Evaluating Runway Efficiency at Boston Logan International Airport Using Simulation

Group 204

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Abstract

This project was undertaken with the goal of determining how efficient the runways at Boston's Logan International Airport were running. The main objectives were to see how long planes departing and leaving the airport were waiting just to use a runway, how these wait times would be affected if two of the airport's busiest runways were shut down, and how they would be affected if a new runway was built. These scenarios were evaluated by simulating a month of air traffic flowing into and out of Logan Airport, under different circumstances.

The simulation model built for this project was created using Python, specifically the Simpy library. The model was very efficient, as it provided easily interpretable results, and only took around 12 seconds to run a full simulation for each scenario. After simulating 5 different scenarios involving different runway configurations, it was found that the runways at Logan Airport are run very efficiently and can adapt well to runway closures. Mean wait times for runways never rose above 1 minute, even with two runways closed. It does not seem necessary for Logan to build a new runway, as adding an extra runway would cost millions of dollars, and it would only decrease wait times by a fraction of a minute.

Introduction

At many of the world's busiest airports, it is not uncommon to see large lines of planes forming at runways. With many of these airports fielding thousands of flights a day, the slightest delay in one flight can create a cascade of delays. Delays, especially on the tarmac, can be incredibly frustrating for passengers, as this adds extra time on what most often is hours of travel.

An effective way to evaluate and solve this problem is through the use of simulation. A good simulation model allows for the imagination and evaluation of real-world systems while applying different factors and variables to them. Simulation models can provide great insights on airports, as they are such large systems composed of many processes that are dependent on each other. Tweaking these systems could unveil the root causes of problems such as delays, and provide ideas on how they could be fixed.

This project will create a simulation model of Boston's Logan International Airport. Specifically, the model will focus on the efficiency of the runways at Logan, to determine how long planes are waiting to use a runway, any root causes of delays, and how any delays could potentially be fixed. Five scenarios of the airport will be simulated; a control scenario simulating the airport as is, a scenario removing the busiest runway, a scenario removing the top two busiest runways, a scenario adding a new runway, and a scenario adding a new runway while shutting down the two busiest runways. At the end of the first simulation, the efficiency of Logan's runways at the moment will be able to be determined by how long the simulated planes are waiting to use the runways. Once the final four simulations have been completed, plane wait times, as well as the number of planes departing and leaving the airport, will yield insights as to how prepared Logan is for runway issues/closure, and if it would be a smart investment for the airport to build a new runway.

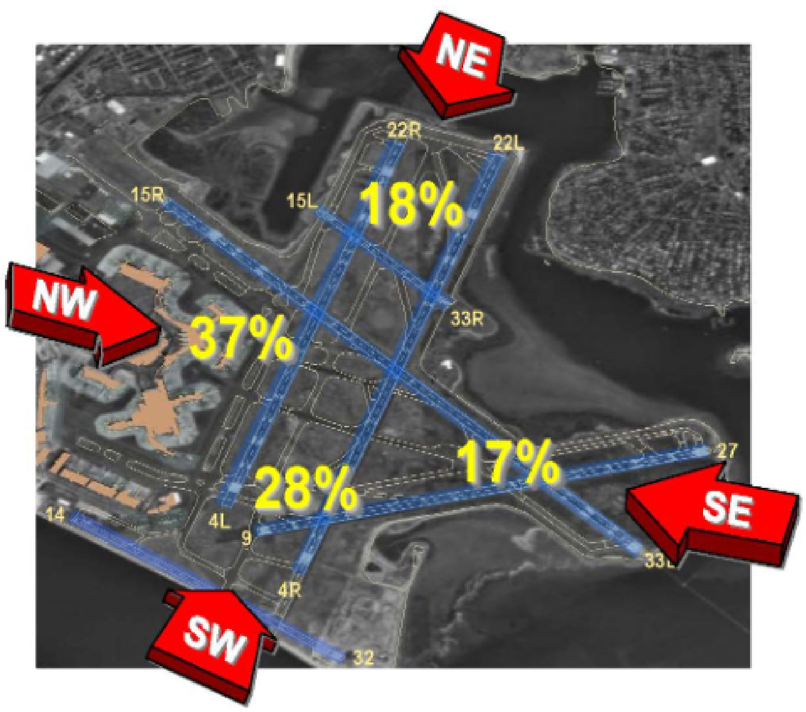
Data

The main dataset used for this project was the *Airlines, Airport, and Flight Routes* (1) dataset from Kaggle. This set of csv files contains data on roughly 7600 airports and 67000 flight routes. The flights relevant to this project are only the ones into and out of Logan Airport, so the data was filtered down to only include these flights, yielding 424 unique flight routes out of Logan. From this data, we were able to calculate the probability of any random flight flowing through the airport being of a certain airline, mode, or flying a certain route.

Departure and arrival data was then collected from *FlightStats.com* (2), by counting all flights flowing through the airport over the course of three days. The probability of a random flight flowing through the airport being a departing flight was then calculated by dividing the total departing flights by the total number of flights over this span. This number was subtracted from 1 to determine the probability of the flight being an arrival. Probabilities of departures/arrivals being of a certain airline, model, and flying to or from a certain destination were also calculated with this data.

With departure and arrival probabilities calculated, process times for departures and landings were now needed. These were acquired from the real time flight tracking app *FlightRadar24* (4). 100 randomly selected flights (50 departures and 50 arrivals) were tracked as they were using the runways at Logan. The times each one took on the runway were recorded, and then the average take off time, and the average landing time were calculated, which were then used in the simulation model for this project.

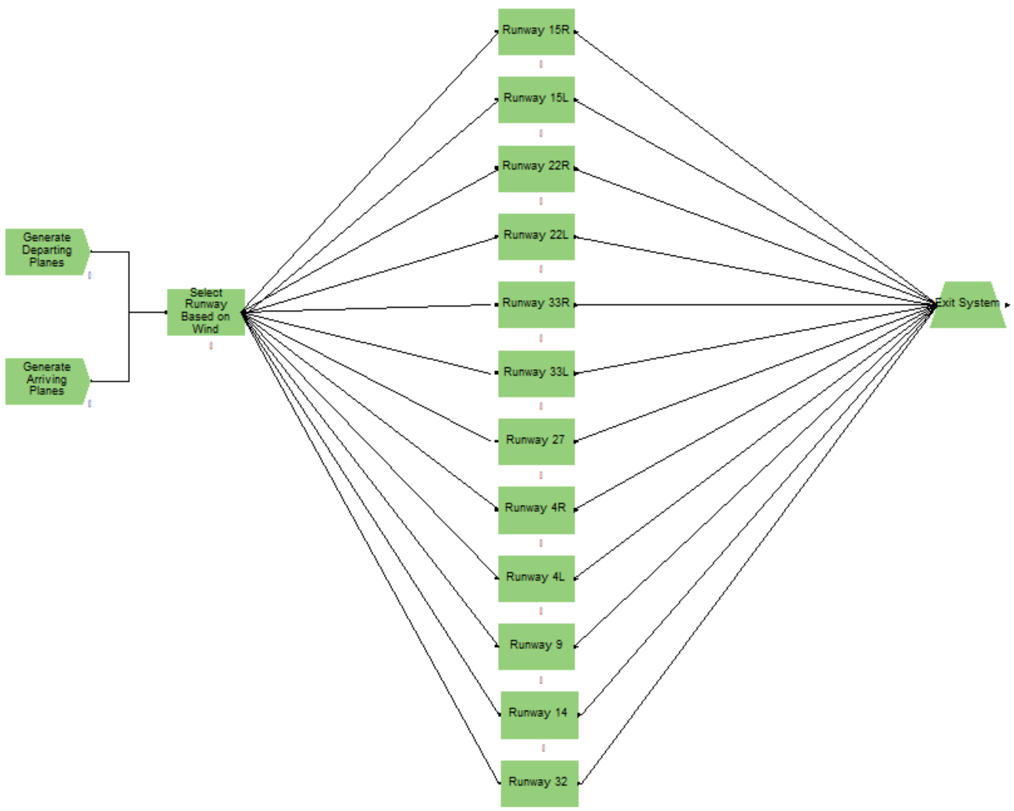
The final piece of data collected was from *Massport* (3), from which runway configurations and wind direction probabilities were extracted. The wind direction probabilities are one of the most important pieces of data to this project, as the direction of the wind determined which runways were utilized, and how they were utilized (e.g. for departures, arrivals, or both). View a layout of all runways from *Massport* below, with the probabilities of the wind blowing in each direction.



Simulation Model

The simulation model developed in this project has one base format, which can be modified in many ways. The model will only be focused around the runway portion of the airport, with planes arriving to the runway as a departing aircraft ready to take off, or an arriving aircraft preparing to land. All other processes at the airport are assumed to be running efficiently. Other assumptions include the weather being clear and ideal (no precipitation/storms) throughout the simulation, wind direction will be randomly selected every 24 hours, all non-jet aircraft will only use runways that are designated for non-jet aircrafts (unless there are none running at that time), and the air traffic controllers will successfully guide all planes to safe takeoffs and landings (no collisions or go-arounds).

Taking these assumptions into consideration, developing a model to simulate Logan's runways was rather straightforward. Observe the flowchart below for the basic model structure.



Step one in this process is to have planes arrive at the runways. Note that the term arrive here represents a plane either lining up on a runway to take off, or descending towards a runway to land. In order to have planes arrive at a runway, we must first randomly generate a plane. When a plane is randomly generated, it must be determined if the plane is taking off or landing on the runway, what airline operates the plane, where the plane is flying to (or coming from), and where the model of the aircraft. All of these attributes were generated at random, using the following conditions.

First, using the departure/arrival probabilities found in the previous section, a plane was randomly selected to be departing or arriving. Note an airport is a nonhomogeneous poisson process, as they do not have constant departure and arrival rates over the course of a twenty four hour day. Therefore, the probability of a plane arriving to the runway being a departure or arrival changes over the course of the day. To solve this problem, arrival rates (to the runway) were divided into four time zones: the morning (6:00 AM - 11:59 PM), the afternoon (12:00 PM - 5:59 PM), the evening (6:00 PM - 11:59 PM), and the night (12:00 AM - 5:59 AM). See the table below for full departure/arrival probabilities.In short, a plane arriving at the runway was more likely to be departing in the morning and the night, and more likely to be arriving in the afternoon and the evening.

Time of Day	Probability Plane is a Departure	Probability Plane is an Arrival
Morning (6:00 AM - 11:59 AM)	0.5408	0.4592
Afternoon (12:00 PM - 5:59 PM)	0.4683	0.5312
Evening (6:00 PM - 11:59 PM)	0.4904	0.5096
Night (12:00 AM - 5:559 PM)	0.5042	0.4958

After determining if a generated plane was departing or arriving, the plane's airline was randomly selected using the airline departure and arrival probabilities based on the condition of the plane being a departure or arrival. The plane's destination (or source airport) was then randomly selected using the route probabilities based on the plane's departing and airline conditions, and finally, the plane's model was selected using the model probabilities based on the plane's departure, airline, and route conditions.

The final part of step one is to set up the random arrivals of planes to the runway. As mentioned earlier, the airport is a nonhomogeneous poisson process, so the arrival times of planes to the runway will be different throughout the day. Using the six hour windows defined earlier, planes will arrive at the runways at a rate of 6.4 planes per minute in the morning, 9.4 planes per minute in the afternoon, 6.9 planes per minute in the evening, and 1.3 planes per minute at night.

Step two of the process is for the plane to pick one of the twelve runways to land on. This is determined based on the wind direction (as that determines which runways are in use), and then by whether the plane is departing or landing. Every plane arriving to the runways will head to the runway with the shortest line. If all runway lines are the same length, the plane will head to the closest runway.

Step three is where the planes actually utilize the runway. Once a plane begins utilized a runway it will take a random amount of time to take off or land. Take off times are exponentially distributed with a mean of 1.5 minutes, and landing times are also exponentially distributed with a mean of 2.1 minutes. Once planes are finished using the runway, they exit the system by either taxiing to the gate for arriving aircraft, or flying to their destination for departing aircraft.

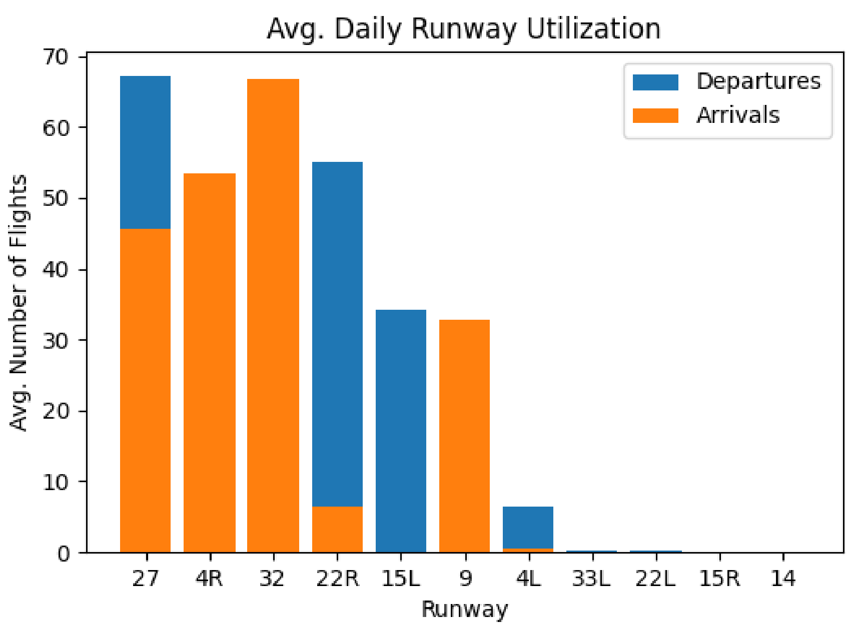
This model simulates an entire day, and runs for 31 trials as that would represent an entire month. Data will be collected at the end of the thirty first trial, and then aggregated to find daily averages. Five different scenarios will be tested: a control scenario with the airport runways as is, a scenario which shuts down the busiest runway, a scenario which shuts down the two of the busiest runways, a scenario which adds a brand new runway, and a scenario which adds a new runway but shuts down the two of the busiest ones.

Since much of the data used in this project is in deeply nested json format, Python was determined to be the best way to interact with it. As a result, this simulation model was built out using the Simpy library. The simulation ran smoothly and efficiently, as for each scenario, it only took about 12 seconds to simulate the entire 31 days.

Results

Control Scenario

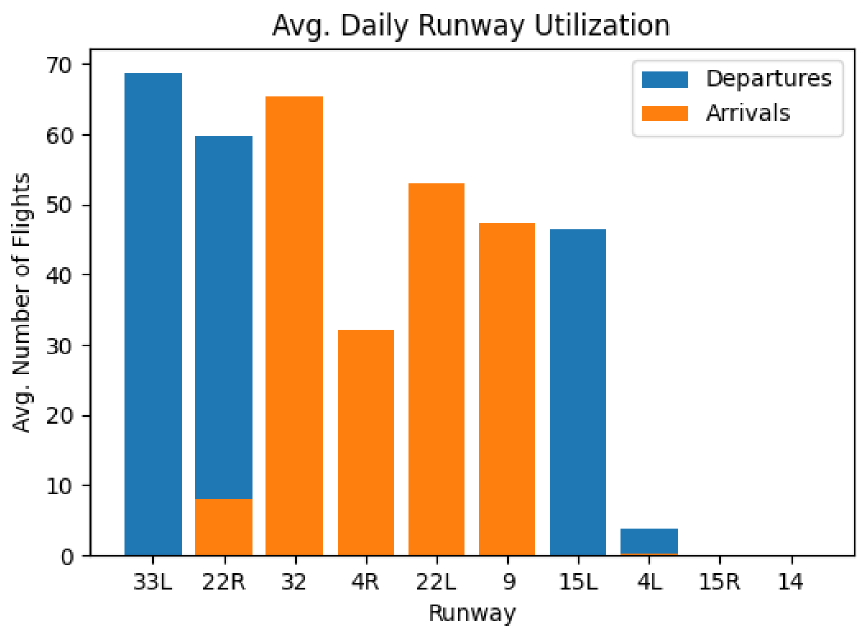
Beginning with the control scenario, 12,896 flights passed through the system (6,523 departures 6,373 arrivals) and it was found that throughout the month, at no point were the average wait times to use a runway over a minute. The average runway wait time for departing flights in this scenario was 0.71 minutes, and the maximum wait time was 5.91 minutes, while the average runway wait time for arriving flights was 0.50 minutes, and the maximum departure wait time was 4.52 minutes. These longer wait times were rare by occurrence though, as the hourly mean runway wait time for departures was under 48 seconds, and under 36 seconds for arrivals, for all hours of the day. It seems that the longer wait times occur at random, infrequent bottlenecks. Observe the chart below which analyzes runway usage.



From the chart, it is obvious that runway usage is not even, as runways 27, 32, 4R and 22R are all fielding between 50-70 flights a day, while no other runway fields more than 35. This is not incredibly surprising however, as these runways are used for the most common wind directions (Northwest 37% of the time, Southwest 28% of the time). Runway 27 fields the most flights with just under 70, and it fields both departures and arrivals. This runway will be deemed as the busiest one, and shut down for the next part of the simulation.

Losing One Runway

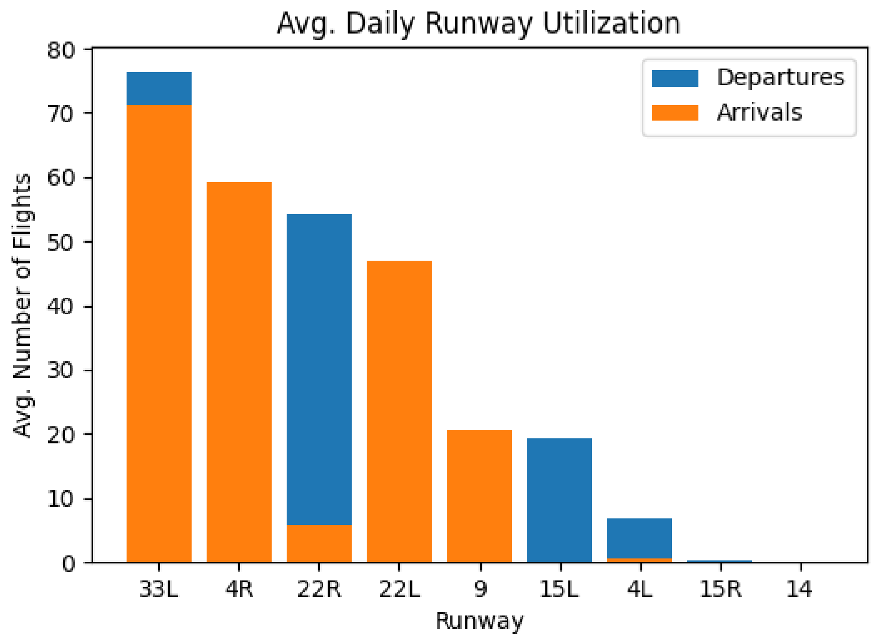
Simulating 31 more days without runway 27 showed that Logan was able to successfully adapt to losing its busiest runway. In this scenario, 12,896 flights still made it through the system (6,515 departures and 6,381 arrivals) while average wait times still remained under a minute (0.71 minutes for departures and 0.50 minutes for arrivals) and maximum wait times were still rare by occurrence, were slightly longer. (7.12 minutes for departures and 5.08 minutes for arrivals). Once again, average wait times were still under a minute for every hour in the day under 48 seconds for departures and under 36 seconds for arrivals). Observe the chart below to analyze runway usage.



With its busiest runway shut down, the airport seems to have done a great job allocating the rest of its runways to pick up the extra work. Most runways now ended up only taking departing flights or arrival flights, with the exception of 22R and 4L, which took both. The airport did seem to allocate more runways to arriving aircraft than departures, as there were four runways strictly for arrivals, while only two were strictly for departures, which might account for the shorter wait times for landing planes. Runway 32 fielded the most arrivals out of any runway at about 65 per day. This runway will be shut down for the next part of the simulation, to see how arriving planes will be allocated to the remaining runways.

Losing Two Runways

After losing runway 32, the airport was still able to maintain average runway wait times of under a minute for 12,896 planes (6,565 departing flights, 6,331 arriving flights). Average runway wait times for departures were 0.73 minutes, and 0.53 minutes for arrivals, while hourly average wait times were just over 48 seconds for departures, and just under 36 seconds for arrivals.These wait times are slightly higher than the previous two scenarios, and correlates to the maximum wait times of 8.53 minutes for departures and 4.91 minutes for arrivals. While 8.5 minutes is a rather long time to wait for a runway, this probability of waiting this long is very low, and this time is a very slight increase in time while losing two major runways. Observe the updated chart below to analyze runway usage:

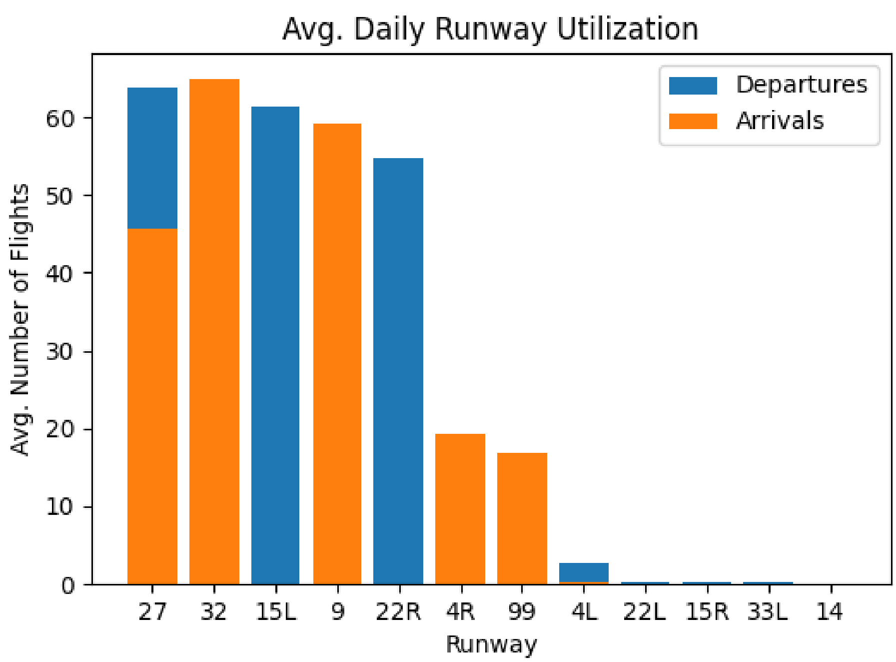


In this scenario, the runways are now sharing much more of the load to handle departures and arrivals. There are now only three runways that field only arrivals, and only one that only fields departures. The rest field both departures and arrivals. Runway 33L was the busiest runway, fielding just under 80 flights per day. It's interesting to note that this runway picked up most of the arrivals left by runway 32, as 33L is now fielding roughly 70 arrivals per day now, with about 10 departures mixed in, as opposed to no arrivals in the last scenario.

Building a New Runway

Through these three simulation scenarios, Logan Airport has proven itself to be the owner of a very efficient runway system. But wait times can always be shorter. Looking at the map, there is space for a new runway to the left and parallel to runway 27. Given the fact that runway 27 is Logan's busiest runway, and the fact that this runway is in the direction of the northwest wind (the most common wind direction), it makes sense for Logan to build this airport, as it could take stress off of the busiest runways. See the image below for how this runway would be configured. It will be called runway 99, and will have all of the same departure/arrivals configurations as runway 27.

After simulating a month with this new runway, it was found that the runway did not add much extra value to the airport. For 12,896 flights (6,503 departures, 6,393 arrivals), mean runway wait times were only down a fraction of a minute (0.72 minutes for departures, and 0.5 minutes for arrivals) with no change in the hourly mean runway wait times. The maximum runway wait times were only slightly decreased, with 5.79 minutes for departures, and 3.97 minutes for arrivals. Observe the chart below to analyze runway usage.

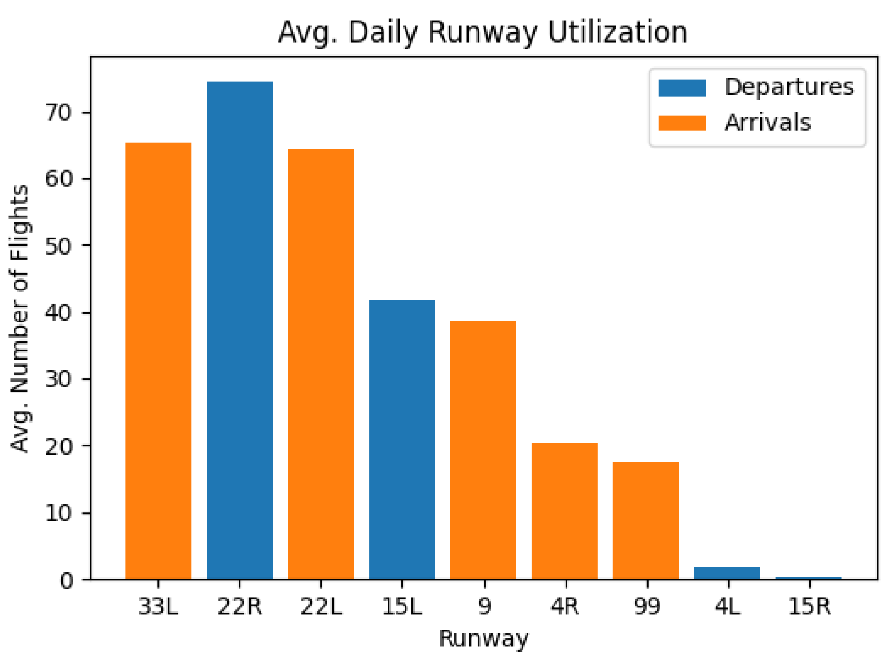


The new runway does not seem to be having much impact on the airport. 27 and 32 are still the busiest runways, even though they now have an extra runway to support them, with both departures and arrivals, in runway 99. Runway 99 was very underutilized, as it only fielded about 20 flights a day (all arrivals) while being in the most utilized runway setup. It was one of the least used runways at the entire airport.

Building a New Runway While Shutting Down Two

While building a new runway may not be very beneficial to the airport at full capacity, it may help in the case of a runway shutdown. Revisiting the earlier scenario in which runways 27 and 32 were shut down, simulating another month without these two runways, but with runway 99 active could potentially yield higher usage of runway 99 and lower wait times.

After running the simulation, this did not end up being the case, as runway 99 airport performance was very similar to the scenario tested earlier when runway 27 was the only runway shut down. For 12,896 flights (6,501 departures and 6,395 arrivals), average daily runway wait times were still under a minute(0.72 minutes for departures and 0.51 minutes for arrivals), there was no change in hourly runway wait times, and maximum wait times were slightly higher (7.78 minutes for departures and 5.4 minutes for arrivals). Observe the chart below to analyze runway usage.



Once again, runway 99 was very underutilized, fielding only 20 landing flights a day once again. The busiest runways are still fielding 60-70 flights a day, but it’s interesting to note that all runways have become allocated to either departing or arriving flights only.

Conclusion

After simulating all five scenarios, it has become very clear that the runways at Logan airport are in fact very efficient. With its current setup, planes are on average waiting under a minute to use a runway for both taking off and landing. This fact holds true, even if Logan loses up to two of its busiest runways. It is worth noting that there were a few rare occasions in these scenarios where planes were waiting up to 5-8 minutes for a runway. However, these rare but random occasional surges in wait times happened in every scenario tested. With the maximum wait times being so common and so rare, it seems as if a short and random bottleneck could be to blame. With the runways running so efficiently otherwise, an outside factor, such as a scheduling issue creating, could be to blame.

It was also determined that Logan has no need to build a new runway. As stated earlier, the runways at Logan are running very efficiently even when they are shorthanded. Runways are very expensive to build, and if Logan were to build a new one, it would be underutilized, and would not make the airport operate any better. This money could be much better spent in other areas of the airport.

In short, Logan Airport is very efficient at getting planes on and off of the ground. It has no need to build more runways. However, if the rest of the facilities can handle it, Logan could very easily handle more planes, which would lead to increased revenue for the airport from departure and landing fees on each runway. This is an option that the airport should strongly consider.

Works Cited

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