# Phase 5: Output Analysis and Final Report

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## Executive Summary

The purpose of the case study is to build a model that simulates operations at Port-au-Prince Airport (PAP) for the chaotic month and a half that ensued the earthquake. The model should help determine methods of optimizing air relief by the Air Force and international aid community. Such a model will examine entities, resources, arrivals, attributes, and many other components to develop the conceptualized model allowing a model to be built. Through the simulation additional resources may be added to see how performance measures are affected and if the model is more efficient. Finally, a recommendation will be made for how to handle similar situations in the future. The purpose of this initial report is to show the understanding of the situation as well as lay out a framework for how the problem could be solved with the current information that is provided.

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## Main Report

I. Project Formulation
    A. The challenge at PAP involves managing limited infrastructure and fluctuating aid demands under crisis conditions. The study begins with a comprehensive analysis of these constraints, setting the stage for targeted relief efforts

II. Setting Objectives

A. Our objectives include streamlining the process of aid delivery, identifying and minimizing restrictions, and developing strategies to better support the international aid community. Learning from past experiences, our goal is to provide insights that will be valuable in future Humanitarian Assistance and Disaster Relief (HA/DR) efforts
B. The plan will progress through each phase and its assigned deadlines during the development of his model.

III. Assumptions and Methodology

A. Fluctuating Aid Demands: External factors in Haiti may require more of certain sustenance such as water than food, or even medicine based on changing circumstances.
B. Air Scheduling: Specific scheduling time slots assigned for military and GOV flights, and flexibility for NGO and other high priority (medical) flights arriving
C. Flexible Ground Crews/Equipment: Easily mobile offloading equipment to necessary locations at PAP. Crew shifts can assumed to be same, even with working hours. Their shifts can be extended/added with easy notice.
D. Small Plane Area: With the small plane area including grass space it is assumed that there is infinite grass space or at least enough grass space to hold all the planes necessary.
E. Plane Resource Capacity: For each type of planes, we took an average capacity for each resource for each specific type of plane that was shown by the excel sheet.
F. From the client meeting it was given that we can assume planes will not break down and they will be able to get through the system if they land.
G. From the client meeting it can was given that NGO crews and Military plane crews will not assist in offloading.
H. From the meeting it was given that NGO planes and GOV plane aid cargo cannot be tweaked and it is set for each flight, however, military planes aid cargo can be requested to a certain threshold.

IV. Model Conceptualization

A. We will develop a conceptual model that intricately details the *entities* involved in relief operations – aircraft, ground crews, offloading equipment, and aid materials. The various entities will interact with each other, such as ground crews and forklifts are assigned to specific aircraft for offloading. A visual diagram will be created to illustrate the dynamic interactions and flow of operations at PAP.
B. Other necessary components consists of the *resources*, where the model will account for aspects such as the runway, offloading region, taxiway, and available equipment/workforce. There are also scheduled and unscheduled flights *arrival*s PAP to account for. The model will gauge for *activities* such as when an aircraft

lands, moves to the offloading ramp, unloads cargo, and then leaves for departure. Lastly, the model will consider *attributes* within the simulation such as cargo types and aircraft sizes as well as the *assignment* of which offloading spaces certain planes will be allocated to.

1. Arriving aircraft will be represented as entities with various attributes ranging from shape/size, to classifications such as military, GOV, or NGO. They will also all have different arrival times/schedules based on their priority to crisis aversion.
2. The model will account for when PAP has reached maximum capacity and flights are forced to divert. Such diversions will help track where there needs to be extensions in the constraints such as within the runway or parking spaces.
3. Aircraft routing in the airfield: the runway, taxiway, and loading ramps will be part of the model/simulation, such as when the the aircrafts move from landing to the offloading ramps. This will be important when considering on how to manage space on the specific paths throughout the runway.
4. How aircraft are offloaded, including ground crews, parking spaces, and offloading equipment: Certain crew teams and offloading equipment will be assigned within the offloading process depending on the type of cargo the aircrafts bring in. This aspect of the model will access the offloading efficiency, availability, and proper assignment procedure.
5. Supplies-demanded & shortages/overstocks: The model will demonstrate the demand of all the supplies that vary during the crisis. This will be necessary for determining how the much throughput the PAP can withhold so that certain planes can be prioritized at times of the Haiti crisis.

C. Data Gathering and Statistical Analysis: We will collect data on past relief operations, aircraft arrival patterns, and supply demands. This data will inform the model's parameters and help simulate realistic scenarios.

D. Model Translation – Programming: The conceptual model will be translated into a computational model using simulation software. This step involves coding the interactions, processes, and decision rules identified during conceptualization.

E. Verification and Validation: Through a series of tests, we will verify that the model accurately represents the conceptual design and validate its outputs against historical data or expert judgment to ensure its reliability.

F. Experimental Design: We will design experiments to explore the effects of various decision variables, such as changes in aircraft scheduling, resource allocation, and supply prioritization, on the model's performance.

G. Analysis of Results: The simulation outcomes will be analyzed to identify patterns, bottlenecks, and opportunities for improvement in air relief operations.

H. Recommendations: Based on the analysis, we will provide actionable strategies to enhance the efficiency and effectiveness of future relief efforts at PAP.

V. Parameters/Decision Variables

A. Key decision variables include aircraft scheduling flexibility, allocation of offloading resources, and prioritization of different types of relief supplies. By adjusting these variables in the model, we aim to identify strategies that significantly improve the response to demand for relief supplies and overall operational efficiency. Specifically, aircraft scheduling flexibility affects the likelihood of bottlenecks occurring on the runway, thereby adjusting and speeding up aircraft and departure times. This will help determine optimal timing patterns for all other tasks after landing. Manipulating the allocation of offloading resources will help minimize waiting periods for necessary supplies and enable more flights to enter the taxi. Lastly, it will be important to assert prioritization factors considering certain relief supplies are required more than others during the relief efforts. Therefore, such strategies of changing the decision variables/parameters boost efficiency and effective responses for aid.

VI. Measures of Performance/Evaluation

A. To evaluate performance, we will establish measures such as timely offloading of aid materials and meeting the daily demand of Port-au-Prince. Success criteria will be defined to align with the overall objectives of the relief efforts.
B. Efficiency of aircraft turnaround time: Assessing the time taken for an aircraft to land, offload, reload, and depart.
C. Utilization of offloading space: Analyzing the optimal utilization of offloading ramps and infield parking for different aircraft types.
D. Ground crew productivity: Evaluating the efficiency of ground crews in unloading aircraft and handling aid materials.
E. Distribution effectiveness: Examining the timely distribution of aid materials from PAP to the affected areas within Port-au-Prince.

VII. Resource Requirements

A. Our analysis will be data-driven, and we will require information on aircraft arrival distributions, offloading-time distributions, and ground crew details.
B. Data: Detailed information on aircraft arrivals, offloading-time distributions, ground crew availability, and daily demand for aid supplies.
C. Simulation software: Access to simulation tools for model development, experimentation, and analysis.
D. Expertise: Collaboration with subject matter experts in logistics, disaster relief operations, and simulation modeling.

E. Stakeholder engagement: Engagement with stakeholders involved in Operation Unified Response to gather insights and validate assumptions.

VIII. Input Data Analysis Summary of Results

A. After meeting with the client our team was able to obtain more data which helped us proceed with the project

B. Some assumptions were made right away with some of the data points. We got rid of the data that was before the hurricane because those arrivals wouldn't matter for the simulation. Additionally, we removed data points that had greater than 4 hours of time between arrivals and replaced it with the current average. The assumption made here was there were no crews working or the weather was too bad for anyone to work or get planes in. These assumptions made the data cleaner and better to work with.

C. With the arrival time data we were able to calculate inter arrival times based on the completed flights into PAP. The average inter arrival time for a plane was 17.52 minutes. This data will be specifically used in Simio to make a simulation.

D. Furthermore, with the inter arrival time data we were able to create a data frame to fit the distribution as well as analyze the data. The data points are continuous because of the type of number it could take on. Planes could arrive at any time and any second making it a continuous data point. Additionally, it was found that an exponential distribution would fit this data the best based on the SSE value being the smallest out of the tested distributions.

E. After evaluating a histogram and line plot it would found that that data was most likely independent and stationary to a certain point. This was determined because there should be no reason why one data point would affect another and the data should be independent from itself. Furthermore, the data looks stationary for most of the data. The data goes off and becomes un stationary but that most likely has a reason. At a certain point the boat port can open back up and that diverts some of the traffic because goods can come in a different way. Because of this the data isn't stationary anymore at that point.

F. All of these figures can be referenced in the appendix under data analysis figures.

IX. Model Verification and Validation

A. Verification Efforts

1. In response to the client's feedback, we've refined our model to ensure an accurate match between the number of ground crews and the demand for key resources like water, medical supplies, food, and logistics, aligning closely with real-world airport operations. Our adjustments have led to each aircraft accurately offloading resources at the correct ramps with optimal groundcrew and forklift utilization. Upon comparing our model's

outputs with the theoretical results you provided, we found a strong concordance, particularly in aircraft numbers and resource management, demonstrating our model's reliability in reflecting actual operational dynamics. We received data from the client, more specifically the total demand of each resource. We compared our calculations from our model of how many resources were actually delivered and then verified our numbers with the numbers the client gave us as shown in figure 6,7,8. As shown in figure 8, we were short of water, food, and medical resources. These enhancements, validated against your data, highlight our commitment to delivering a precise and robust model that meets your operational planning and optimization needs.

B. Validation Efforts
   1. In response to your feedback, we have made comprehensive updates to our model to more accurately mirror the operational dynamics of the airport. This includes changing the distribution of inter-arrival times for the runway, taxis, and ground service time for each plane from an exponential to a uniform distribution, ensuring a more constant flow of traffic. We've also adjusted the number of ground crew to better align with operational requirements and meticulously compared and fine-tuned the model's estimates for water, logistics, medical, and food resource demands against the data you provided, achieving a closer representation of real-world needs. Furthermore, we have addressed your point regarding the ground service time at the offloading ramps by transitioning from an exponential to a uniform distribution. This adjustment aims to better reflect the predictable and consistent service times observed in actual operations, enhancing the model's accuracy in simulating the time it takes for aircraft to be serviced and resources to be offloaded. These modifications collectively enhance the realism and precision of our model, ensuring it closely matches the airport's operational dynamics. We will re-validate these changes by comparing the updated model's outputs with the theoretical results you've shared, and prepare focused questions to delve deeper into the model's precision and underlying assumptions in our forthcoming discussion. Through this iterative refinement process, leveraging your invaluable feedback, we aim to continuously improve the model's accuracy and its true representation of airport operations.

X. Study Plan

A. In this phase of the case study, we developed a detailed plan outlining our approach. The plan encompassed four key components: response variables, factor levels, study parameters, and a list of configurations.

B. The response variables included various types of essential supplies such as water, logistics, food, and medical supplies. Our findings showed significant increases across all categories: food supplies rose from 5,500 to 8,000 tons, water from 6,000 to 10,000 tons, logistics from 18,000 to 26,000 tons, and medical supplies from 4,800 to 7,000 tons. These increases were observed under a new model configuration, where adjustments to other influencing factors resulted in substantial growth in supply volumes.
C. In this study, we modified four key factors in our simulation to observe their impacts over time. These factors included the number of parking spaces, forklifts, ground crew, and the frequency of arriving planes. Changes to the parking spaces, forklifts, and ground crew were implemented gradually throughout the simulation rather than instantaneously at the beginning. For instance, we added one parking space every four days, with a maximum of two additional spaces allowed. Similarly, one forklift and five ground crew members were added daily over a six-day period, after which no further additions were permitted. This ratio ensured one forklift per parking space, optimizing operational efficiency. All modifications were carefully considered to enhance the model's effectiveness and suitability for the scenario.
D. For the study parameters, we opted to conduct 30 replications of a 45-day scenario that mirrors the actual situation presented to us. This model functions as a terminating model, concluding after 45 days, but the multiple replications provide clarity on the expected outcome of the model. We chose to execute 30 replications to ensure the most precise statistics and deeper insights into the model's behavior. Although we did not implement any specific variance reduction techniques, the use of numerous replications inherently aids in minimizing variance and achieving more reliable results.
E. For the list of configurations, we developed four distinct setups. The first configuration applied to phases 1-3 and incorporated all the basic requirements specified by our client, representing the initial model. In configurations 2-4, we expanded the operational capacity by increasing the number of aircraft spaces on the runway, the number of forklifts, and the ground crew, as well as the arrival rates of incoming planes over a period of time. For example, a parking space took 4 days to make so every 4 days we were able to add a new parking space. Furthermore, everyday for the first 6 days we were able to add one forklift and 5 ground crew. So for the first six days those variable numbers went up by the respective amount. For the plane arrival increase it was an instant implementation and increased arrival rates. For a visual representation of how these configurations augment the supply levels, please refer to Figure 9 in the appendix. To see how the configurations performed, reference Figure 10 for those numbers.

XI. Summary

A. This study utilized a simulation model to enhance air relief operations at Port-au-Prince Airport following the devastating earthquake. Our model, developed through an iterative process of conceptualization, verification, and validation, effectively captured the dynamic interactions among aircraft, ground crews, and aid materials under crisis conditions. Through 30 replications of a 45-day scenario, the model predicted the operational impacts of various configurations and modifications. Key adjustments included increases in parking spaces, forklifts, and ground crew, along with optimized aircraft arrival rates. These changes significantly boosted the supply throughput for essential items—food, water, logistics, and medical supplies—enhancing the airport's capacity to manage aid during peak demand periods. Our analysis highlights the critical role of flexible resource allocation and scheduling in mitigating bottlenecks and improving overall efficiency at the airport.

XII. Recommendations/Conclusion

A. Future studies should look into different ways to arrange airport resources to best handle emergencies under various scenarios and consider the benefits of larger airport infrastructure improvements, like bigger runways. It's also important to explore advanced simulation methods that use real-time data to improve operational decisions. Additionally, examining how outside factors like politics, economics, and international aid affect emergency responses is crucial. Research on how different organizations can work better together during emergencies would also be helpful. These studies will enhance our understanding and effectiveness in managing disaster situations at airports like Port-au-Prince.

B. These recommendations aim to guide future research directions that build on the current model's findings, enhancing both the theoretical understanding and practical capabilities of disaster response operations at Port-au-Prince Airport and similar environments.

XIII. Remaining Elements of The Study

A. Client Meetings: Having multiple conversations with the client throughout the process to gain additional information and get their input on the results of the process.

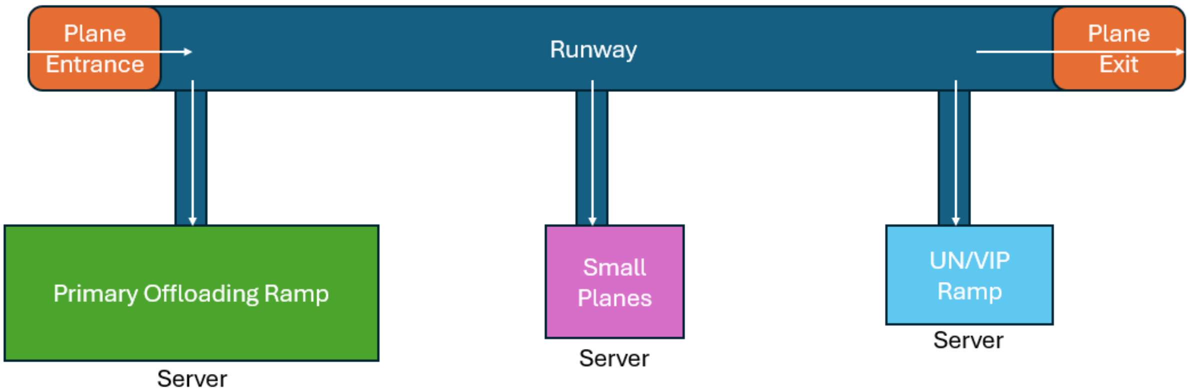
B. Experimental Design: Designing experiments to explore different scenarios and test effectiveness of simulation model.

C. Analysis of Results: Analyzing the simulation results to identify key insights, trends, and areas of improvement.

D. Recommendations: Formulating actionable recommendations based on the analysis to enhance air relief operations at PAP.

XIV. Diagram

A.




XV. Appendices

A. Log of team member meetings
   a. Saturday January 27th, 2024
   b. Monday, January 29th, 2024
   c. Tuesday, January 30th, 2024
   d. Wednesday, February 28th, 2024
   e. Thursday, February 29th, 2024
   f. Thursday, April 4th, 2024
   g. Monday, April 8th, 2024

B. Log of client meeting
   a. Wednesday, February 28th, 2024
   b. Monday, April 1st, 2024
   c. Monday April 8th, 2024

C. Individual team member responsibilities
   a. Chase Powers: Team Leader
      i. This position will manage the progression of the project while making sure objectives are being met.
   b. Josh Yago: Assistant Team Leader
      i. This position will help the Team Leader manage the progression of the project while assisting the Data Manager and the Simulation Manager.
   c. Sam Gee: Simulation Manager
      i. This position is in charge of the simulation throughout the building process as well as the needed changes to make it run better.
   d. Swayam Singh: Data Collection Manager
      i. This position is in charge of collecting data as well as asking the required questions to get the data that is needed from the client.

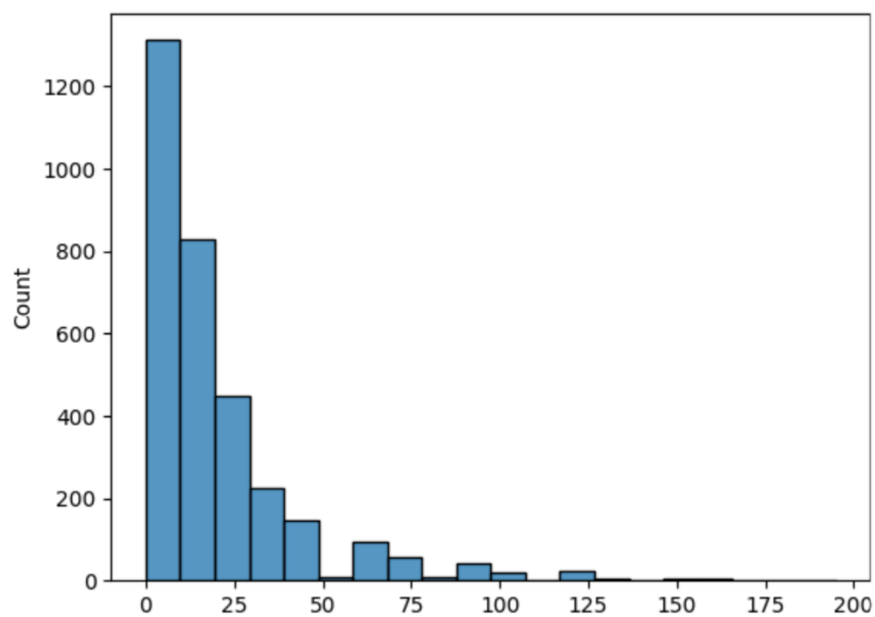
D. Details of your input data analysis

a. We asked questions about the arrival times for the planes, leading us to be given an excel sheet with arrival times for every landing.
b. We used the excel sheet to pass a data frame of the excel data into jupyter notebooks, and then inspected the times between each arrival for our data frame
c. After inspection, we deleted some outliers that were making our data difficult to display and interpret, operating under the assumption that any gaps between arrival times greater than 250 minutes were off-duty hours that occurred towards the end of the relief effort.
d. We graphed to confirm independence, stationarity, and homogeneity
e. We tested some prominent distributions to which one best fit, and exponential both visually represented our data and had the lowest error.

E. Data analysis figures

| |
|---|
| 20 |
| 20 |
| 39.99999999 |
| 0 |
| 20 |
| 20 |
| 0 |
| 20 |
| 19.99999999 |
| 40 |
| 20 |
| 0 |
| 20 |
| 0 |
| 19.99999999 |
| 60.00000001 |
| 0 |
| 19.99999999 |
| 100 |

a. Figure 1: Example of inter arrival times (showing its continuous)




b.
Figure 2: Histogram of the data (showing exponential)

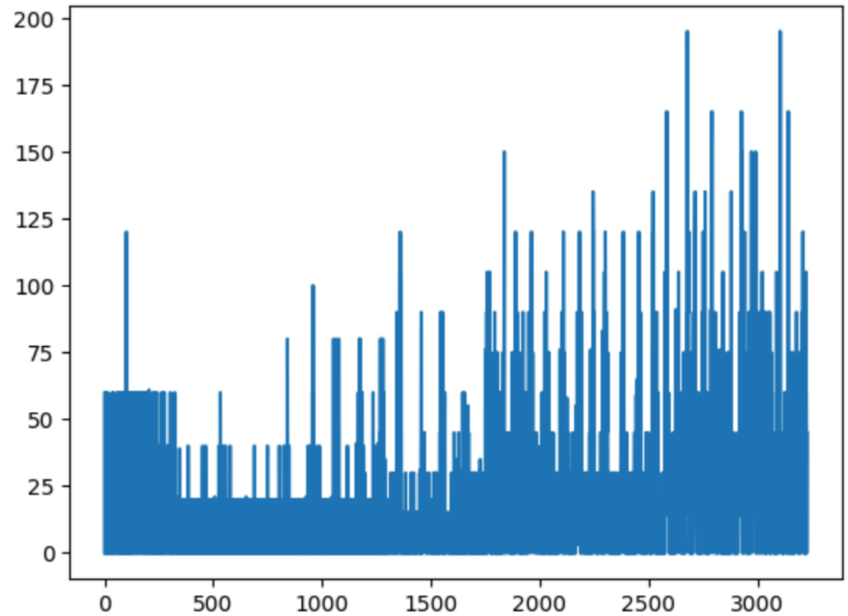
c. 


Figure 3: Line Plot of the data (showing sationarity to a point)

d.

| | | | | | | |
|---|---|---|---|---|---|---|
| expon | 0.045607 | 1689.675862 | 1701.836337 | inf | 0.396594 | 0.000000e+00 |
| norm | 0.054907 | 2484.870027 | 2497.030502 | inf | 0.256983 | 1.382487e-188 |
| gamma | inf | inf | inf | inf | NaN | NaN |
| lognorm | inf | inf | inf | inf | NaN | NaN |

Figure 4: Table of the fitter module calculating the best distribution for the data (exponential being the best)

e.

| **Process** | **Proposed Distribution** | **Rationale** | **SSE (Sum of Squared Errors)** | **Notes** |
|---|---|---|---|---|
| Inter-arrival Times | Exponential | Best fit based on SSE and characteristic of the data | 0.045607 | Assumes arrivals are memoryless |

Figure 5: Summary of Proposed Probability Distributions

f. Figure 6: Amount of all resources delivered

| First 15 | Water | Food | Medical | Logistics | Last 30 | Water | Food | Medical | Logistics |
|---|---|---|---|---|---|---|---|---|---|
| | 390 | 290 | 250 | 700 | | 195 | 145 | 125 | 200 |
| 15 total | 5850 | 4350 | 3750 | 10500 | 30 total | 5850 | 4350 | 3750 | 6000 |
| | | | | | | | | | |
| What was made | 152.9 | 123.5 | 108.8 | 408.7 | | 152.9 | 123.5 | 108.8 | 408.7 |
| | 2293.5 | 1852.5 | 1632 | 6130.5 | | 4587 | 3705 | 3264 | 12261 |

g. Figure 7: Demand of all resources

| | |
|---|---|
| Water Needed | 11700 |
| Food Needed | 8700 |
| Medical Needed | 7500 |
| Logistics Needed | 16500 |
| Water Made | 6880.5 |
| Food Made | 5557.5 |
| Medical Made | 4896 |
| Logistics Made | 18391.5 |

h. Figure 8: Percent of resources (amount delivered/total demand)

| | | |
|---|---|---|
| Percent Water | 58.81 | % |
| Pecent Food | 63.88 | % |
| Percent Medical | 65.28 | % |
| Percent Logistics | 111.46 | % |

List

i. Figure 9: List of Configurations

| Configuration: | # Spaces | # Forklifts | # Ground Crews | Arrival Times |
|---|---|---|---|---|
| 1 | 9 | 5 | 20 | 100% |
| 2 | 11 | 5 | 20 | 70% |
| 3 | 9 | 11 | 50 | 70% |
| 4 | 11 | 11 | 50 | 70% |

j. Figure 10: Table of Configuration Production

| Configuration: | Logistics | Food | Water | Medical | Total |
|---|---|---|---|---|---|
| 1 | 18,141.50 | 5,577.83 | 6,926.44 | 4,903.53 | 35,549.30 |
| 2 | 25,711.33 | 7,873.02 | 9,769.78 | 6,924.64 | 50,278.76 |
| 3 | 25,818.39 | 7,882.94 | 9,777.28 | 6,935.77 | 50,414.38 |
| 4 | 25,843.83 | 8,024.25 | 9,980.77 | 7,046.00 | 50,894.85 |

F. Documentation

   a. EI was received on February 28th with Dr. Kallemyn to look over our code as well as help explain the dataset and ways to calculate inter arrival times.
   b. No help was received on this assignment. All work was done within the group. All information used was referenced from the provided docs with information.