MAT 4376 - Project 3

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Link to Game

https://vivante.itch.io/flying-through-borealia-queueing-systems

Github

https://github.com/EvaGostiuk/MAT4376-project-3-team-3

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Data Dictionary

Flight-Related

Integers:
S2 - The date and time the passenger scanned their boarding pass at S2 (date/time)
Flight_ID - The identification number of the flight (not unique)
Tot_pass - The total number of passengers

Characters:
Sch_Departure - The date and time that the flight was scheduled for departure
Act_Departure - The date and time at which the flight actually departed
Departure_Date - The date that the flight departed
Departure_Time - The time that the flight departed
Time_of_Day - The time of day that the flight departed
Day_of_Week - The date of the week that the flight departed on
Month - The month that the flight departed in
Year - The year that the flight departed in

Passenger-Related

Integers/Real Numbers:
Wait_Time - The time it takes a passenger to go from S1 to S2
C_Start - The number of security agents at S1 when the passenger arrives at S1 (collected in 15 second intervals)
C0 - The number of security agents at S2 when the passenger arrives at S2 (collected in 15 seconds intervals)
C_avg - The average number of security agents while the passenger is in the PBS queue (collected in 15 second intervals)
Order - A unique number corresponding to the order at which the passenger was scanned at S2
Min - Minimum wait time
Mean - Mean of the wait time
Median - Median wait time
Max - Max wait time

Geography-Related

Characters:
Airfield - Three letter abbreviation of the Auckland Airfield (TLA)
BFO_Dest_City - The destination city of the flight (if a Borealian airfield, i.e. SAF, CWL, QUE, AUC, only a TLA)
BFO_Destination_Country_Code - The destination country of the flight

Queuing-System-Related

L - mean number of clients in the queuing system
L_q - mean number of clients waiting in line
L_s - mean number of clients in service

W - mean time a client spends in the system
W_q - mean time a client spends in line
W_s - mean time a client spends in service

Throughput - rate at which customers are successfully served or processed by the servers

Airfield Reports

Summary: There were four airfields included in the datasets given to us: Auckland, Saint-Francois, Chebucto, and Queenston. The latter two had no information on wait time for any of the entries so they were excluded from the prediction of wait times using queueing theory. The first two airfields included information on the wait times, thus we conducted our queueing model analysis solely on these two airfields (individually). We have included "fun facts" and visualizations on all four airfields from the data that was provided to us, which includes information on destination countries and cities, frequency of departures by hour and day, and much more.

For the Queuing System:

The use of an M/M/C for creating a queuing system was chosen due to the assumption that there would be more than 1 server at both airports. Using an M/M/C helped consider multiple numbers of servers in each airfield. For this section, I chose to look at both 2 servers and 3 servers to analyze its effects of different server wait times. We also assume that $\rho < 1$ (where $\rho = \boldsymbol{\lambda} / (\mu)(c)$ for an M/M/C model) which indicates a steady state does exist, and the queue will eventually come to an end.

Auckland Report

Queueing System

For both scenarios of servers we get the following values:

$\boldsymbol{\lambda} = 0.26$

$\mu = 0.18$

The following is the output of the queuing system using Little's Queuing Formula (rounded to the nearest hundredth) :

AUC airfield

Values	c = 2 Servers	c = 3 Servers
L	2.82	1.60
L_q	1.41	0.18
L_s	1.41	1.41
W	10.81	6.11
W_q	5.40	0.71
W_s	5.41	5.41

For 2 Servers (M/M/2): $\rho = 0.72$.

Since the following relations hold:

$L = (0.26)(10.81) = 2.8106$

$L_q = (0.26)(5.40) = 1.404$

$L_s = (0.26)(5.41) = 1.4066$

Then a steady-state distribution exists when c = 2.

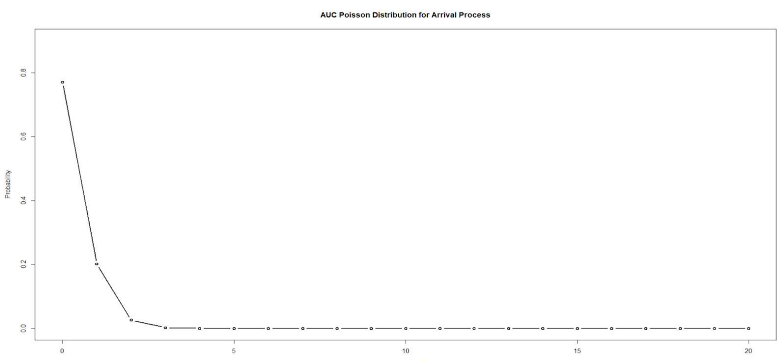
On average, 2.8 clients are waiting to be served at all times.

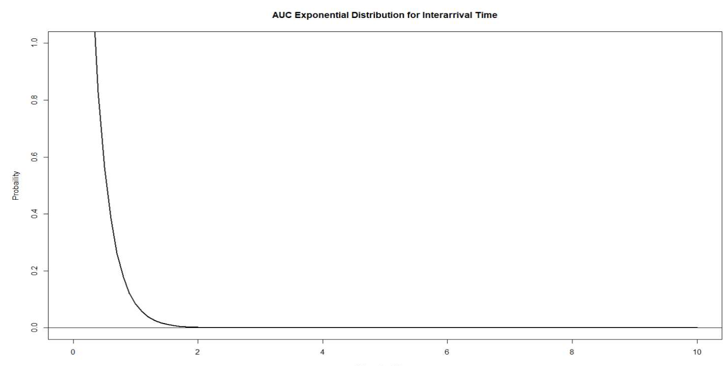
- P(n=0 clients in the system) = 0.17
- Traffic intensity = 1.41
- Server use = 0.71

- W_q when there is a queue = 9.22
- Throughput = 0.26

For 3 Servers (M/M/3) : ρ = 0.48.
Since the following relations hold:
L = (0.26)(6.11) = 1.59
L_q = (0.26)(0.71) = 0.18
L_s = (0.26)(5.41) = 1.4066
Then a steady-state distribution exists when c = 3.
On average, 1.61 clients are waiting to be served at all times.

- P(n=0 clients in the system) = 0.23
- Traffic intensity = 1.41
- Server use = 0.47
- W_q when there is a queue = 3.41
- Throughput = 0.26

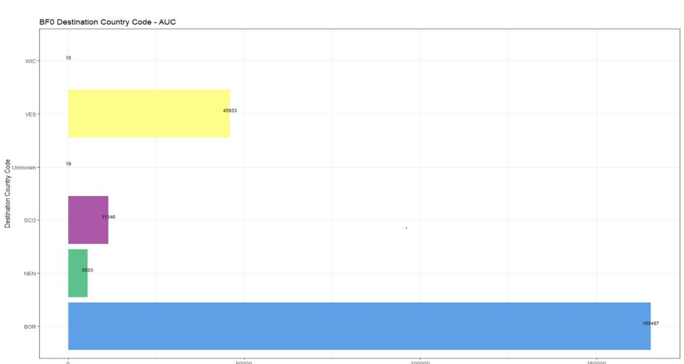




Looking at AUC using a Poisson distribution, it counts the number of discrete events from a fixed time period. The line begins at **λ**= 0.26, since it is the base assumption of AUC's arrival rate

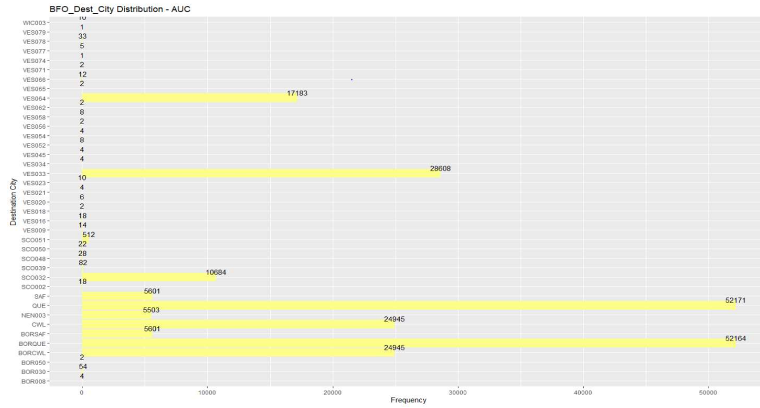
Looking at AUC using an Exponential distribution, it measures the time between arrivals, since **λ**= 0.26, the line converges at **λ.**

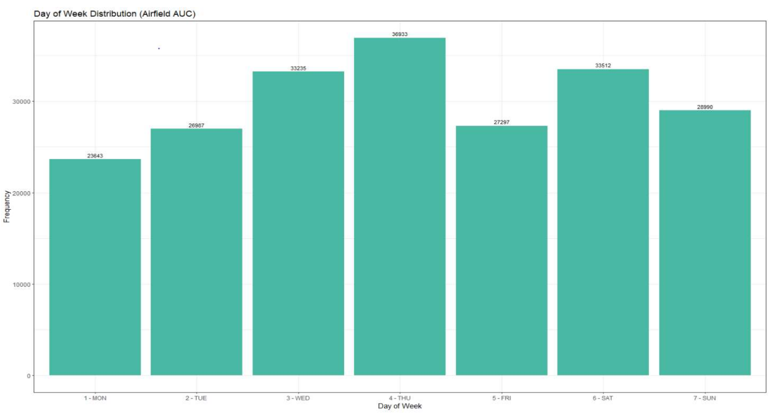
Visualizations



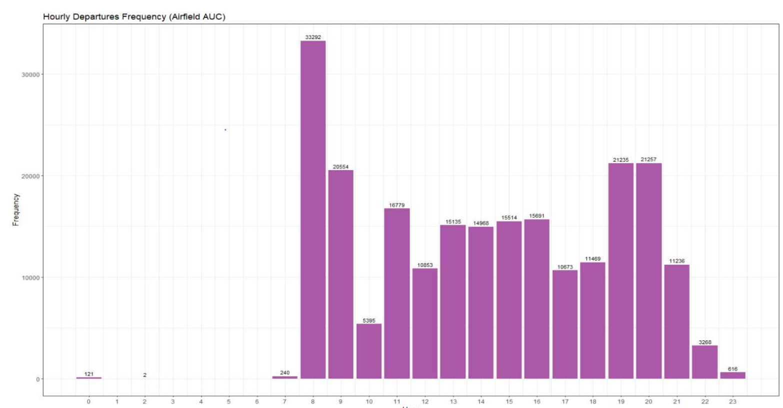
For flights originating in Auckland, the country in which the highest number of flights were destined to was Borealia. There were 165,487 domestic flights and only 66,692 international flights. The second most destined country for flights originating in Auckland was Vespuchia but with only about a quarter of the number of flights that were destined for Borealia.

The cities with the highest number of destined flights that originated in Auckland were those landing in Queenston, whether the city code was QUE or BORQUE. There were a significant number of international flights, mainly to Vespuchia or Scotland.

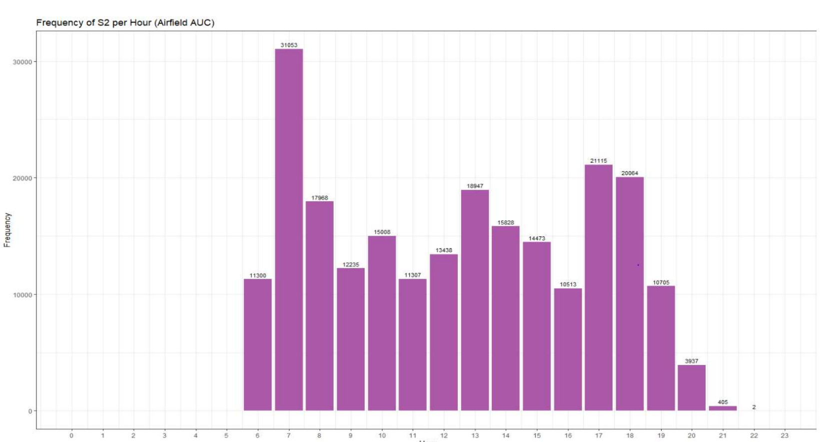




Looking at the daily distribution of departing flights from the Auckland airfield, the day of the week with the highest number of departures is Thursday with over 36,000 flights. The day of the week with the least amount of departures is Monday, with only 23,600 flights.

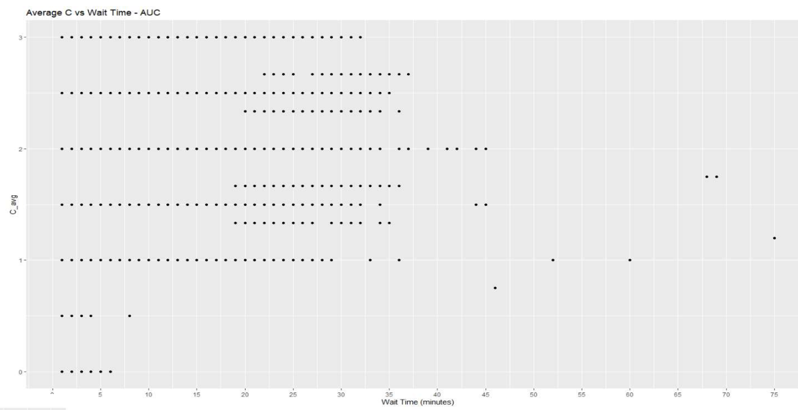


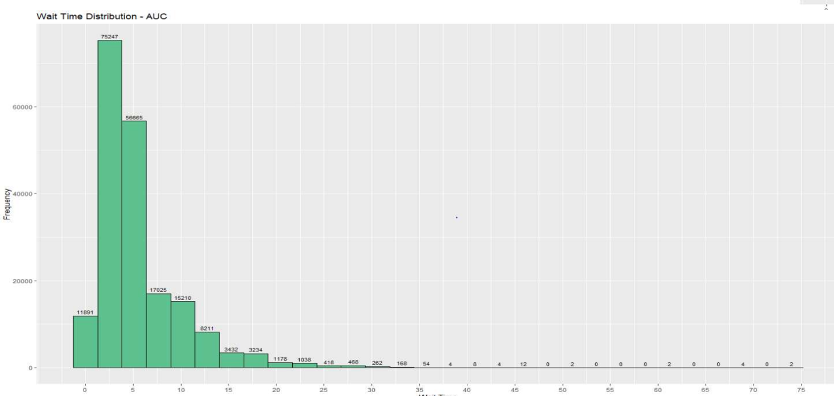
Looking further into the distribution of departures by the hour, the most common departure hour from the Auckland airfield was at 8 AM, and the least common departure hours were between 1 AM and 6 AM. Other common departure times were 7 PM or 8 PM.



Now looking at the frequency of scans at S2 by the hour, the most common time that passengers scanned was at 7 AM. This aligns with the departure times as most passengers would go through security within an hour or two prior to their departure time. There were no scans at S2 between 11 PM and 5 AM.

When looking at the average number of security agents against the wait time in minutes, there wasn't a big pattern that stuck out. Most of the wait times were below 40 minutes, no matter if there were 3 agents or 1 agent. There was the occasional passenger that had to wait a significant amount of time when there were only 1-2 agents, but this was not a common occurrence.





Before switching gears into queueing theory to predict wait times, we first wanted to look at the distribution of the frequencies of the wait times. In the visualization to the left, you'll see that there is a relatively unimodal distribution with a peak of around a 2.5-minute wait time and with the majority of wait times less than 30 minutes at the Auckland airfield.

Saint-Francois Report

Queueing System

For both scenarios of servers we get the following values:

λ = 0.21

μ = 0.13

The following is the output of the queuing system using Little's Queuing Formula (rounded to the nearest hundredth) :

SAF Airfield:

Values	2 Servers	3 Servers
L	5.23	2.02
L_q	3.58	0.36
L_s	1.65	1.65
W	25.15	9.69
W_q	17.20	1.74
W_s	7.95	7.95

For 2 Servers (M/M/2): ρ = 0.81 .

Since the following relations hold:

L = (0.21)(25.15) = 5.23

L_q = (0.21)(17.20) = 3.58

L_s = (0.21)(7.95) = 1.65

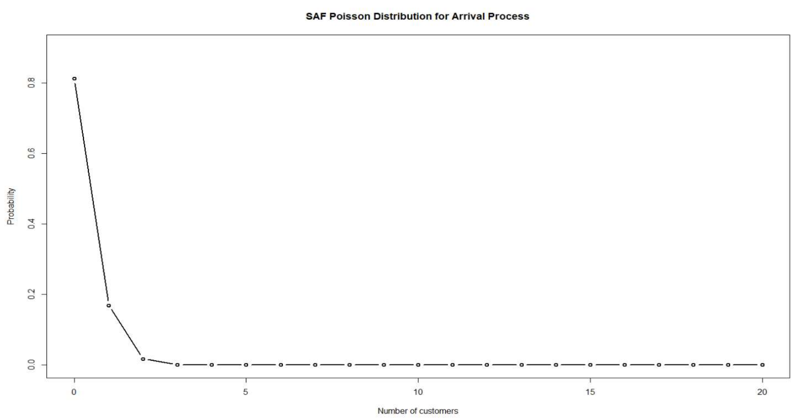
Then a steady-state distribution exists when c = 2.

On average, 5.23 clients are waiting to be served at all times.

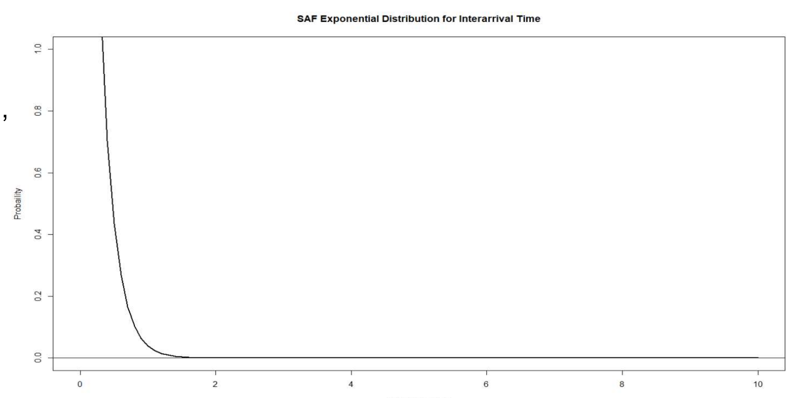
- P(n=0 clients in the system) = 0.09
- Traffic intensity = 1.65
- Server use = 0.83
- W_q when there is a queue = 22.98
- Throughput = 0.21

For 3 Servers (M/M/3) : ρ = 0.54.
Since the following relations hold:
L = (0.21)(9.69) = 2.02
L_q = (0.21)(1.74) = 0.36
L_s = (0.21)(7.95) = 1.65
Then a steady-state distribution exists when c = 3.
On average, 2.02 clients are waiting to be served at all times.

- P(n=0 clients in the system) = 0.18
- Traffic intensity = 1.65
- Server use = 0.55
- W_q when there is a queue = 5.90
- Throughput = 0.21



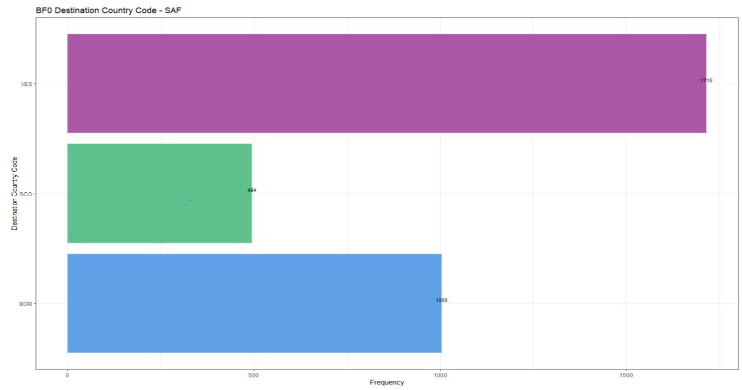
Looking at SAF using a Poisson distribution, it counts the number of discrete events from a fixed time period. The line begins at **λ**= 0.21, since it is the base assumption of SAF's arrival rate

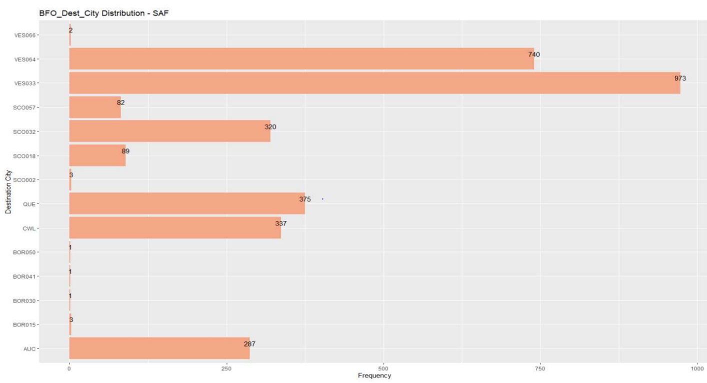


Looking at SAF using an Exponential distribution, it measures the time between arrivals, since **λ=** 0.21, the line converges at **λ.**

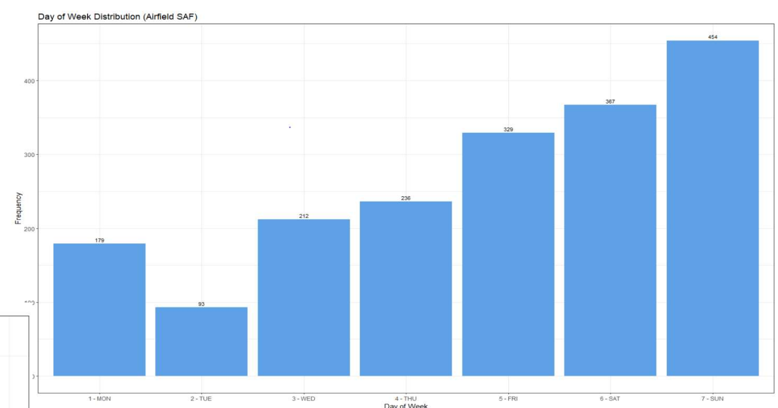
Visualizations

For flights originating in the SAF airfield, the country in which the highest number of flights were destined to was Vespuchia. This means that SAF had more international flights than domestic flights (over double the domestic flights if you include flights destined for Scotland (SCO)).

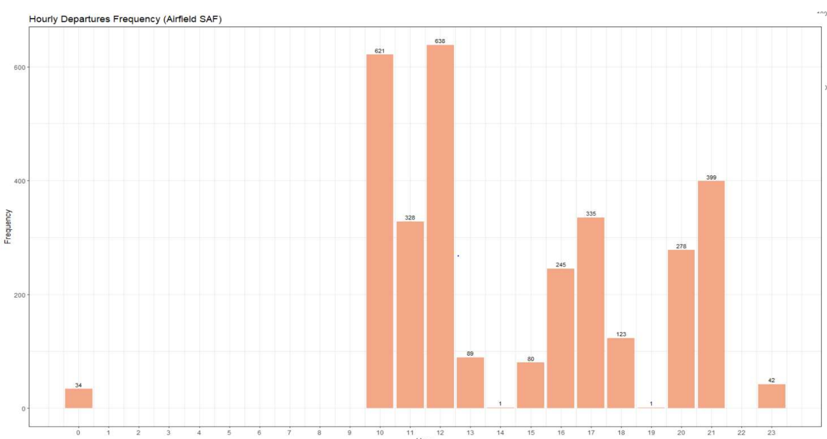




For flights departing from the SAF airfield, the two most frequent destination cities were located in Vespuchia. These two international destinations made up over 53% of the SAF departures. The next two cities with the highest number of destining flights were Queenston and Chebucto, which were both domestic flights.

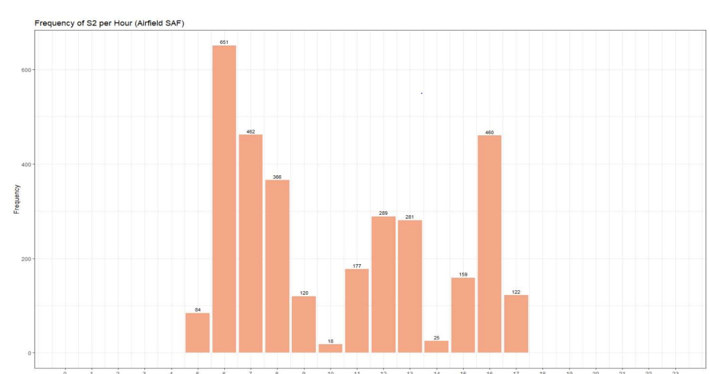


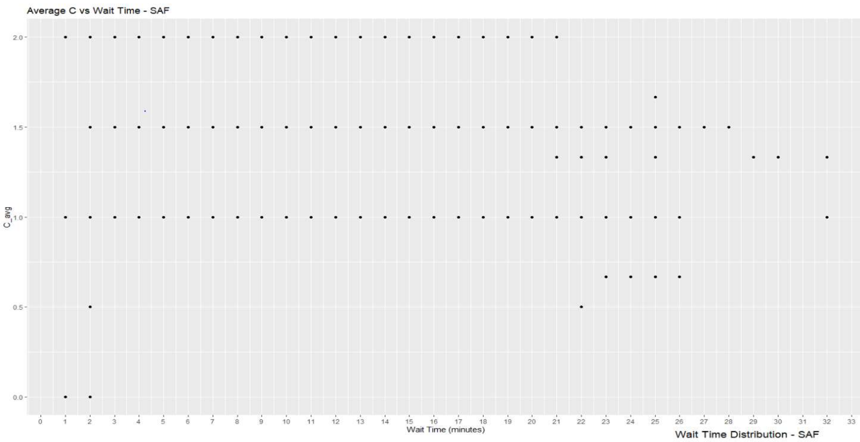
Looking at the distribution of departures from SAF by day of the week, Sunday was recorded to be the most frequent day to depart from this airfield, and Tuesday was the least frequent day of departure.



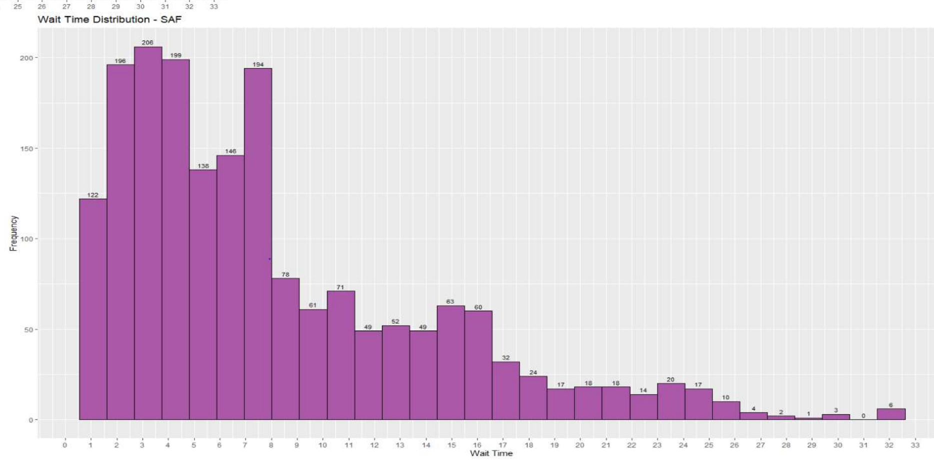
Now, looking further into the distribution of flight departures, we looked at the hour of the day that the SAF flights departed. The most frequent hours of departure were 10 AM and 12 PM, and the least frequent hours of departure were between 1 AM and 9 AM, and at 10 PM.

Looking more specifically at the frequency of S2 scans per hour, the most frequent hour that a passenger was scanned through S2 was at 6 AM, and the least frequent hours that a passenger was scanned at S2 was between 6 PM and 4 AM, where no passengers were scanned at S2 in SAF at this time (in our datasets).





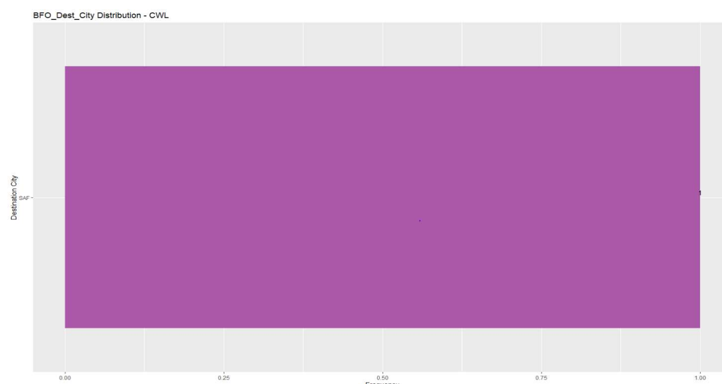
When looking at the average number of security agents against the number of minutes the passengers waited, the higher the number of security agents, the lower the wait time and vice versa. Logically speaking, if there are more agents to serve the passengers, then there will be fewer passengers waiting in line - which is reflected in the visualization to the left.



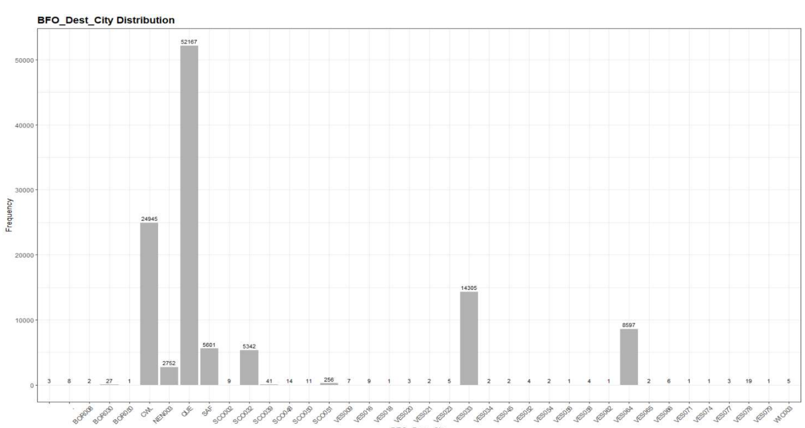
Before we began our journey into queueing theory, we first wanted to look into the distribution of wait times for the SAF airfield. From the image on the right, you'll see that the wait time is bimodally distributed with peaks at 3 and 7.5 minutes. Typically, there is a shorter wait time at this airfield with the majority of passengers having less than a 16-minute wait time.

Chebucto Report

Visualizations



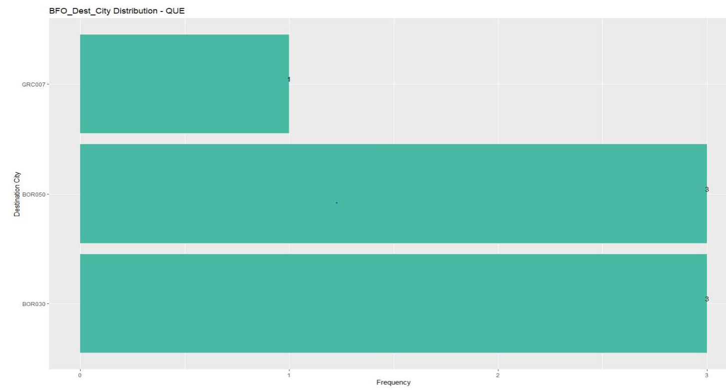
There was only one departing flight from the Chebucto airfield, which was destined for the Saint-Francois airfield.



When looking deeper into the cities, Queenston was by far the most popular travel destination as it is in the Borealia country. In addition, the second highest city was Chebucto, which validates that Borealia is the most popular country for travel destinations. The following two most destined cities were both located in Vespuchia, which is one of the neighbouring countries of Borealia.

Queenston Report

Visualization

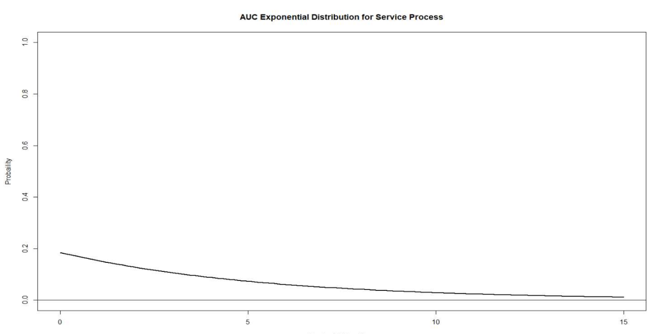


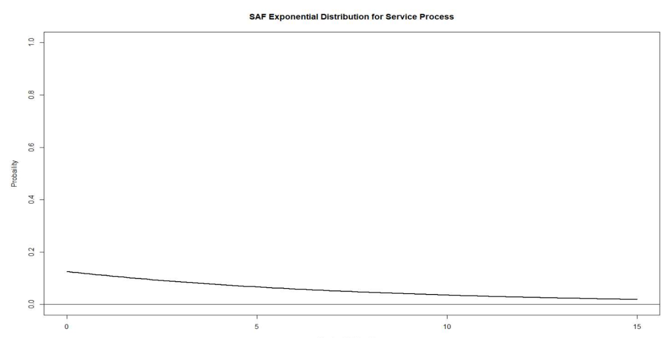
For flights originating in Queenston, there were 3 cities to which the airfield had flights. These cities were located in Greece and Borealia, with the two Borealian cities having 3 destined flights each, and the Greek city having only one flight.

<u>Final Report (Comparisons)</u>

Queueing System Comparison

Assuming an ideal scenario with three servers at both the AUC and SAF airfields, let's compare their queuing systems. We observe that AUC expects to serve an average of 1.61 travelers simultaneously, while SAF anticipates serving 2.02 travelers simultaneously.



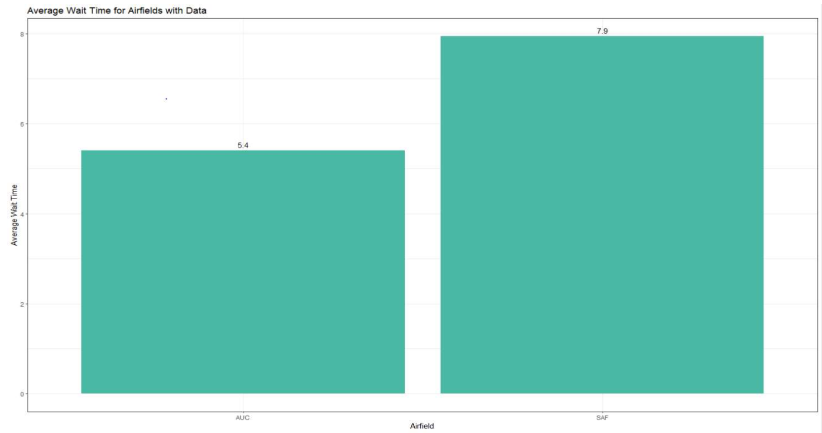


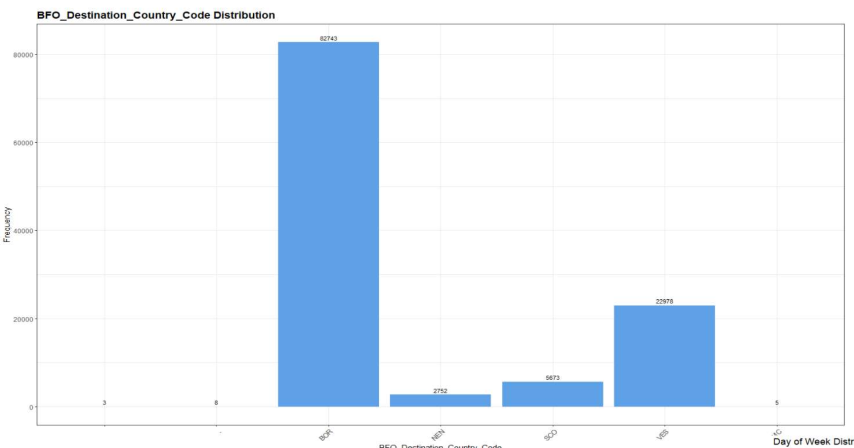
When comparing the distribution of service times between AUC and SAF, we notice that the overall service times for travelers are similar. However, AUC has a higher probability of serving a traveler without any waiting time compared to SAF. In addition, since $\boldsymbol{\lambda}_{AUC} > \boldsymbol{\lambda}_{SAF}$ then AUC is a busier airport with a higher rate of incoming travelers. Consequently, AUC is expected to have a faster service time compared to SAF. Since both airfields are operating below its full capacity ($\rho < 1$), then there is usually little or no queuing. Furthermore, $\rho_{SAF} > \rho_{AUC}$ which means SAF will have slightly longer wait times than AUC and may experience more congestion in the queue.

Moreover, both airfields operate below their full capacity, indicated by a traffic intensity ($\rho < 1$). This suggests that there is typically minimal or no queuing at either location. However, it is worth noting the difference in traffic intensity: $\rho_{SAF} > \rho_{AUC}$, implying that SAF may experience slightly longer wait times and potentially more congestion in the queue compared to AUC which is suggested from the visualizations and queuing models.

Visualizations

The airfield with the highest average wait time was Saint-Francois (SAF), with an average of 7.9 minutes. The only other airfield that contained data on wait time was Auckland (AUC), which has an average wait time of 5.4 minutes. This is interesting because the Auckland airfield had a significantly higher number of flights than Saint-Francois, but since there were so many more flights in Auckland, it is likely that there were shorter-length flights than those in the Saint-Francois airfield. There were no wait times recorded for CWL or QUE.





In general, the most popular travel destination by country is Borealia and the least popular country is Newfoundland.

For the Auckland airfield, Thursday and Saturday were the most common days where flights departed. Monday had the lowest frequency of flights.