Results for 100000 airplanes

Runway	Avg circling time(min)	Arriving	Departing
4	428.14865	1756241.7	1755169.9
3	1003.9629	1766831.8	1764547.5
2	4267.448667	1759196.2	1758398.2
1	21546.41333	1342548.433	871951.3333

and increasing number of runways would lead to increasing number of arriving and departing passengers. On the other hand, decreasing number of airplanes, increasing required time on ground, and increasing number of runways would decrease the average circling time. Since the results of two-runway airports are similar to those with three or four runways, it is concluded that airports with two runways are most cost efficient. With further refinement, such simulation can be applied to handle airport traffic control under more complex circumstances.

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