# Augmenting Passenger Throughput in Airport Terminals

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# 1. Executive Summary

One of the universal aspects of the airport experience is waiting in line. In addition to clear detriments to customer satisfaction, high congestion presents serious security concerns related to an increase in ground-side terrorist attacks over the past decade. While airlines have access to advanced passenger data for upcoming flights, a lack of data sharing critically fails to leverage the potential to augment passenger throughput in airport terminals. This report examines the potential efficacy of day-to-day demand forecasting accomplished through enhanced data sharing between the Department of Homeland Security, Department of Transportation, airport management, and participatory airlines.

Using a wide variety of available data, design processes, and consultation of industry experts the team was able to construct a simulation for quantitatively estimating the impact of such a system. The simulation included a wide variety of variables for predicting human behavior and passenger preference using statistical models and configurable parameters for status quo behavior. On a dataset consisting of more than 300 individual flights for Newark Liberty International Airport the team was able to analyze the impacts of potential algorithms for assigning arrival times to passengers and providing enhanced metrics to the Transportation Security Administration. Over many trials for a wide variety of parameters, these methods resulted in a nearly 25% decrease in queueing time. This investigation demonstrates the quantitative benefit of improved data sharing to all involved stakeholders while presenting a feasible design for a central data sharing and demand forecasting system. With the implementation of such a system, travelers could expect a fast, safe, and predictable airport experience.

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## 2. Problem Statement and Background

*Area IV*: Airport Management and Planning

*Option A*: Maximizing Airport Capability

*Subtopic*: Demand Forecasting and Data Sharing

*Area of Concern*: Traveler Queueing Delay, Congestion in Terminals

*Primary Stakeholder(s)*: Frequent Fliers, TSA, Airport Managers

Airport management and planning is a key area with many challenges and opportunities for improvement in the airport industry. Maximizing airport capability possesses large potential benefits for multiple stakeholders, from airport patrons to administrative staff and management. Current standards for airport operation product a high-stress environment for travelers that centrally involves waiting in lines. A world with perfect day-to-day demand forecasting would have overwhelming consequences due to the perfect allocation of resources. With flawless demand forecasting and transparent data sharing, airports could effectively allocate ground side resources without waste, provide clean facilities to passengers, and staff their stations to maximize passenger throughput in response to anticipated arrival rates. This model of an efficient airport would be a much more enjoyable experience for travelers, a more manageable environment for the TSA, a cost-effective operation for airport managers, and reflect positively on the public opinion of airlines. Given the immense benefit of a world with perfect demand forecasting, it is pertinent to investigate methods for utilizing data sharing to improve the passenger experience and achieve optimal demand forecasting in airport terminals.

In order to effectively understand the stakeholders and processes involved the team first conducted a variety of background research. The conclusions of this stakeholder research are summarized below.

**2.1 Airport Managers**

At a basic level, airport managers are decision-makers and policy-managers for an airport. At a large airport there will be several managers across departments, while smaller airports may only employ one. Their responsibilities include ensuring compliance with regulations and guidelines, supervising staff, managing budgets, adapting to outside factors and the community, maintaining records, and overseeing maintenance of airport equipment. (Houston, 2019)

An airport manager's qualifications include experience at the boundary of aviation and business. They are usually employed by the city and work closely with legislature for change. Airport managers are adeptly compared to mayors – they oversee a wide variety of fields and operations while maintaining common goals and ensuring the cohesion of up to thousands of personnel and hundreds of acres of land. Subtypes of managers include an operations manager, who is responsible for various day-to-day operations and logistics. This might include retail operations and budgeting at a macroscopic level for the airport's various constituents. On the airside, they will coordinate ground operations such as baggage, manage fueling, and work closely with air traffic control to plan and coordinate departures (Vaughn Spotlights, 2018).

A general manager is the culmination of other responsibilities, emphasizing communication and management skills. They work closely with government and federal agencies to maintain a working relationship. Their main responsibility is to manage and monitor the airport's high-level operations, including contracts, budgeting, personnel, operational activities, and interaction with other institutions and departments (Vaughn Spotlights, 2018).

Within an airport, overarching software systems like the one pictured below frequently orchestrate operations and maintain central metrics. These systems effectively coordinate the operations of various stakeholders although centrally provide information to airport employees and airport managers (AltexSoft, 2020).

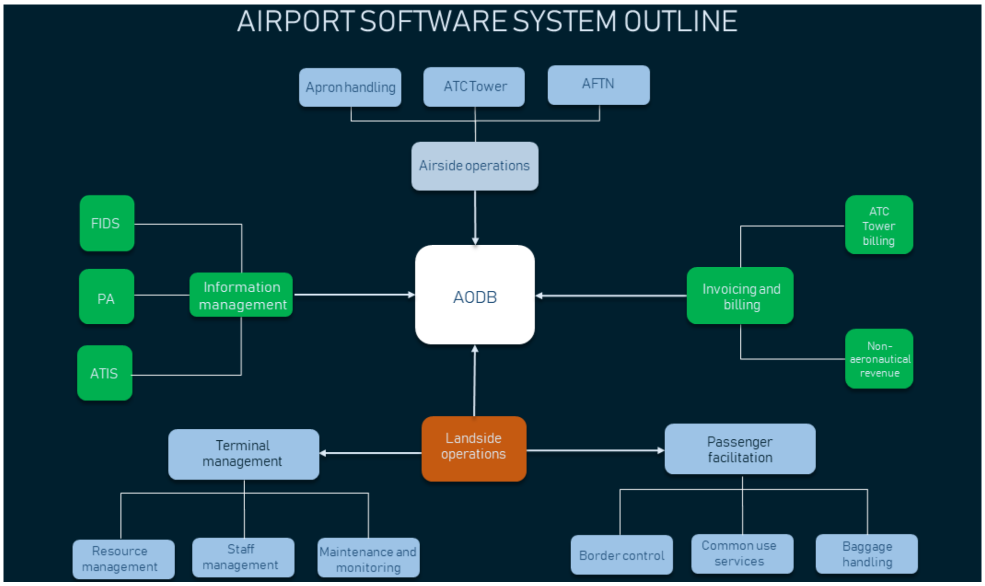


*Figure 1 | The Airport Operational Database, which is commonly provided by IT groups like Leidos and Siemens, is the backbone of software in an airport (AltexSoft, 2020).*

### 2.2 Transportation Security Administration (TSA)

TSA officers (TSO's) are responsible for scanning a boarding pass and ID and performing a facial check to ensure a match between the individual and ID photo. They must also operate Advanced Imaging Technology (AIT) which includes full-body imaging devices scanning for both metallic and nonmetallic threats. TSA pre-check is among the various programs to exempt passengers from AIT scanning which can help reduce delay in TSA queueing (Palmer, 2020).

### 2.3 Field Research

The team visited University Park Airport, which featured a small terminal and only four airlines: Delta, United, Allegiant, and American Airlines. The team discovered there was only one floor accessible to patrons, which was reasonable for the small customer volume and airport size. Even so, there were some infrastructure systems in place to reduce confusion during busier hours. For example, the Delta Airlines counter had a self-check-in station for patrons to sign in and complete transactions without airport staff. While the team did not observe any customers using the feature at the time, it would likely be used during busier hours to reduce long wait times.

The terminal featured monitors spread along the wall, although the team observed that only half of the monitors were turned on. The monitors displayed weather, advertisements, and general information about the airport. The major concern observed by the team was the airport's approach for handling delayed flights. There were minimal locations for patrons to view flight information and only a single TSA checkpoint for all customers to use before boarding the plane. While the challenges are different between airports based on size, the challenges of demand forecasting and handling large crowds is only more extreme at large airports.


*Figure 2 | During the research visit, a flight was delayed by an hour. Guests had to be notified over the loudspeaker system, unless they had been actively scanning the single monitor displaying departures and arrivals of all four airlines with the airport.*

While performing the field research, the team met Anna, a first-time visitor. Even though the airport is small, she was confused by the lack of directions explaining where to go and what to do. After checking in at the counter, Anna was told that the flight was delayed and had been so for a while. In addition, there was a substantial line for check-in at the booth of the single airline conducting operations at the time. Even in a relatively empty airport with few operations to manage, the problems defined by the team persist. A revolution to passenger queueing and delays could revolutionize every level of the aviation industry, from small local airports to international transport hubs.

### 2.4 Summary and Study Implications

To continue idea generation from the field research and conversations at the airport, the team conducted interviews with two experts who had previous experience with airport management. These interactions and their contributions to prototype development are detailed in Section 4.4. Their insights on key topics involving data sharing, demand forecasting, and management of resources were vital in developing themes and determining an approach to future ideation and solution generation.

After concluding research and interviews with experts and everyday patrons at the University Park Airport, the team developed main themes and insights that would drive ideation forward and serve as a key focus in human-centered design. These themes were vital in staying focused on key issues facing main stakeholders in everyday interactions at an airport.

# 3. Literature Review & Research

Airport management and planning is a multidimensional problem with numerous parameters contributing to the overall efficiency of any given airport. Out of the fourteen potential options for maximizing airport capability, the team decided to focus its research on two key areas:

Demand Forecasting and Data Sharing.

### 3.1 Demand Forecasting

Demand forecasting is analysis using historical data to predict customer demand and optimize supply decisions for business management. In the airport industry, Demand Forecasting is used to predict when "busy times" for air travel will be and determining how much long-term growth the airport will have. Demand forecasting analysis is typically carried out when change is due to occur and is usually contracted out to a consulting company. AIQ Consulting uses special modeling software, TransvisionAIR, to simulate how passenger traffic flows through an airport (AIQ, 2015). Their services involve biometrics for improving passenger automation to optimizing plans for future growth and recovery of airports post-COVID (AIQ, 2020).

Airport demand forecasting is a useful tool for airport planning and operations but is highly dependent on the accuracy of the prediction models used. If demand is underestimated, it can cause congestion and delay. If overestimated, there can be severe economic consequences (Karlaftis, 1996). Recent research used statistics to adjust models for observed data at two major airports and check correctness against measured data. The optimal difference achieved was 2.2% by an artificially intelligent model; this is considered very low in error (Karlaftis, 1996).

Because it is highly fueled by metrics and statistical models with a huge number of parameters, airport demand forecasting has become a prime target of artificial intelligence research in recent years. A team of researchers concluded the rapid growth of neural network research with low computational requirements and comprehensive operations with high flexibility for airport demand forecasting (Kolidakis, 2018).

**3.2 Data Sharing**

Data sharing is the distribution of the same set of information across individuals, organizations, and institutions. The current standard in the aviation industry is to collect as much data as possible relating to the operations of an airport. A key problem arises when considering information-sharing between airports and airlines (Saulat, 2018).

Many private airlines do not share data because they do not want information to be used to pursue competition against their business (Business Airport International, 2021). The value of information presents a natural hesitance to forfeit a potential competitive advantage, so the problem becomes incentivizing data sharing behavior. According to Bublitz et al (2020), the solution is simple. If airlines participate in data sharing, the advantages could hugely improve customer satisfaction and increase their demand for air travel. More customers mean more business, and, ultimately, a distributed reward across all airlines. Expert opinion converges on one conclusion: if airlines and airports choose to share data, efficiency can be increased (Hrishikesh, 2015). The issue is deciding what data should be shared and how airports determine the weight of being competitive over passenger experience. Bridging this gap by demonstrating the overwhelming value of sharing data is a lucrative problem in the industry.

Airports and airlines can benefit each other by sharing data, therefore improving efficiency. A key example of this is that airports know the number of passengers that arrived for their flights and airlines know how many have not checked in. If the airport and airlines were to share this information with each other, check in times could be reduced for travelers and airports can optimize staffing to process customers faster. Many international airlines already collect data on passengers that could be used to allocate staffing in airport management and increase revenues (LaGrave, 2019). In Canada, airports use the Known Traveler Digital Identity system to speed up security and the customs process for border crossings (Tansey, 2020). According to the Canadian Government, “The Known Traveler Digital Identity system takes emerging digital technologies such as advanced biometrics, cryptography and distributed ledger technologies to give travelers control over, and the ability to share their information, via personal mobile devices, with governments and travel providers to facilitate and expedite progress from departure to destination airports, and beyond” (Government of Canada, 2018). Demands for additional processing during international travel make it increasingly frustrating for travelers, so a streamlined process may be welcome. Gatwick Airport in the UK has also introduced a fascinating new way to improve customer experiences using data sharing. Their AirTurn turnaround time tool communicates with all teams involved in the turnaround of an airplane. This technology alerts personnel when they need to act to reduce downtime. The faster the turnaround time, the more flights the airport can process (Tansey, 2020). SITA’s Health Project is a new technology brought on by the COVID-19 pandemic, which enables airlines to see health documents uploaded by users. This technology makes use of pre-existing concepts used by airlines for no-fly lists (Youd & Smith, 2021).

# 4. Methodology

To effectively navigate the problem-solving process, the team employed a variety of methods for guiding discussion and ideation. This included the use of themes and insight statements to narrow down themes related to the problem statement. In group analysis of these insights, the team was able to center discussion and gain dynamic understanding of a multi-faceted topic. This included a set of team processes that cycled through team members for discussion and promoted equal opportunity to contribute to discussion. The team also made use of the suggestions of ACRP industry experts, who suggested a variety of directions for problem-solving that hold promise in overcoming challenges faced by imperfect demand forecasting and airport traveler delay. Finally, the team allotted time for brainstorming meetings which encouraged the open and unfiltered sharing of ideas from all team members. In this process, ideas were categorized and reduced to a select set of possible solutions.

The entire process was guided by the Design Thinking process and driven by empathy. The use of the POV statement, team's field research, and discussions with industry experts allowed the team to derive a more detailed understanding of the stakeholders involved. The systems-thinking solution would produce a solution which satisfies consumers, by means of reduced wait times during travel. In response, this benefits airlines, who desire return service from their customers. Better data for queuing and reduced congestion would ease operations for staff and airport managers, who might facilitate this process. Finally, the TSA would benefit from better data forecasting and provide enhanced safety to air travelers with reduced risk of ground-side attacks in high-density areas. This complex system of stakeholder interactions was central to the team's problem-solving approach, which is outlined below.

**4.1 Themes & Insight Statements**

The primary design challenge focused on improving efficiency of airport traveler experience within an airport in a cost-effective and meaningful way. Five main themes surrounding patrons were identified: passenger check-in lines, first-time passenger experiences, unfortunate delays, TSA screening process, and passenger down time.

With check-in lines, more people with excessive baggage in line leads to increased frustration. Most passengers seem to prefer the faster and more efficient process of a self check-in. There are few cues to let passengers know the check-in line wait is, or if changes have occurred, until they are physically present in line. First-time passenger experiences are difficult, as they know they must check-in first but are confused at where they should go for the next step. Delays cause crowds, changes to other flights, and frustration among passengers. Passengers often find out after they are already at the airport about a delayed flight and end up having to wait around in terminals. Similarly, the TSA screening process has long lines due to poor passenger-TSO ratio. Safety procedures are important for protecting passengers but are time-consuming. Passengers frequently associate the airport experience with these time-consuming procedures and queues even though they might prefer to enjoy food and drink while in a terminal. Flight gates are often not close to food/shopping areas in the airport, leaving passengers with additional down time while waiting.

Through these persistent themes and well-defined POV statement, the ideation process began. Keeping in mind the team’s meeting with Anna at the airport, the flight was delayed and had been so for a while. In addition, there was a substantial line for check-in at the booth of the single airline conducting operations at the time. A revolution to passenger queueing and delays could revolutionize every level of the aviation industry, from small local airports to international transport hubs.

### 4.2 Initial Ideation Concepts

Multiple group sessions were held where individuals shared ideas and sketched them with a description on a sticky-note. These ideas were expanded upon by other members and grouped at the end to reveal common themes and techniques to approach the issue of queuing in airports.

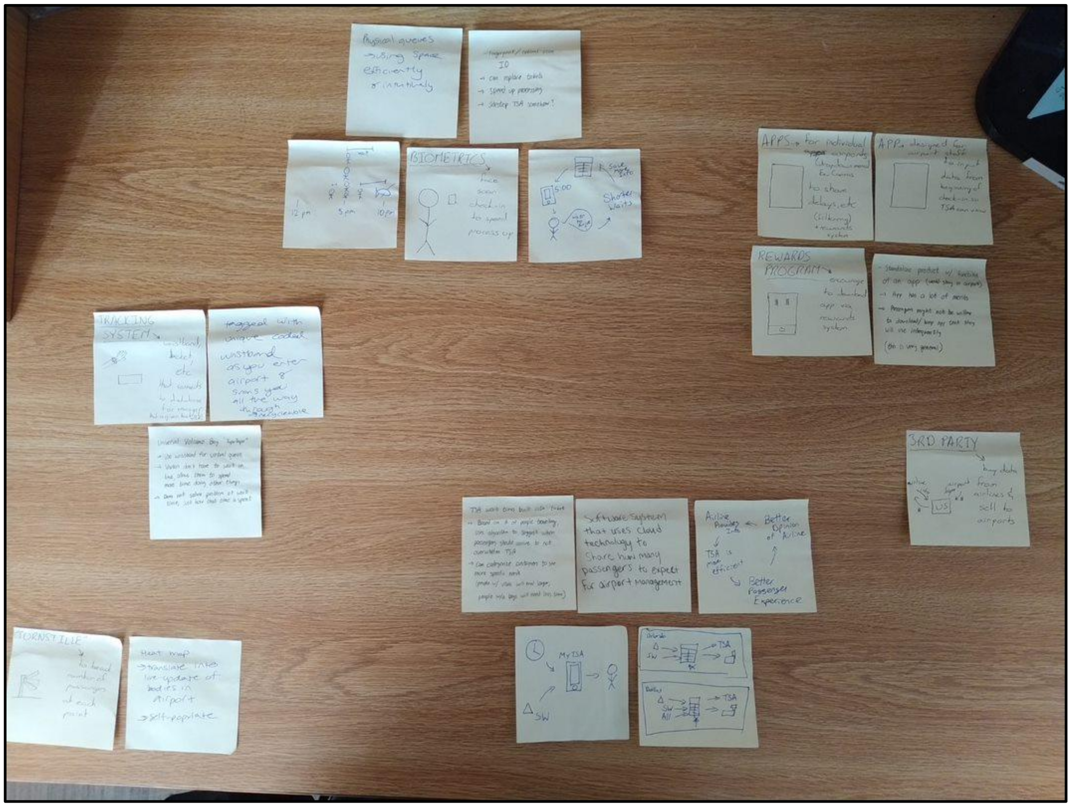


*Figure 3 | The main concepts selected from the first two meetings are shown above. Ideation was grouped into categories which included biometrics, apps, third party firms, tracking systems, databases, physical monitors, and demand forecasting techniques.*

Biometric solutions included three main ideas of a fingerprint, retinal, or face scan to decrease time spent in queueing lines. Apps were highly discussed, and three different types were mentioned as described below. A third party firm could buy data from airlines and sell the data back to airports, giving the airlines an incentive to integrate data with airports despite competitive advantage. Tracking systems were broken into two main categories, heat maps and turnstiles section. Database ideas included storing airline ticket data and projecting passenger number to expect using cloud computing software. The primary physical monitor idea utilized a wristband that passengers would wear once entering the airport. Three other physical monitor ideas included a small device to hold, a clip device, and a necklace. Finally, demand forecasting techniques involved a variety of large-idea concepts, mainly incorporating ticket modification.

### 4.3 Narrowed Ideation Concepts

After completing initial brainstorming, the team began to narrow down concepts based on initial advantages and concerns related to each approach at making airport lines more efficient. While avoiding selecting a topic before a selection matrix, a narrow focus was needed to further develop analysis of strengths and weaknesses of the multiple approaches ideated.

| IDEA | DESCRIPTION | ADVANTAGES | CONCERNS |
|---|---|---|---|
| Wristband/<br><br>Queues | - Patrons are given a unique coded wristband when entering the airport that scans them the entire way through<br>- Tracks location and relays information to staff<br>- Can be used for a virtual queue (inform passengers when to wait in line) | - Visitors do not have to wait in line<br>- Allows patrons more time to spend doing other things<br>- Simple design that could be prototyped physically with technology aspects<br>- "Circular Economy" | - Privacy/security concerns for patrons<br>- Uncomfortable to wear<br>- Needs to be adaptable for many wrist/arm sizes<br>- May be expensive to implement<br>- Does not solve problem of wait time, just how time is spent |
| App | - Could be designed for patrons to use at individual airports (drop down menu) which would show delays, rewards system, map, airport info, etc<br>- Could be designed for airport staff to input data from beginning of check-in so TSA and manager can view | - Unique idea that many airlines, but not airports, have begun to use<br>- Shifts towards more technology/modern<br>- Simplifies process for both patrons and staff<br>- Relatively inexpensive in practical sense | - Patrons may be unwilling to go out of their way to download an app<br>- Patrons need technology and knowledge of how to use and download app<br>- Difficulties in designing an app in two weeks/ inexperience from the group |

| | | | |
|---|---|---|---|
| | - Include a rewards program to encourage users to download app and spend money | | |
| Database | - Software system that uses cloud technology to share how many passengers to expect for airport management<br>- Could be a third party (buying and selling data between airlines and airports) | - Solves problem of data sharing<br>- Many other countries globally already share this data, very possible to do<br>- Much more accurate predictions with better data and specific numbers on passengers | - Legal issues<br>- Despite financial incentives, this would lower competitive advantage<br>- Difficult to prototype an actual database |
| Biometrics | - Create a standalone product with functions that can be used at any airport<br>- Biometrics include face scan to check in or a fingerprint/retinal scan | - Recently on the rise in airports, this would make something that is usable for all<br>- Can replace physical tickets<br>- Decreases time spent in line (speeds up processing)<br>- Requires fewer staff | - Already begun to be tested in airports,<br>- Solution must be unique/innovative<br>- Difficult technology to prototype<br>- Expensive technology to develop in practicality |
| Heat Map | - Use thermal detection to determine patron flow and quantity at any given time | - Gives real-time access to airport of the patron flow<br>- Allows for accurate count of number of passengers in any given sector of airport to determine staffing | - Extremely difficult to prototype<br>- Expensive<br>- Potential maintenance concerns |
| Ticket<br><br>Modification | -TSA wait time built into ticket based on demand forecasting of people traveling<br>- Uses algorithm to suggest when passengers should arrive to not overwhelm TSA | - Could categorize customers to see specific needs<br>- Helps give customers accurate time of when to check-in<br>- People without bags will need less time to process | - People with Visas will need longer time to process<br>- Times may be inaccurate and cause further confusion<br>- Unsure of how specifically passengers will react |

### 4.4 Interactions with Industry Experts

After brainstorming categories of potential solutions, the team presented some of these concepts to industry experts Dr. Richard I. Nettey and Felipe Rodriguez, both offering key insight.

Dr. Nettey confirmed the viability of virtual queues, which are occasionally used for taxi systems outside the airport but cautioned against the security risk of allowing passengers to wander and congregate elsewhere while awaiting a “take-a-number"-style of system. This would fail to adequately address the concern of security risk created by passenger congregation. Combined with economic barriers, this presented a counterargument to the idea of using wristbands.

The use of an app was widely supported by industry experts, although the team noted similarities to the existing MyTSA App which offers historical delay information. In these discussions, the team was giving advice for pushing the successful adoption of a mobile app, which included the promotion of influencer social media personalities and the endorsement of organizations such as the AARP for older passengers.

Regarding biometrics, Rodriguez noted the existence of various TSA pre-Check and Global Entry programs which offer similar expedited passenger movement through security. Dr. Nettey offered a comparison to the TSA Clear program which allows passengers to skip the line. The industry experts agreed that a solution in the realm of biometrics would be viable if constructed in a way that consumers get enough benefit to trust and adopt the use of biometric information. For individuals not adopting a new system, they could continue to use existing infrastructure.

The team also asked both experts for feedback on a solution involving the manipulation of ticket times. Felipe Rodriguez provided a detailed account of each of the steps in the process that encourage an early arrival for air travelers, which includes document verification, securing parking, checking luggage, resolving financial issues, boarding the aircraft, interacting with ramp agents, and overcoming delays. Felipe Rodriguez noted the distinction that it is not as significant for domestic flights which leave more frequently. The increase in suggested early arrival time has grown from one to two hours, due largely in part to backups at TSA checkpoints. Dr. Nettey suggested that the value gain of customers experiencing shorter wait times would outweight the competitive advantage retained by airlines when choosing not to participate in data sharing.

Another useful stakeholder contribution was the advice of Dr. Nettey, that the team should explore the viability of data sharing between airlines and the FAA and the TSA. The location of the administrations in different departments of government poses an issue in sharing this information, although doing so would maximize the value of information already known to certain stakeholders. Rodriguez suggested that the classification of flight capacities as Sensitive Security Information (SSI) by FAA regulation was a driving factor in this lack of data sharing.

This professional feedback helped the team refine the brainstorming process when implementing a design thinking approach for problem solving. Based off the feedback received, the team remained hesitant with biometrics and wristbands and placed higher value on innovative technology such as applications and ticket modification. While the team avoided directly eliminating ideas with potential, the concerns of innovativeness with biometrics and safety/customer satisfaction of the wristbands were noted. Dr. Nettey’s insights on security risks as an airport manager and Felipe Rodriguez’s focus on creation of a unique solution drove the focus of solution selection.

**4.5 Solution Selection**

There were six solutions generated and narrowed down to by the end of the ideation: wristband virtual queue, delay app, shared database, biometric check-in, heat map analysis, and ticker modification. Multiple characteristics were selected and voted on by team members to create a decision matrix to quantify the ability of solutions to address key needs. Team members ranked the six solutions individually and explained reasoning in a follow-up meeting. The values from each individual were combined, and key insights were gathered. Through the activity, commonalities in preferences and concerns for specific ideas were revealed.

*Decision Matrix*

After spending the previous four weeks researching the problem and developing ideas, it was time to determine the final idea for the design challenge. The team used a Decision Matrix to assess which idea was the best fit for the team based on six criteria. Proposed suggestions for ideal criteria were voted based on those that were thought to be the most beneficial. Each member was given five categories to choose from out of the 11 initial proposals. The proposed criteria and votes are shown in Figure 4 below.

| Proposing Criteria | Votes |
|---|---|
| Cost | ooooo |
| Ease of use | oooo |
| Non-invasiveness | o |
| Contactless | |
| Accessibility across Demographics | |
| Desirability to Consumers | ooooo |
| Potential Efficacy | o |
| Difficulty to Implement | oooo |
| Innovativeness | ooo |
| Reliability | |
| Attractiveness to Stakeholders | oo |

*Figure 4 | The initial 11 proposed criteria and the number of votes for each idea are displayed.*

The team assessed the voting results and created six distinct criteria based on what was deemed most beneficial. In one instance, multiple categories were combined into one broader category. "Desirability to Consumers" and "Attractiveness to Stakeholders" were combined into a broader "Attractiveness to Stakeholders" category since consumers are a stakeholder for the project. A "Safety and Security" category was also added since consumer safety is a top priority. Team members ranked each idea from 0-10 based on the six criteria, with 0 being the worst and 10 being the best. Figure 5 shows a sample of one team member's rankings.

| | Ideas | | | | | |
|---|---|---|---|---|---|---|
| Categories | Wristband Virtual Queue | Delay App | Shared Database | Biometric Check-in | Heat Map Analysis | Ticket Modification |
| Cost | 1 | 7 | 8 | 4 | 4 | 6 |
| Innovativeness | 4 | 8 | 6 | 9 | 9 | 7 |
| Difficulty to Implement | 8 | 6 | 5 | 7 | 4 | 8 |
| Attractiveness to Stakeholders | 6 | 7 | 5 | 7 | 7 | 6 |
| Ease of Use | 7 | 7 | 6 | 8 | 8 | 8 |
| Safety & Security | 4 | 8 | 5 | 5 | 6 | 5 |
| **Sum** | 30 | 43 | 35 | 40 | 38 | 40 |

*Figure 5 | A sample Decision Matrix, with ideas ranked by criteria on a scale from 1-10 and summed at the bottom.*

To finally determine which idea would work best for the team, every team member's results were compiled in a master spreadsheet and added together. The ideas with the highest overall rankings indicated solutions that were feasible, approved by a majority, and solved key constraints. The final tallies of each idea are shown in Image 3 below.

| | Ideas | | | | | |
|---|---|---|---|---|---|---|
| **Categories** | Wristband Virtual Queue | Delay App | Shared Database | Biometric Check-in | Heat Map Analysis | Ticket Modification |
| **Josh** | 32 | 44 | 42 | 41 | 45 | 46 |
| **Ella** | 28 | 40 | 35 | 39 | 37 | 44 |
| **Michael** | 35 | 40 | 42 | 37 | 37 | 42 |
| **Joe** | 29 | 40 | 36 | 37 | 31 | 33 |
| **Jacob** | 30 | 43 | 35 | 40 | 38 | 40 |
| **Aggregate** | 154 | 207 | 190 | 194 | 188 | 205 |

*Figure 6 | The master Decision Matrix with score totals. The "Delay App" idea has the highest score at 207.*

Ultimately, the team decided to move forward with the second place "Ticket Modification" idea, despite the two point difference from the delay app. It was decided that an app that gave TSA wait line times and warned users about delays did not distinguish itself enough from the already-existing MyTSA app. App implementation would be more difficult to reach stakeholders of elderly passengers and regular fliers, as they would not be incentivized or able to download and fully utilize the product. Furthermore, the team wanted to push for an innovative idea and determined that the "Ticket Modification" would be easier to implement as it was more unique with less competition. The idea to algorithmically determine when passengers should arrive based on demand forecasting seemed more feasible and more innovative.

### 4.6 Rapid Prototyping

The main goal of the team's rapid prototyping phase was to experimentally determine the efficacy of various systematic solutions for data-sharing and day-to-day demand forecasting. Having selected ticket arrival time manipulation as the chosen solution, the immediate goal was to integrate it with a back-end system that would securely share data and algorithmically distribute arrival times for minimal queueing delay.

The first drafts of this system were done on pen and paper during a team meeting, considering various aspects of both the status quo and intended application of data-sharing across agencies and through a centralized system. The team developed these into diagrams (shown below).


*Figure 7 | A diagram of the status quo shows the limited interaction across groups, failing to leverage the capability of an airport environment to provide highly accurate data about its anticipated throughput and arrival times.*

A draft of a diagram for the final system introduces an optimal arrival time distribution system for collecting shared data, calculating optimal arrival times, and distributing these times to airlines. Eventually, these optimal arrival times would be shared with customers who arrive at a distribution centered around the scheduled time with some shape and noise.

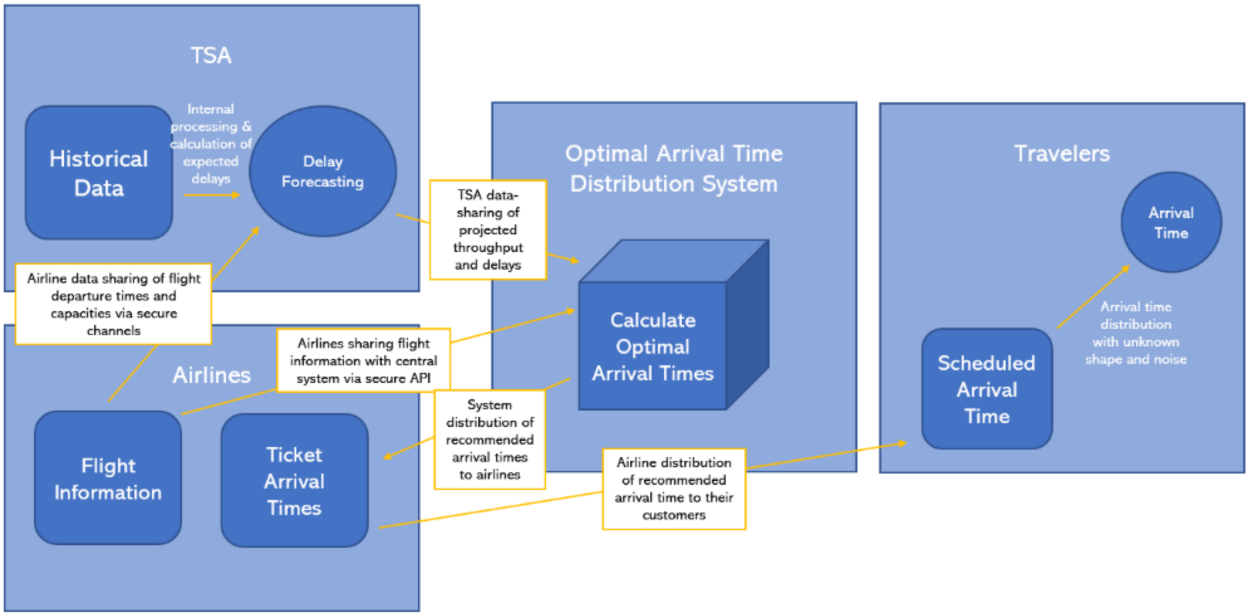


*Figure 8 | A draft of a diagram for the final system shows heavily increased interaction among the stakeholders.*

## 5. Design Solution

The objective of the final prototype is to demonstrate the viability and quantifiable benefit of implementing a centralized system for data-sharing and providing ticket arrival times to airline passengers. This prototype consists of a simulation to allow the dynamic testing of parameters and possible algorithms for ticket arrival time manipulation and to generate metrics advertising the success of this type of system. It also includes a mockup of a ticket that would be presented to an end user by an airline.

### 5.1 Customer Experience

A key component of a system for ticket arrival time modification would include the user-facing aspect. In such a system, a traveler would receive a recommended arrival time when their flight departure and boarding time are communicated to them. This time could also be communicated at the time that a traveler's flight might change gates or departure times prior to their arrival at the airport. In order to demonstrate this updated communication, the team mocked a communication that might be sent from an airline to their passenger as seen below.


*Figure 9 | A sample of a communication a traveler might receive from an airline prior to their date of departure.*

As an element of human behavior, it is clear to understand that not every passenger would willingly adapt a new arrival time. This inconsistency is reflected in the implementation of the solution below.

### 5.2 Passenger Data

In order to construct an accurate simulation of status quo behavior a variety of data was collected. First, the team sought to statistically model current passenger arrival behavior. Passenger arrival time is assumed to be normally distributed. Referencing a set of travel articles, the team concluded that a traveler is recommended to arrive two hours before flight departure on average and cannot arrive later than 45 minutes before departure in order to check bags with an airline (Jordan, 2014 & Elliot, 2017 & Serdengecti, 2021). The team did not distinguish between behavior for domestic and international flights.

Let 45 minutes represent $\mu - 2\sigma$ so that 2.27% of travelers are late for their flight. With $\mu = 120$ minutes, the team concluded a normal distribution of arrival with $\sigma = 37.5$ minutes. Some sample assumptions for this arrival distribution are included below:

1. 2.27% of travelers are late
2. 68.26% of travelers arrive between 82.5 minutes and 157.2 minutes before departure
5. 15.85% of travelers arrive more than 157.5 minutes before their flight departure

To classify different individual passenger behaviors in a simulation given the above arrival time assumptions, the team referenced passenger type frequency from the New York & New Jersey Port Authority report of Newark Liberty International Airport traffic from February 2022. The team then calculated generative frequencies using weighted probabilities of annual flight frequencies by casual passenger type. This results in ranges of the normal random variable for airport arrival time based on cumulative probability expected under the assumed arrival time distribution for given passenger types. The team assumes business traveling to be a dominant behavior when predicting arrivals given that the report did not distinguish flight frequency by trip type.

| **Traveler Type** | Business | 1-2 Annual Flights | 3-5 Annual Flights | 6-10 Annual Flights | 11+ Annual Flights |
|---|---|---|---|---|---|
| **Reported Frequency** | 17.4% | 56.6% | 26.3% | 10.8% | 6.3% |
| **Generative Frequency** | 17.4% | 46.8% | 21.7% | 8.9% | 5.2% |
| **Normal RV Range** | 79.656-101.935 | 123.011-235.884 | 101.935-123.011 | 59.034-79.656 | 0-59.034 |
| **3D Model** |  |  |  |  |  |

### 5.3 Flight Data

Given its geographic proximity to the team and status as holding the worst average TSA security wait time, according to an assessment from Upgraded Points (2018), the team chose to use data from Newark Liberty International Airport in the initial simulation. The team collected flight data from the unofficial Newark Liberty International Airport guide which provided a greater scope of flight information than the Newark Airport's official flight tracker (*Departures from Newark Airport*, 2022). In order to contain the scope and number of parameters of the simulation, the team chose four of Newark airport's five biggest airlines which were dominantly represented on the initial chosen day, Tuesday, April 05, 2022. These airlines included Delta, American, United, and JetBlue, and recorded flight information ranged from 6:00AM to 4:00PM. The simulation could then run from 4:00AM to 4:00PM, a busy 12-hour span, with room for passengers to arrive for the first scheduled flights. This was aggregated by the team into a comma-separated values sheet as pictured below. In total, the team sampled 317 flights.

```
Airline,Time,Destination
Delta,6:00,ATL
American,6:00,CLT
Delta,6:00,DTW
United,6:00,IAD
JetBlue,6:00,CLT
United,6:00,DCA
JetBlue,6:00,SJU
United,6:00,YYZ
American,6:05,PHX
```

*Figure 10 | A sample of the comma separated values representing flight data recorded by the team.*

In order to determine approximate capacities, the team referenced United Airlines' official fleet, as the largest commercial airline operating out of Newark Liberty International airport (*T*he Port Authority of NY/NJ, 2022). Their fleet consists of primarily Airbus A319-100, Airbus A320-200, Boeing 737-800, and Boeing 737-900ER with capacities of 126-150 passengers and 126-179 passengers respectively (*United Airlines Fleet Information*, 2022). For this reason, the team chose an average flight capacity of 150 passengers. Due to computational constraints, the team let an individual simulated passenger represent 15 individuals of a given type so that 10 individuals are generated and simulated for each flight. For the 317 flights sampled, the simulation then processes 3170 individual travelers.

## 5.4 TSA Data

In order to approximate status quo delays and predict staffing of TSO's, the team referenced data available through the MyTSA mobile application and publicly available endpoints from the Data.gov TSA security checkpoint wait times API (Department of Homeland Security, 2022). The team referenced these delay times for Tuesday, April 05 and used them to make TSA staffing decisions.

In order to accurately represent improvements in TSA staffing allocations, the team constrained the simulated TSA to staff only 24 aggregate hours in the 12 hour simulation window. The following pseudocode represents the decision-making performed by the simulated TSA.

```
Assign 1 hour to each of the 12 hour windows
Hours remaining = 12
While(some hours remain)
    Select highest forecasted hour
    Assign 1 hour of working time to that window
    Cut forecast for that hour in half
Return hours assignment
```

### 5.5 Processing and Parameters

The simulated environment consists of three stages of processing.

Individuals first wait in line at the check-in booth for the airline corresponding to their specific flight. These queue times may be different for each of the four airlines.

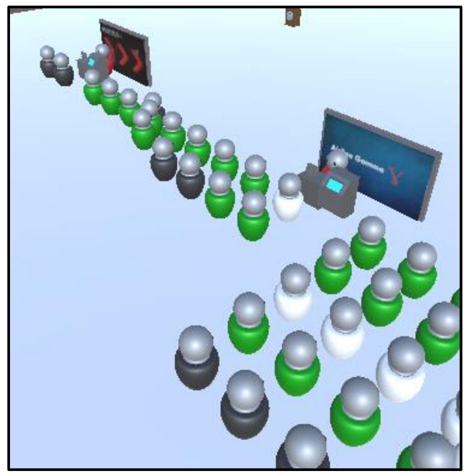

*Figure 11 | 3D models demonstrating congestion and queueing at an airline check-in*

Individuals then move to wait in line for TSA document processing, which would indicate the stage where a TSO reviews a boarding pass and form of identification.

Individuals finally move to a baggage processing queue which is where their bags would be scanned and they are able to advance into the sterile area and terminal.

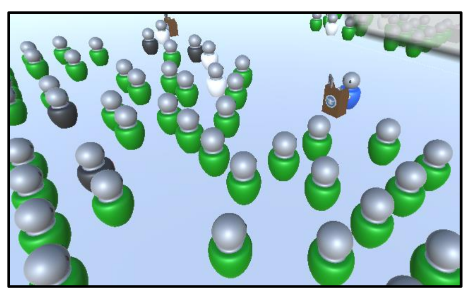

*Figure 12 | 3D models demonstrating congestion and queueing at a TSA document-processing checkpoint.*

The simulation user is able to configure parameters for the time required for each of these stages. These parameters represent the time it takes a given station to process fifteen individuals in minutes.

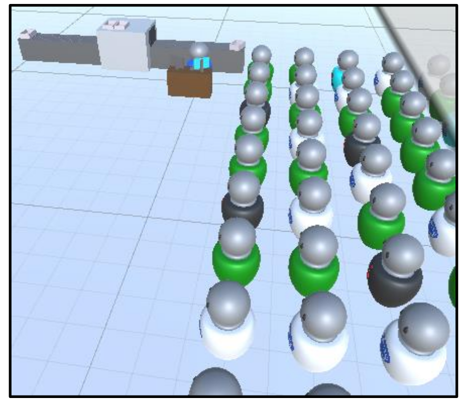

*Figure 13 | 3D models demonstrating congestion and queueing at a TSA baggage-processing checkpoint.*

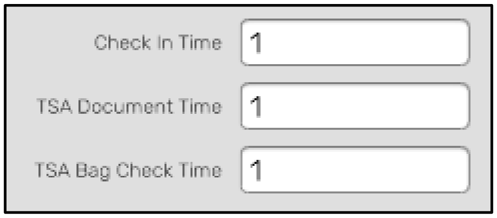


*Figure 14 | The graphical user interface (GUI) for configuring simulation parameters.*

This interface also includes a display listing upcoming flights with their time, airline, and destination. The simulation runs on a configurable simulation time which is mapped to a real-time with flight information. The user can adjust the simulation speed via a slider on the interface.

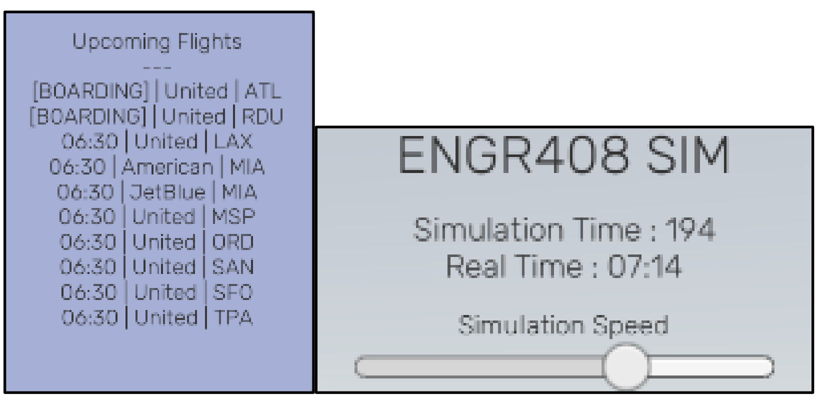


*Figure 15 | Graphical user interfaces for upcoming flights and configuring simulation speed.*

The metrics for the simulation's results are provided in a user interface window present along the righthand side of the simulation and dynamically updated as the simulation progresses. The primary performance indicators are average and median delay and average time spent at the gate.

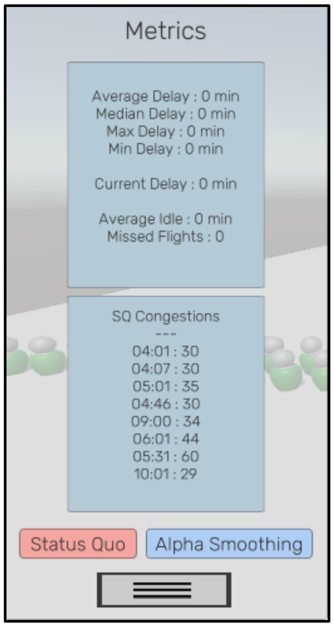


*Figure 16 | Graphical user interface demonstrating metrics for delay and congestion in the simulation.*

### 5.6 Implementation Details

The simulation offers two key modes of operation: the status quo and ticket arrival time manipulation. During status quo operation, passengers arrive according to the assumed normal distribution and the simulated TSA makes staffing decisions by referencing historical data. The following density of arrivals is observed over the course of the simulation.

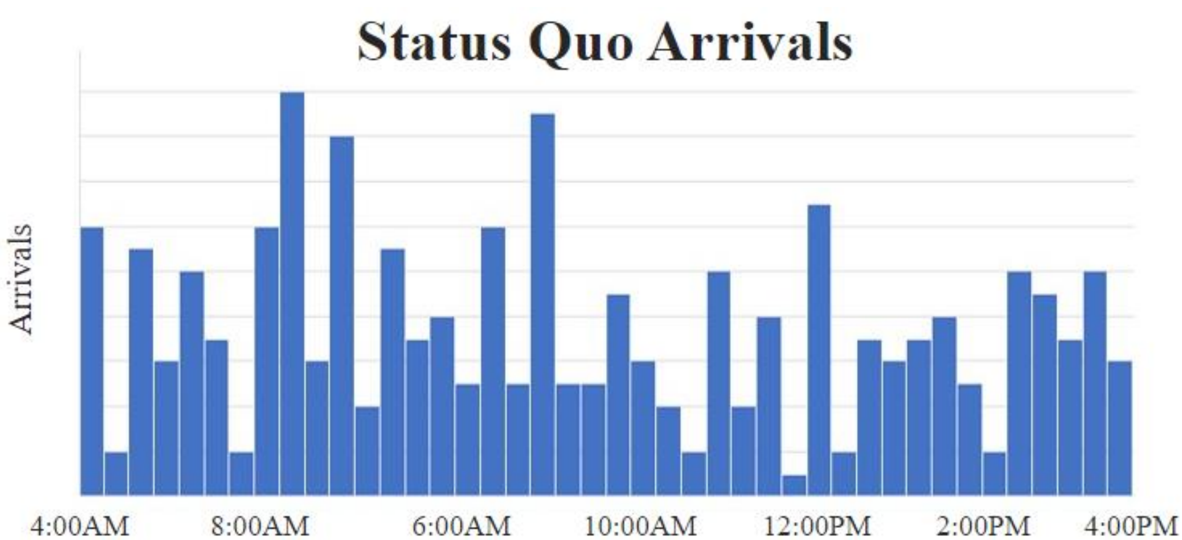


*Figure 17 | Arrival density over the course of a status quo simulation.*

After simulating the status quo behavior, the team then applies the ticket arrival time manipulation. This first involves algorithmically flattening the arrival density distribution by adjusting passenger arrival times using the following code:

```
private void smoothArrivalTimesAlpha(){
    // Smoothing parameters
    float smoothingPercentage = 0.25f;
    int iterations = 50;
    int range = 3;

    // Smooth in iterations
    for(int i = 0; i < iterations; i ++){
        // Retrieve max arrival PD
        (int Index, int Value) pdf = calculateArrivalSolutionProbabilityDensity(range);

        Debug.Log("Max Ind " + simulationTimeToRealtime(pdf.Index) + " with " + pdf.Value);

        // Sort travelers arriving at this time by departure time
        arrivalsSolution[pdf.Index].Sort(delegate(Traveler a, Traveler b){
            if(a.departure < b.departure){
                return -1;
            }
            else if(a.departure > b.departure){
                return 1;
            }
            else{
                return 0;
            }
        });

        // Adjust passenger arrival times
        int adjustment = (int)(smoothingPercentage * pdf.Value);
        for(int j = 0; j < adjustment; j += 2){
            if(arrivalsSolution[pdf.Index - (j % range) + 1] is null){
                arrivalsSolution[pdf.Index - (j % range) + 1] = new List<Traveler>();
            }
            arrivalsSolution[pdf.Index - (j % range) + 1].Add(arrivalsSolution[pdf.Index][0]);
            arrivalsSolution[pdf.Index].RemoveAt(0);
            if(arrivalsSolution[pdf.Index + (j % range) + 1] is null){
                arrivalsSolution[pdf.Index + (j % range) + 1] = new List<Traveler>();
            }
            arrivalsSolution[pdf.Index + (j % range) + 1].Add(arrivalsSolution[pdf.Index][arrivalsSolution[pdf.Index].Count - 1]);
            arrivalsSolution[pdf.Index].RemoveAt(arrivalsSolution[pdf.Index].Count - 1);
        }
    }
}
```

```
private (int Index, int Value) calculateArrivalSolutionProbabilityDensity(int range){
    int maxValue = 0;
    int maxIndex = -1;
    for(int i = range; i < arrivalsSolution.Length - range; i ++){
        if(getArrivalProbabilityDensity(arrivalsSolution[i]) > maxValue){
            maxValue = getArrivalProbabilityDensity(arrivalsSolution[i]);
            maxIndex = i;
        }
    }
    return (Index: maxIndex, Value: maxValue);
}

private int getArrivalProbabilityDensity(List<Traveler> tList){
    if(tList is null){
        return 0;
    }
    else{
        return tList.Count;
    }
}
```

*Figure 18 | Program to flatten arrival times, parametrized by a number of iterations, amount of smoothing, and range to distribute times across.*

After programmatically adjusting the arrival times, the following updated arrival density function reflect a less noisy arrival rate.

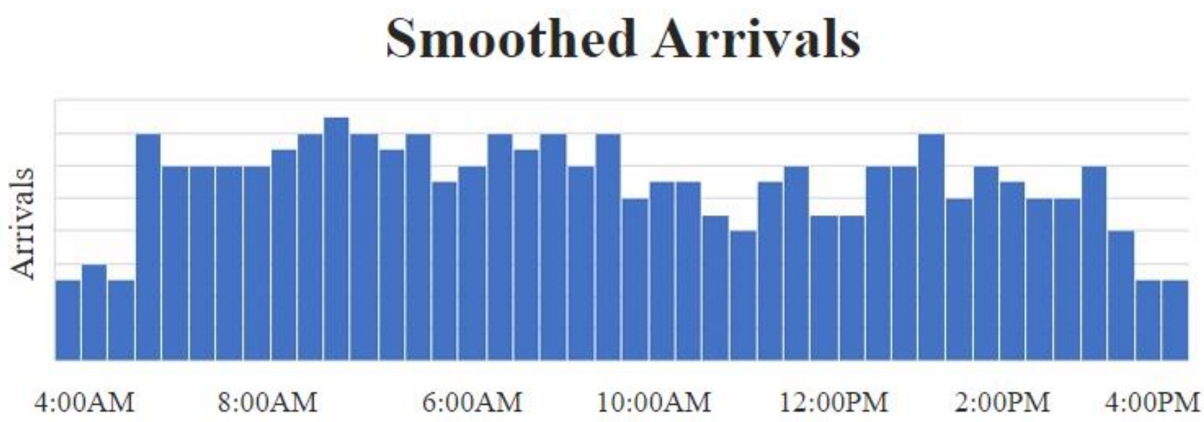


*Figure 19 | Arrival density assuming behavior according to assigned arrival times over the course of a simulation.*

To finally simulate the updated behavior, the team applies two distinct changes. Individuals are given a random chance to prefer their assigned arrival time over their assumed status quo arrival time. This randomly ranges from 25% compliance to 75% compliance. The simulated TSA is also allowed to change their staffing decisions – subject to the same constraint on aggregate hours – after being provided the assigned arrival times. This replaces the historical data referenced by the simulated TSA in the above pseudocode.

### 5.7 Results

A final implementation of the delay simulation including a variety of 3D assets produced by the team is shown below.

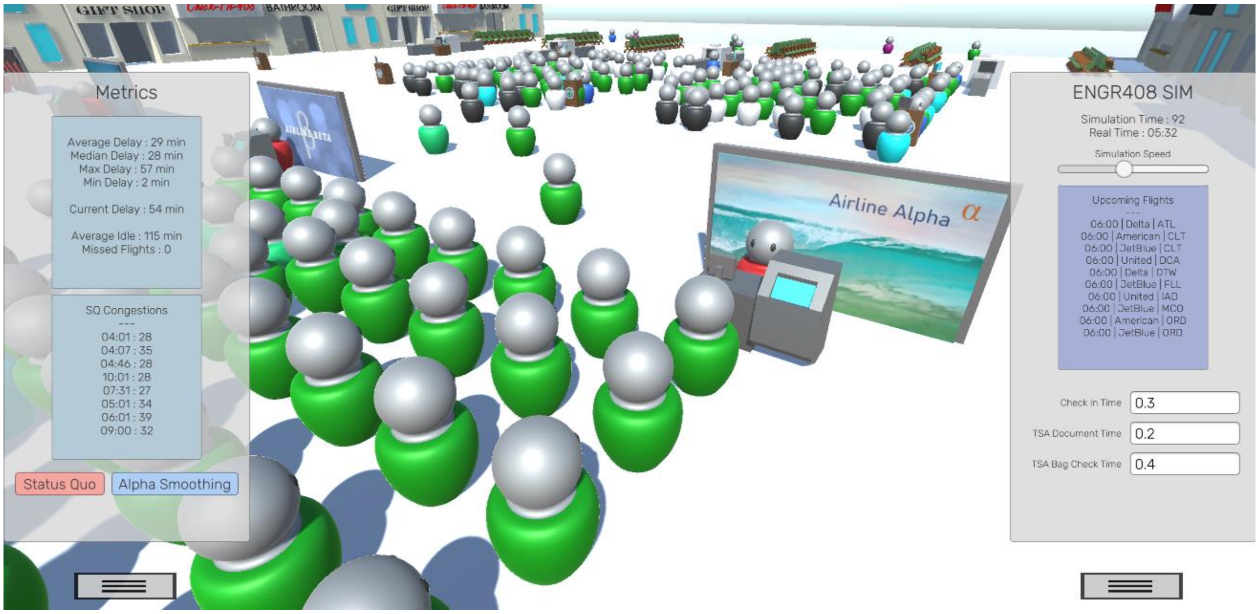


*Figure 20 | Simulated travelers wait at an airline check-in while GUI components show parameters and metrics along the sides of the simulation window.*

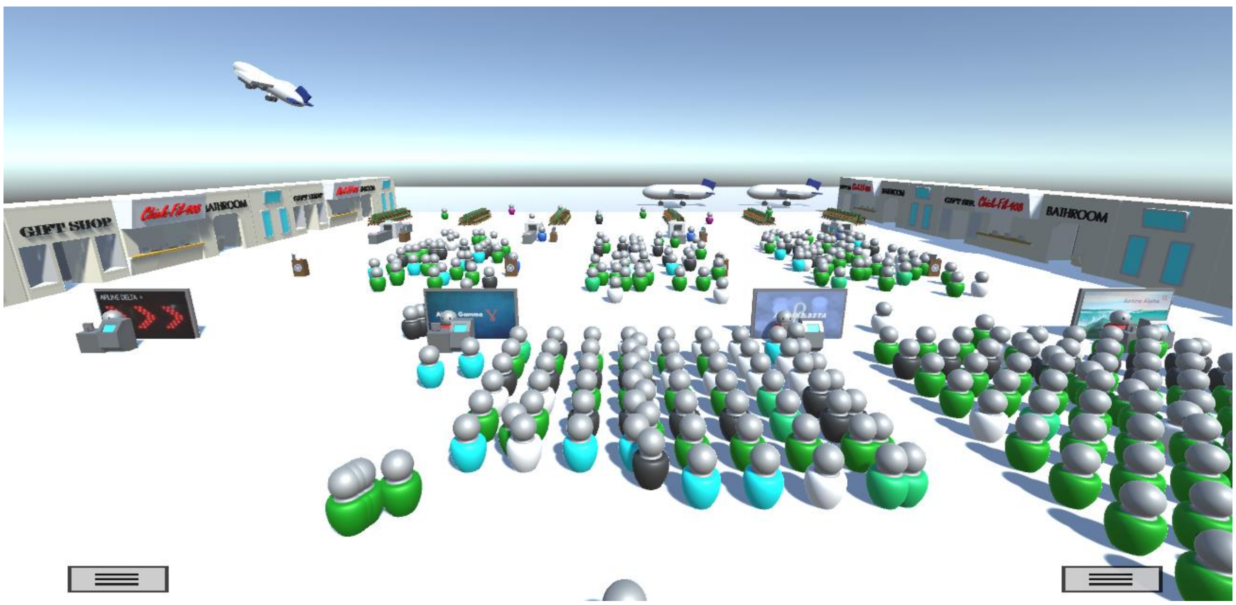


*Figure 21 | A point in time where the TSA has chosen to staff 3 of the 4 available stations.*

While it is difficult to choose a set of parameters that accurately reflect the delays experienced at each of the three stations, it is possible to simulate many times over many sets of parameter values and compare the improvements between the status quo for arrivals against the ticket modification solution with data sharing. The team ran the simulation three times for each method for each of three sets of parameters. The results are reflected in the tables below, where parameter values represent the times for airline check-in, document processing, and baggage processing respectively.

| **Status Quo Arrival** | | | |
|---|---|---|---|
| **Parameter Values** | 0.2 / 0.3 / 0.4 | 0.1 / 0.1 / 0.3 | 0.05 / 0.1 / 0.2 |
| **Avg. Mean Delay** (minutes) | 197 | 177 | 41 |
| **Avg. Median Delay** (minutes) | 103 | 113 | 29 |

| **Ticket Arrival Time Modification** | | | |
|---|---|---|---|
| **Parameter Values** | 0.2 / 0.3 / 0.4 | 0.1 / 0.1 / 0.3 | 0.05 / 0.1 / 0.2 |
| **Avg. Mean Delay** (minutes) | 147 | 150 | 9 |
| **Avg. Median Delay** (minutes) | 76 | 81 | 20 |

Synthesizing the reduction in delay over each parameter set, each of which is run for three trials for each method, the following conclusions can be drawn.

1. The solution reduced average queueing delay from 138 minutes to 102 minutes.
2. The solution reduced median queueing delay from 82 minutes to 59 minutes.
3. The solution reduced average queueing delay by **36 minutes** or **26.09%**.
4. The solution reduced median queueing delay by **23 minutes** or **28.05%**.
5. The solution increased time spent at the gate by **11 minutes** or **36.67%**.

While a small sample size and unpredictable variables constitute challenges to the accuracy of these results, they nevertheless demonstrate a substantial improvement over current methods for data sharing and demand forecasting. The average simulated traveler could spend almost 20 minutes less at the airport overall while spending much more of their time enjoying concessions at the gate and less of it waiting in line in high-congestion areas.

# 6. Project Impacts

## 6.1 Safety and Risk Analysis

The table below details key hazards ranging in severity and likelihood associated with the proposed solution for improving airport efficiency, including cybersecurity and delays.

| Hazards | Likelihood | Severity | Mitigation | Result |
|---|---|---|---|---|
| Cybersecurity attacks compromising the integrity of SSI data stored in data-sharing systems | Remote (C) | Hazardous (2) | Employ state-of-the art practices for encryption and data security, frequently push software updates, upgrade hardware, and maintain a team to monitor the integrity of the system | C2 -> E2 |
| Systematic failure of arrival time system results in erroneous arrival times, major congestion and delays | Extremely Remote (D) | Catastrophic (1) | Implement safe-checking mechanisms constraining the assigned arrival times on tickets with rule-based filters, limit potential congestion of system failure to the worst-case of the status quo | D1 -> E3 |
| Delays/systematic failure in time taken to send out tickets through email server | Extremely Remote (D) | Major (3) | Send out ticket notifications via email at least three days in advance and a confirmation ticket the day of if an updated time is needed | D3 -> E2 |
| Patrons arriving earlier/later than expected due to ticket modification, resulting in congestion and increasing safety risks | Probable (B) | Minor (4) | System simulation and times will be modified as they are used in the market to best adjust and flatten the curve of arrival times | B4 -> D4 |

| | | | | |
|---|---|---|---|---|
| System crashing and/or minor bugs that cause operational delays | Probable (B) | Minimal (5) | System updates prioritized and automatically installed on users' computer | B5-> C5 |
| Passengers travelling together (families, corporate groups, etc.) given different arrival times by the system | Remote (C) | Minimal (5) | Use user data to identify and keep groups of passengers linked as directed to maximize efficiency | C5->D5 |

**6.2 Financial Assessment**

A majority of project costs come from development of the simulation and algorithm, which is projected to take a team of 12 experienced programmers six months for initial release.

| **Project Operation Cost of Ticket Modification** | | | | |
|---|---|---|---|---|
| **Item** | **Rate** | **Quantity** | **Subtotal** | **Notes** |
| Simulation/ Database Updates | $35 / hr | 260 hrs | $9,100 | Cost for mid-level programmer to update and increase accuracy of simulation |
| Training for Airport Managers (*Airport Manager* Salary, 2022) | $35 / hr | 100 hrs | $3,500 | Cost to train airport managers how to integrate and problem-solve the system |
| AWS EC2 Compute Costs (*Amazon EC2 On-Demand Pricing*, 2022) | $0.09 / GB | 16,000 GB | $1,440 | Each of 80 million annual travelers generating 200 Kb of data |
| Recurring year subtotal | | | $14,040 | Per Year |
| Year 2-10 Subtotal | | | $126,360 | Recurring year subtotal multiplied by 9 |
| **Construction and Implementation Cost** | | | **$96,000** | Project implementation cost |
| **Development Project Preparation Cost** | | | **$357,520** | Project preparation cost |

| | | | | |
|---|---|---|---|---|
| **Concept Development Cost** | | | **$5,500** | Concept development cost |
| **10 Year Total Cost** | | | **$599,420** | Total 10-year cost |

With managers having access to a simulation accurately displaying capacity, they will optimize staffing. Additionally, the decreased time in terminal will result in more spending at concessions.

| **Tangible Benefits: Revenue Generation** | | | | |
|---|---|---|---|---|
| **Item** | **Rate** | **Quantity** | **Subtotal** | **Notes** |
| Employee Savings (*TSO Salary*, 2022) | $28 | 1460 | $40,880 | Cost saved through not over-staffing TSO's (estimated that a four-hour shift worth of time is saved daily) |
| Food Service Revenue (Ma, 2019) | $1 | 50,000 | $50,000 | Projected with 5% of 1,000,000 yearly tenants at a medium-sized airport spending an additional $10 at concessions. Assume airport retain 10% of the profit. |
| **Year 1 Subtotal** | | | **$90,880** | |
| **10 Year Subtotal Benefit** | | | **$908,800** | Year 1 multiplied by 10 |

The savings overcome initial cost of $459,020 and annual operating costs of $14,040 in 6 years.

| **Benefit to Cost Ratio** | | |
|---|---|---|
| **Item** | **Subtotal** | **Notes** |
| 10 Year Total Benefit | $908,800 | Year 1 multiplied by 10 |
| 10 Year Total Cost | $599,420 | Includes concept, project development, implementation, and operation cost |
| **Benefit Ratio** | **1.52** | 10-year total benefit divided by 10-year total cost |

**6.3 Feasibility and Future Development**

In order to feasibly implement the system for data-sharing and ticket arrival time manipulation, funding would likely need to come from the Department of Homeland Security or the Department of Transportation who would then maintain the system. In either case, the cost of the project detailed above represents a small fraction of the $134,492,000 2022 TSA discretionary operations budget or the $35,532,000 2022 TSA research and development budget (Department of Homeland Security, 2022).

In a phased implementation timeline, development of the system would first involve developing and maintaining a simulation of airport arrivals in order to test and examine the effects of different systems on the airport ecosystem. This would include performing enhanced statistics to optimize the distribution of arrival times and to increase the accuracy of human behavior from the simulations performed by the student team.

Having decided on a specific programmatic implementation, the sponsoring agency would have to implement a production-level system in a secure environment and expose outgoing application programming interfaces (API's) for airlines to interact with. This central database would have to undergo thorough penetration testing to ensure its security; this entire process might be expedited by using tools offered specifically for the development of Government services.

Once a central data system is running at a production-level, the Transportation Security Administration would need to implement a user-facing front end application which provides information about upcoming arrival times to managers in charge of staffing decisions and resource allocation. This front end should effectively communicate the comprehensive data in a digestible way such that the human-in-the-loop, the TSO's and managers, are able to make accurate and effective decisions based on the information made available.

Finally, airlines would need to integrate with the API to send their flight schedules and receive suggested arrival times. While most airlines retain an internal workforce of software development teams, this represents a substantial effort. Encouraging airlines to integrate with the system also poses a political challenge, given the critical mass necessary to achieve high performance of the arrival time manipulation system. This might be encouraged through policy change that either mandates or subsidizes the cost of implementing an integration with the central API. At the very least, airlines could be required to send their schedules and flight changes directly to the system, in order to make accurate approximations of arrival density and adjust the participating airlines' passenger information accordingly.

Once airlines integrate with the system, they will receive back suggested arrival times for the anticipated number of passengers on each reported flight. The airline may choose whether they actually want to communicate this information to their customers, although they should be encouraged to do so. This also represents a phase in the development process where the front-end developers retained by airlines rollout modifications to the way that they are communicating with their customers. Once this system has been successfully implemented, the timeline is complete. Passengers could expect to have significantly reduced queueing times, and the TSA would have highly accurate predictive information available on a day-to-day basis. Holistically, the traveler's experience is improved, and the airport environment is safer.

# Appendix A

*Contact Information*

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# Appendix B

Penn State University is an institution of higher education in Pennsylvania. It houses the college of engineering which includes numerous engineering degrees at both the undergraduate and graduate levels. The college of engineering supports an undergraduate minor in engineering leadership in which undergraduate engineers can build the non-technical skills to support the great technical skills they are developing through their engineering curriculum. The engineering leadership development program offers students classes in project management, leadership education and development, business basics, and cross-cultural teaming. Students in the minor are dedicated to building these skills in addition to the technical workload required of their discipline's curriculum. The engineering leadership program also offers a graduate program in the form of a Master of Engineering and an online graduate certificate in Engineering Leadership and Innovation Management.

# Appendix C

*Industry Contacts & Airport Operators*

To gain a deeper understanding of the design challenge and the airport industry, the team consulted with Dr. I. Richmond Nettey, an airport management consultant and professor at Kent State University, and Mr. Felipe Rodriguez, a professor at the University of Maryland Eastern Shore. The team had routine meetings with these industry experts via Zoom throughout the semester. Using their knowledge and experiences, the team was able to create a solution that was both innovative and viable to implement with current airport infrastructure.

# Appendix E

*Evaluation of Educational Experience*

*Student*

1. Did the Airport Cooperative Research Program (ACRP) University Design Competition for Addressing Airports Needs provide a meaningful learning experience for you? Why or why not?

The ACRP University Design Competition did provide a meaningful experience by facilitating professional communication between our team and industry experts, serving as an opportunity to practice the engineering design process, and allowing us to generate a practical solution to a critical problem.

2. What challenges did you and/or your team encounter in undertaking the competition? How did you overcome them?

Our team faced challenges related to the feasibility and implementation of our solution. It was important to us that we created a prototype that was not only statistically accurate and useful, but able to be realistically implemented. We addressed these concerns by setting up multiple meetings with a variety of stakeholders, and creating two versions of our prototype that proved the increase in efficiency our solution provided quantitatively. We were also able to face challenges related to the assumptions we made by using historical data to drive the simulation and establish realistic parameters.

3. Describe the process you or your team used for developing your hypothesis.

Our team developed our hypothesis by first carefully assessing which research area and subsection we wanted to pursue in a democratic, open manner. Once the research area was chosen, our team then delegated out different avenues we wanted to explore and did background research on each of the specific options. After, we each presented our findings and selected the option that resonated the most with everyone. Finally, we used the background knowledge we previously acquired to develop a meaningful hypothesis about our design problem.

4. Was participation by industry in the project appropriate, meaningful and useful? Why or why not?

Yes, consistent communication with industry experts was essential for determining how to approach the concept generation, selection, and prototyping phase. Industry experts functioned as a large assert in terms of ensuring our solution remained practical, useful, and implementable.

5. What did you learn? Did this project help you with skills and knowledge you need to be successful for entry in the workforce or to pursue further study? Why or why not?

Our group learned about delegation, effective communication, project management, and problem solving. The leadership and management skills of each team member grew exponentially through the course of this project, and practical knowledge about creating Gantt charts, cost benefit analysis, and risk management set each individual up to be successful in a workforce environment.

*Faculty*

l. Describe the value of the educational experience for your student(s) participating in this competition submission.

Students in our leadership course are learning how to lead within the engineering context. This project provides an exceptional and organized experience for our engineering students to apply the knowledge and their personal leadership style as they lead their teams throughout the semester. The challenges provided mimic a real-world experience giving students an opportunity to practice both technical and non-technical problem-solving skills.

2. Was the learning experience appropriate to the course level or context in which the competition was undertaken?

Yes, the learning experience was appropriate for the level of our students and fit within the context of our learning environment, per the note above.

3. What challenges did the students face and overcome?

Students faced some challenges getting in touch with experts and through that learned how important it is to talk with the "user" in order to come up with the best solution. Some students tried to jump ahead to the solution and not work through the design process to use all the information gathered in order to come up with a creative solution. They learned that user-centered research is important when coming up with solutions to challenges.

4. Would you use this competition as an educational vehicle in the future? Why or why not?

We have used this competition as an educational vehicle for the past several years. The competition structure allows us to combine innovative project development via the 5-stage design process while giving student teams opportunities to learn about leadership.

5. Are there changes to the competition that you would suggest for future years?

Yes. We plan to continue to use it based on the organization, the well thought out options for projects, the support, and the industry contacts. Making some of the appendices into an online form would be helpful, and perhaps allowing for one submission of some appendices if a group is turning in multiple projects.

# Appendix F

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