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**2017**
**MCM/ICM**
**Summary Sheet**

# Time Flies


To reduce airport security wait times, with little expenses, a new model was generated for customer satisfaction. Both a mathematical model and "zone" model was created. The new model focuses on improving the efficiency by grouping together similar travel styles rather than the current model, which simply attempts to hire additional staff to improve passenger throughput. This new model also minimizes the expenses for The United States Transportation Security Agency (TSA). The modifications made are: one, security lanes are categorized into Rewards Members, Special Needs/Children, Express, and Overflow; two, security officers receive specialized training and work in security lane best fit for them; three, fingerprint technology is implemented in the Rewards Members lane. A simulation was conducted for the current and improved model.

With the improved model, cultural differences were considered and thus security lanes can be modified to accommodate specific travel style demands in various destinations. The strengths and weaknesses were established for the benefit of both customer and employee satisfaction. The new model improves the flow of traffic through categorization and not technology, further technological advancements can be made to increase customer throughput further.

# Contents

# 1. Introduction

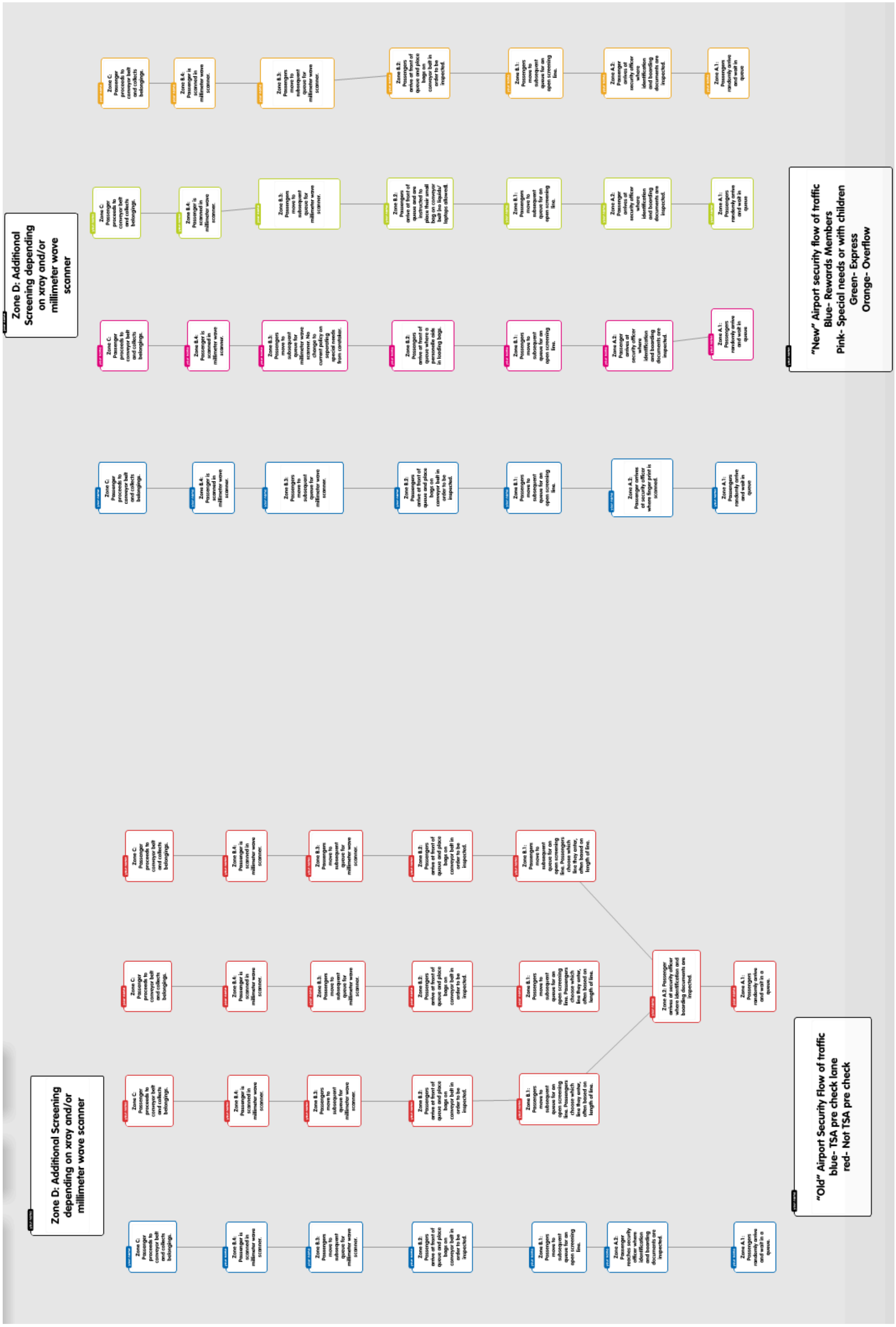
## 1.1 Context

The United States Transportation Security Agency (TSA) has potential to improve their methods in customer satisfaction while managing safety and security. In *plane* terms, determine the issues affiliated with airport security checkpoints, along with, allowing passengers to proceed to their destination with reduced variance in wait time. The objectives include the following:

- Develop a model or multiple models of the current flow of passengers and identify bottlenecks where problems occur.
- Construct at least two improved models and describe how the changes affect the current process.
- Consider how different cultural aspects influence the improved model and how the improved model allows for these cultural aspects.
- Globally or specially, recommend a policy for the security managers associated with the improved model.
- Finally, discuss strengths and weaknesses in the suggested model, and introduce plans for enhancement.

## 1.2 Our Work

The "old" and "new" traffic flow models are depicted below. The concept of change made from the "old" model to the "new" model is categorization of customers and employees. Where the "old" model depicts two types of travelers (precheck or not pre-check), the "new" model organizes security lanes based off travel styles and demographics of the airport. The model is simply a representation of these new security lanes, the number of lanes depends on the demand of types of travelers.


Zone D: Additional Screening depending on xray and/or millimeter wave scanner
"New" Airport security flow of traffic
Blue- Rewards Members
Pink- Special needs or with children
Green- Express
Orange- Overflow
Zone D: Additional Screening depending on xray and/or millimeter wave scanner
"Old" Airport Security Flow of traffic
blue- TSA pre check lane
red- Not TSA pre check

## 2. Assumptions

The following are the assumptions that were accounted for before initiating the project. The data provided is reliable and was collected in a proper manner.

- The data provided was not gathered during a time which would not apply to a random day - for example, a holiday where the data would change drastically.
- All United States airports use or will use TSA Pre.
- Most passengers are not going to be rechecked.

## 3. Current Model

### 3.1 Development

The principles of queueing theory were used to develop the model of the current process. The TSA security checkpoint is, in layman's terms, a First-in, First-out (FIFO) queue where passengers enter a line, are served by a TSA officer, enter another line, are served by another officer, and so on until they have been sufficiently screened and can exit the screening area. As stated in (source), the time intervals between successive customer arrivals can be modeled by sampling times from a specified probability density function. The same can be said of the length of time it takes each customer to be served: it can be modeled by sampling times from a specified probability density function, often assumed to be exponential.

The provided data included arrival timestamps for both TSA Precheck passengers and regular passengers. The data also showed four types of screening processes that passengers must go through at the TSA security checkpoint: ID check process, millimeter wave scan, x-ray scan of personal items, and collection of scanned property. Using the R programming language, a script was written to analyze each column and fit it to a probability density function. Since some columns were timestamps and some were lengths of time, the script loops through the data to parse it into a uniform format of seconds, then find the difference between successive passengers for those columns whose data type were timestamps (TSA precheck arrival time, regular passenger arrival time, millimeter wave scan time, and x-ray scan time). Next, R was used to compare the lengths of time in each column to several continuous probability density functions: Normal, Lognormal, Exponential, Logistic, Weibull, Cauchy, Gamma, and Student's t. The algorithm uses the fitdist function from the fitdistrplus package to find a maximum likelihood estimation (MLE) of the parameters of each distribution. For example, it would estimate the population mean and standard deviation that would be used to generate a normal probability distribution. Next, the algorithm tests the likelihood that the data points from a given column come from the generated distribution using the Kolmogorov-Smirnov goodness of fit test. The Kolmogorov-Smirnov goodness of fit test was chosen over a Chi-Square goodness of fit test, because it is more powerful when the sample size is not large, as is the case with the provided data. The algorithm uses the ks.test function from the main stats package to run the Kolmogorov-Smirnov test and outputs a p-value. If the p-value was less than the widely accepted α level of 0.05, indicating that the alternative hypothesis that the provided data did not come from the generated distribution and was rejected, the empirical and theoretical CDF plot, empirical and theoretical density plot, Quantile-Quantile plot, and Probability-Probability plot was examined for a visual match (see below for examples). For every category except X-ray scan interval times, there was more than one probability density function for which $p < \alpha$, and so the probability density functions for our model based on visual inspections was chosen. Each of the chosen probability density functions is shown below.

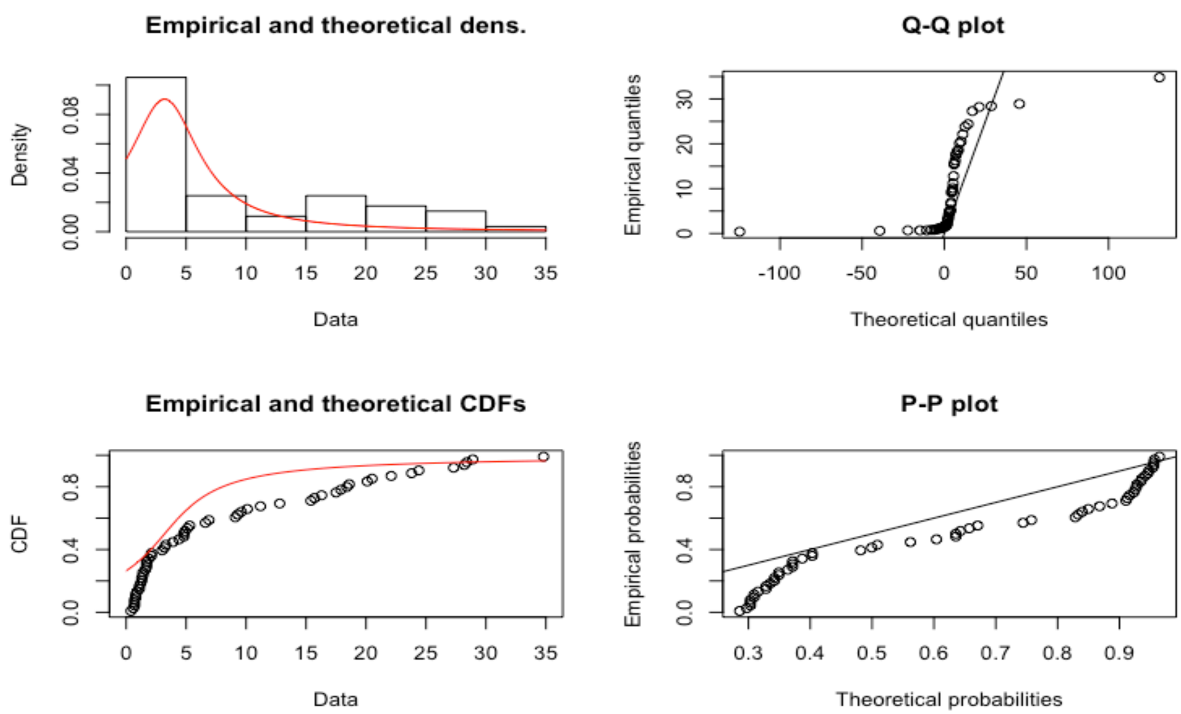



*Figure 1: Cauchy Distribution Fit for TSA Precheck Passenger Arrival Intervals, p = 0.01939, cauchy distribution parameters: m = 3.205467, gamma = 3.521331*

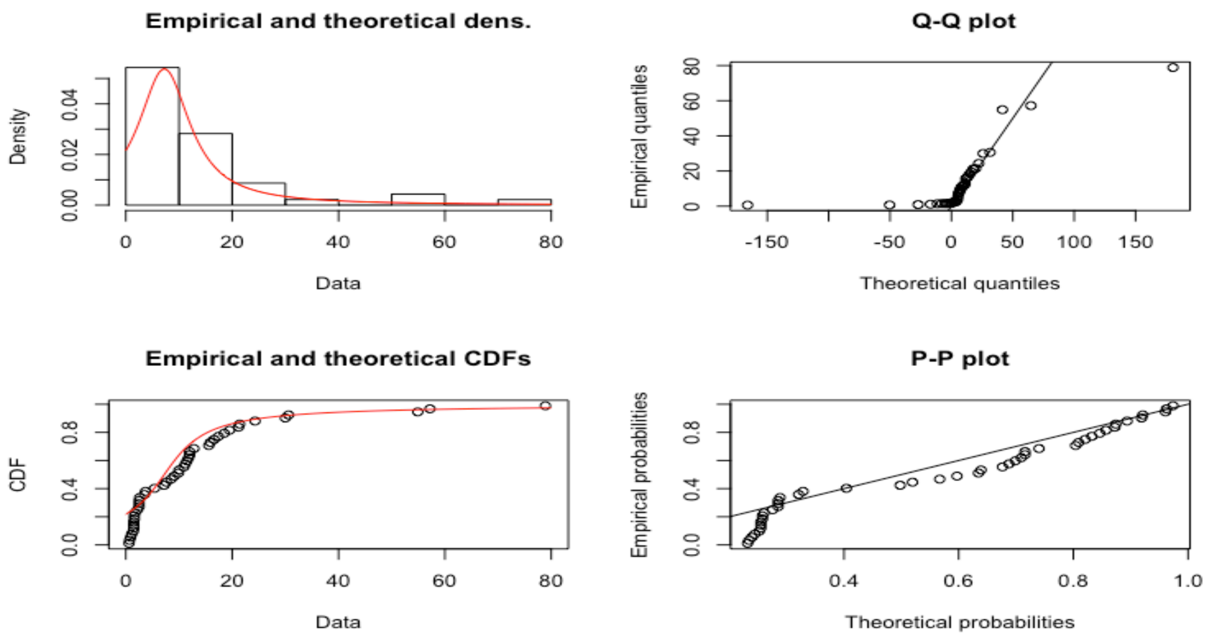



*Figure 2: Cauchy Distribution Fit for Regular Passenger Arrival Intervals, p = 0.01415, cauchy distribution parameters: m = 7.232164, gamma = 5.919411*

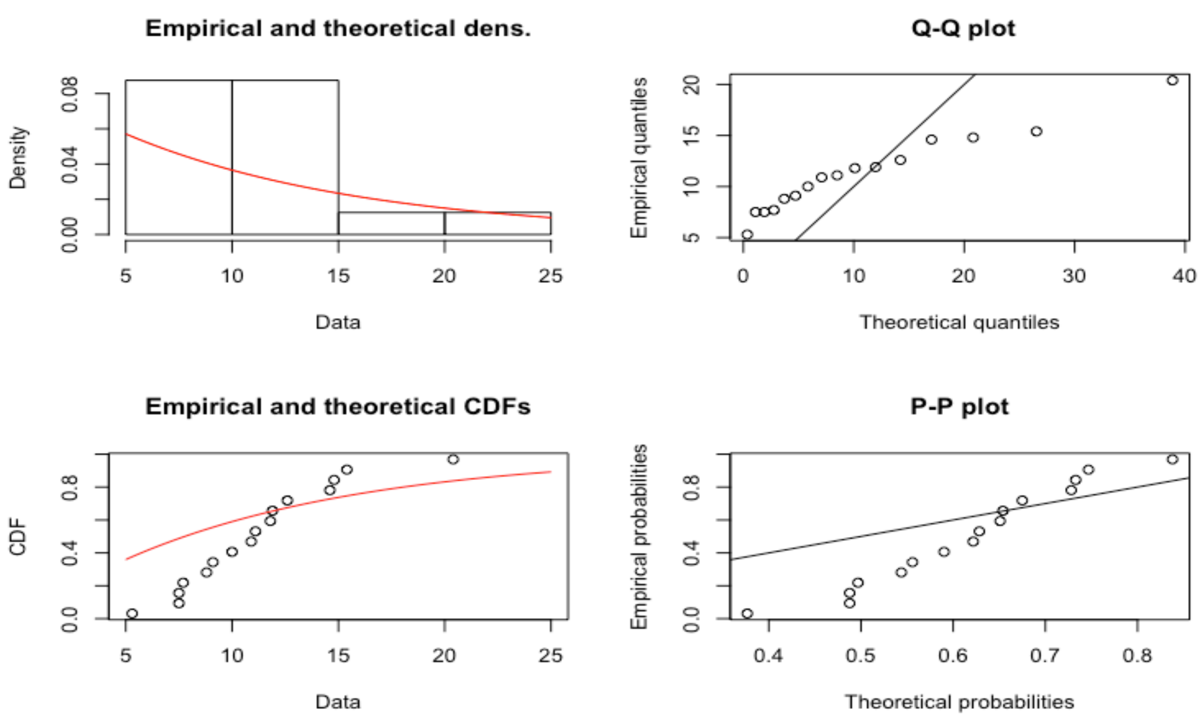



*Figure 3: Exponential Distribution Fit for ID Check time lengths, p = 0.00614, exponential distribution parameters: rate = 0.08918618*

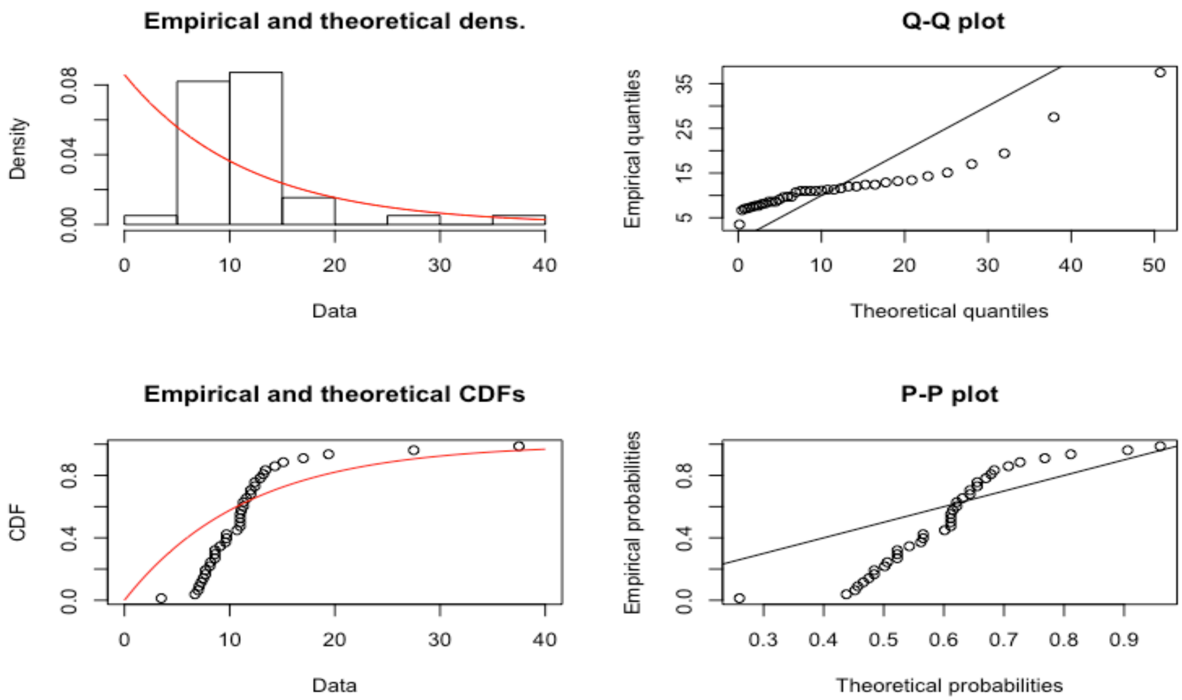



*Figure 4: Exponential Distribution Fit for Millimeter Scan time lengths, p = 3.532e-6, exponential distribution parameters: rate = 0.08594094*

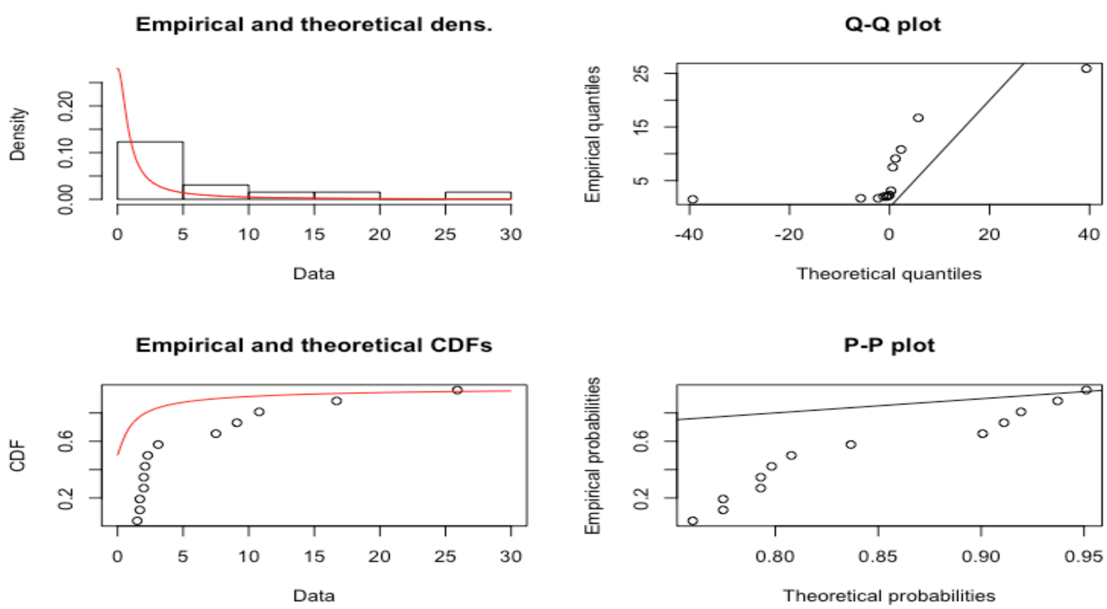



*Figure 5: Student's T-Distribution Fit for X-Ray Scan time lengths, p = 6.034e-7,*

*t-distribution parameters: df = 0.5728939*

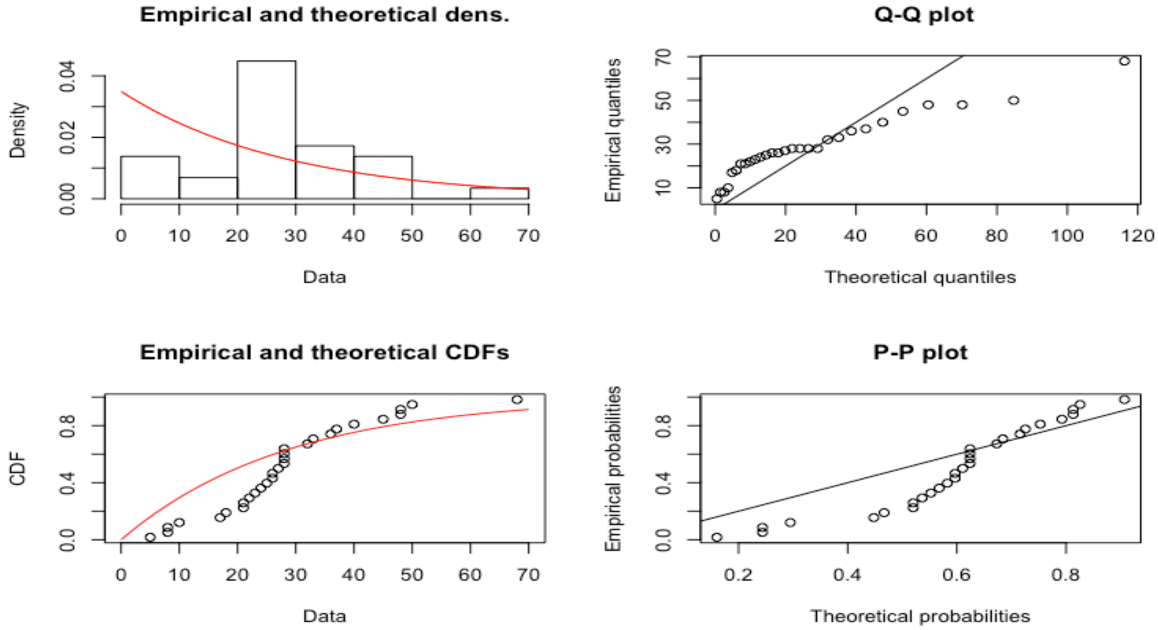



*Figure 6: Exponential Distribution Fit for Time to get scanned property, p = 0.006814, exponential distribution parameters: rate = 0.03493976*

With the probability distribution functions generated, the functions built into several programming languages to sample from the distribution were able to be used, when a passenger was simulated moving through the security checkpoint.

The flow of passengers through the checkpoint is modeled as a directed graph. Edges represent queues waiting for the next security screen point, represented by nodes, to become available. The visualization of the directed graph below was generated in Matlab. For further information, see section 3.5. The graph on the left represents the flow of TSA Precheck passengers starting at the bottom, where they enter the queue for the ID check. After the ID check, they can choose one of three queues for the millimeter wave scanner. At that point they must remain in the same path to queue for the x-ray scanner and then to queue to collect their property. Regular passengers go through the same process, but with five choices for queues for millimeter wave scanners.

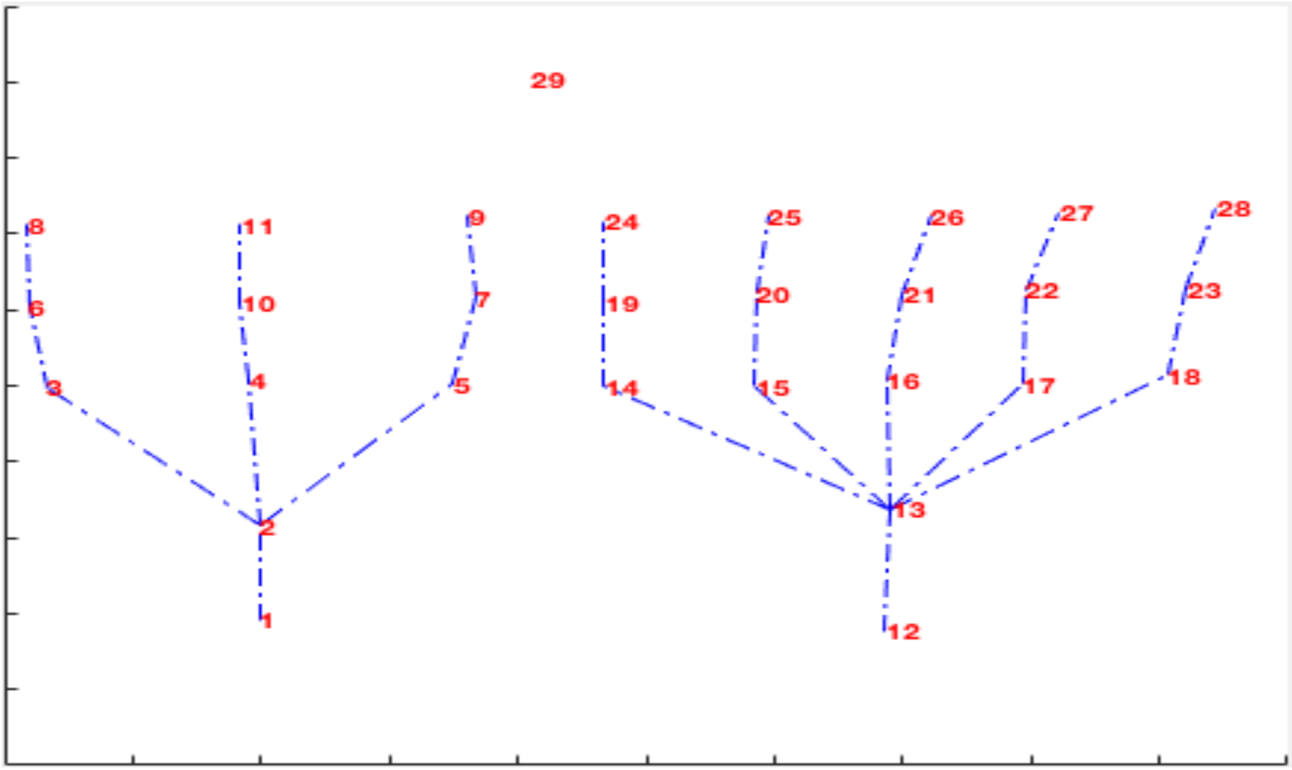
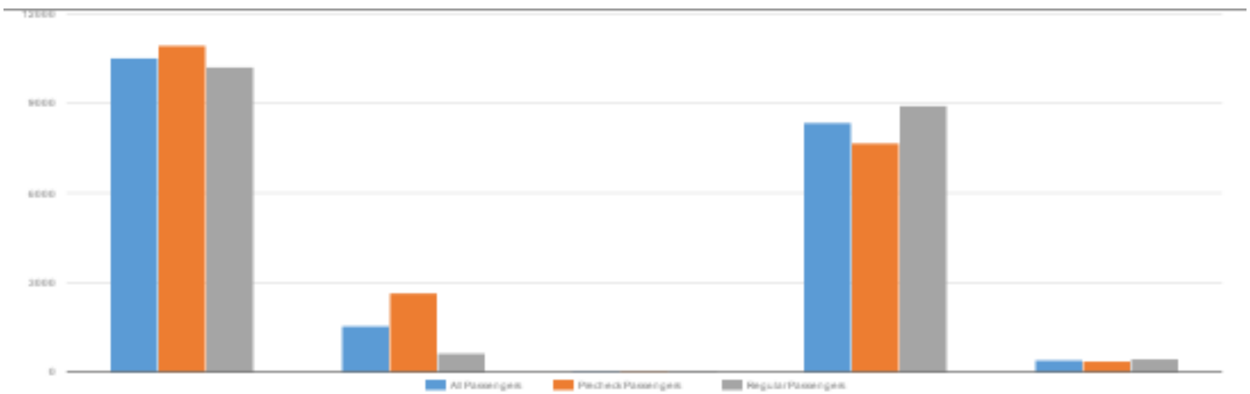



*Figure 7: Modeling the paths of passengers through the TSA security checkpoint as a directed graph*

## 3.2 Current Model Simulation

For simpler queueing systems with regular arrival processes and a single queue, mathematical formulas exist that enable the calculations of statistics about wait times; however, for a complex system with queues in series and parallel such as this model, this cannot be done without a computer simulation. The system lends itself to an object-oriented approach where passengers, queues, and security checks can be represented as objects. This led to the choice of Java, a fundamentally object-oriented language, for the computer simulation of the model. The simulation generates 500 passengers that pass through the security checkpoint as modeled in section 3.1. The probability that each passenger is a member of TSA Precheck is 45%, as stated in the problem statement. Passengers are assigned as either TSA Precheck or not based off of a random number generator. The simulation starts at 0 seconds, and the arrival time for each passenger type is generated by sampling the probability density function for arrival intervals from section 3.1 and adding that to the arrival time for the previous passenger. The time that it takes each passenger to go through each security screening is generated by sampling from the probability density functions modeled in section 3.1. The simulation is run until the last passenger exits the security checkpoint. Averages and standard deviations for total time in security and in each of the four queues, for all passengers and for both passenger subtypes, are exported to a CSV file. For the entirety of the code, see appendix 9.3. The program runs the simulation 10,000 times to get a sampling of many different days in a security checkpoint. The result of this simulation is shown below.



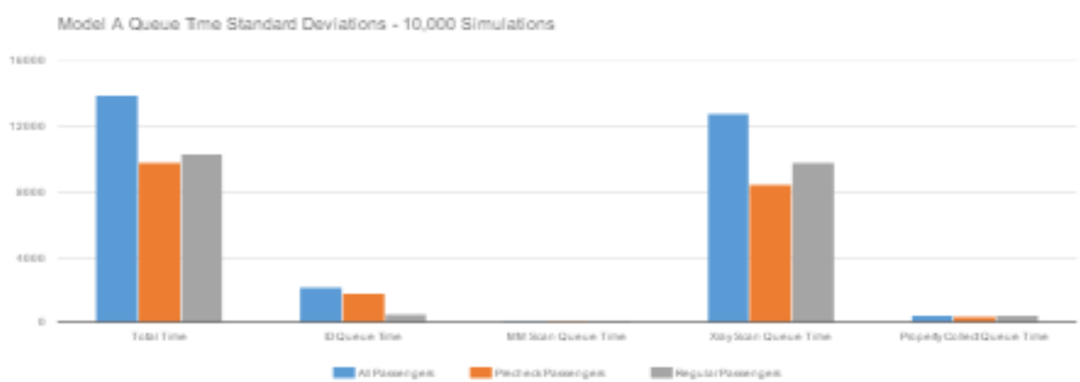



*Figure 8*

## 3.3 Bottlenecks

From the graphing in Excel, it became clear that the longest queues were forming behind the X-ray scanners. This experience will familiar to anyone who has ever flown and waited in a long line with their shoes off, waiting to load their bags onto the conveyor belt while the TSA officers suspiciously inspect a half-empty water bottle that someone forgot in their purse. The second longest queues form at the entry queue for ID checks. Since there are only two TSA officers completing ID checks for all 8 lanes, this would be a reasonable adjustment.

## 3.4 Pros and Cons of Current Model

Although the current model of airport security is effective, it can be improved with little cost. One of the main problems with the current model is that it has a high variance of wait time. Passengers that arrive at the beginning of the simulation, when the queues are all empty or nearly empty, pass through security almost instantly, while the last passenger to arrive can sometimes take several hours to get through. This is most likely because passengers in the simulation sometimes arrive in clusters, stressing the virtual checkpoint to its figurative limits. However, extreme wait times have been seen in the recent past, as in Chicago's O'Hare International Airport. In section 4, cost-effective modifications are made to the model to reduce wait times and wait time variance and improve passenger throughput. By providing passengers with additional direction, yet also the flexibility of security lanes that adapt to the flow of specific travel types, this variance in wait time will decrease.

## 3.5 Current Model-Matlab

Matlab was used to readily create directed graphs that represent the flow of traffic through airport security. Figure 7 above depicts the current model's directed graph. Using a graphical user interface, the current and new model was depicted in a directed graph and adjacency matrix. After running the script, one can simply double click to add a node, and then single click and drag to connect each node. This was a great tool for the model because it creates the matrix based off the directed graph. Furthermore, one can easily modify the directed graph to test for better paths.

## 4. Improved Model

To decrease security wait times, and increase customer satisfaction, 750 new Transportation Security Officers and aides were hired throughout the country in 2016 (TSA's airport wait times grow shorter, with some help from airlines). Although this did decrease wait time by about 30%, it also cost a great deal of money. Instead of decreasing wait times by hiring more officers, the new model will simply increase the efficiency of each officer with minimal additional staff. The improved model simplifies and specializes airport security in order to increase customer satisfaction. First, by categorizing customers by travel style, slower passengers will not hold up faster passengers. This will decrease the wait time variance. Secondly, by implementing fingerprint technology in the Rewards/ TSA pre check lane, passenger throughput will also increase. As customer throughput increases in the Rewards/TSA pre check lane more lanes will be opened for other travel styles, i.e. an extra express lane or overflow lane and thus through a trickle down effect will also increase customer throughput. Furthermore, by categorizing customers, each security lane can accommodate to more specific needs of a mass group of travelers. For example, the Special needs and children security lane will have a "bag loader" to aide in a smoother transition for parents. In addition, TSA officers will apply and be appointed to security lanes that they will be most productive in. They will achieve this by listing in order which lanes they prefer to work in. Then, using a Matching Algorithm and estimated times from each security lane, the optimal number of each type of security lane will be open with the optimal officers in each lane.  Each TSA officer will work in the "best" lane and each lane will have the most successful officers for the job. By allowing the officers to choose whether they would like to work with kids, business travelers, leisure travelers, etc., they have more control over their job and employee satisfaction will also increase.

### 4.1 Directed Graph of the Improved Model

The main change in the improved model is that passengers are now able to choose lanes per what category they fit into. This allows us to split the original two paths into four: express, special needs/ families with children, express, and overflow. Although two additional nodes are added for Id check, necessitating two additional TSA officers to run the screening stations, the same number of paths after ID check (eight) is maintained, making this a simple and cost-effective modification.

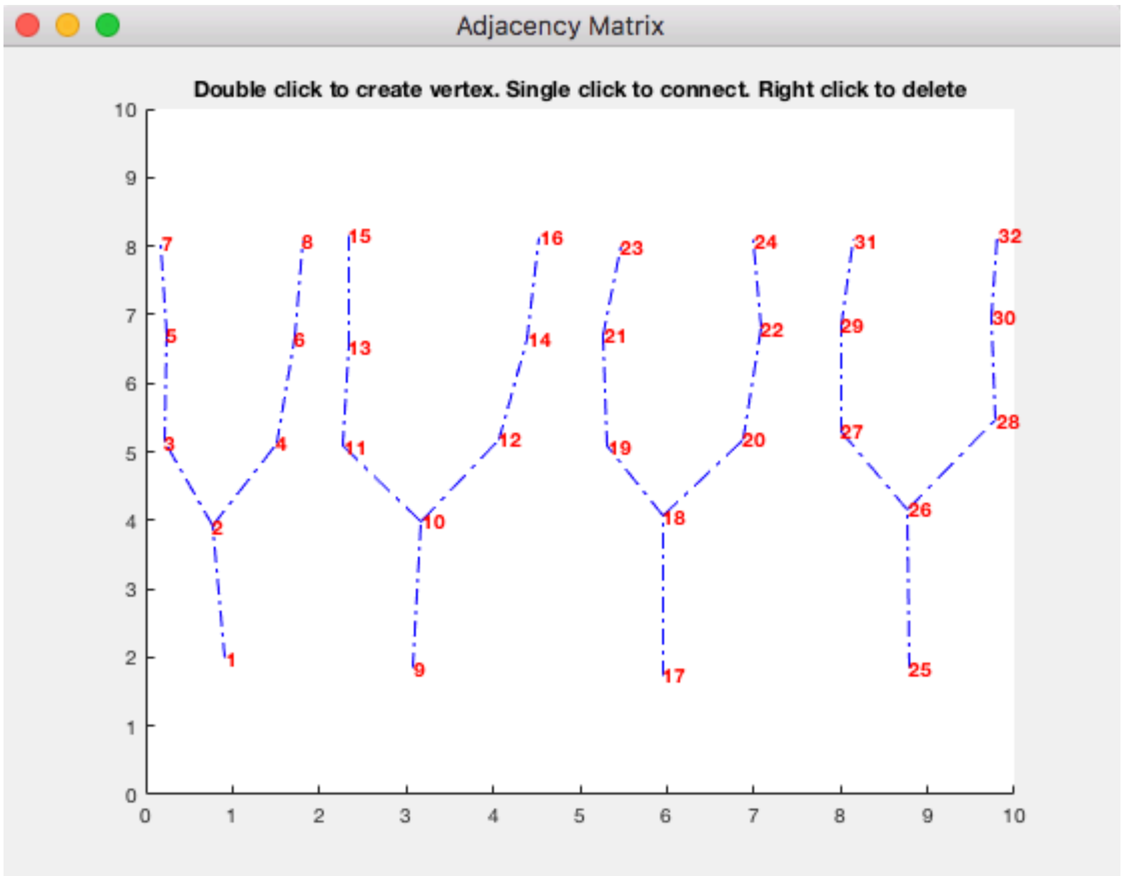


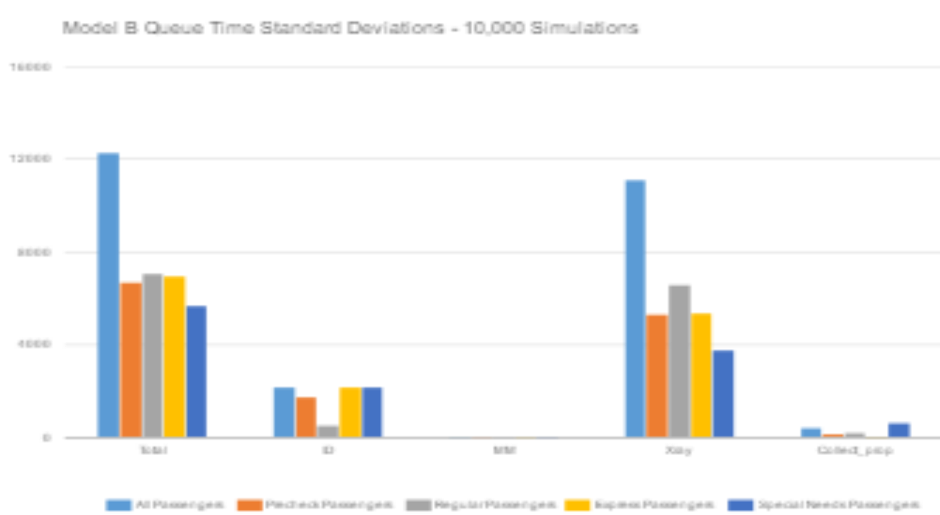

*Figure 9*

## 4.2 Computer Simulation for Improved Model

To simulate the improved model, we assumed that the pool of passengers that the algorithm draws from remains the same, but the algorithm assigns passengers to the new categories according to the following pseudocode:

```
if( time_to_get_property < 8 seconds )
        type = express
else if( time_to_get_property > 50 seconds )
        type = special
else if( passenger is TSA_Precheck)
        type = precheck
else
        type = regular
```

The code uses time to get property as a proxy for express and special needs passengers. It assumes that express passengers can collect their bags very quickly as they don't have laptops or liquids, and special needs and families will require additional time. Since this is the last node in the directed graph, it has to be exited before each other passenger in every previous queue can move forward. Placing passengers that take a longer time in this queue allows every other passenger to move through their queues without being held up by these passengers. The rest of the simulation runs as the original model does, and is repeated 10,000 times to get a sampling of potential days. The results of the simulation are shown below.



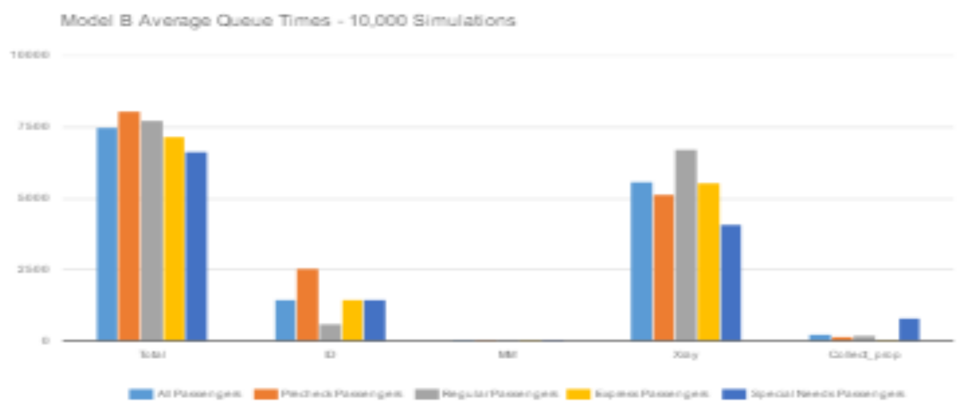



*Figure 10*

## 4.3 Results of the Improved Model

The results for the improved model were surprising. The average total time decreased by 28% for all passengers and the average standard deviation decreased by 11%. Each of the individual average queue times decreased as well. Even though additional lanes were not added for the improved model, every average queue time decreased.

| Field | Percent decrease in Average | Percent Decrease in Standard Deviation |
|---|---|---|
| Total Time | 28.68% | 11.62% |
| ID Queue Time | 4.82% | -0.61% |
| MM Queue Time | 21.74% | 8.22% |
| Xray Queue Time | 33.26% | 13.05% |
| Collect Property Queue Time | 39.59% | 3.82% |

*Figure 11: Changes in queue time statistics between models*

# 5. Considering Cultural Differences

The improved model was formed in a manner where changes associated with different cultures are limited and do not have much variation. Personality and social norms across cultures were considered (e.g. Americans tend to place personal gain over others, whereas, the Chinese places collective goals over themselves) (Jude Tan)[3]. Though Americans value privacy more often than not, the finger scanners would be beneficial because 45 percent of Americans are currently in the Pre TSA program[4], which requires fingerprints regardless. If the fingerprint scanner was advised that, if completed, the passenger would have the potential to go through TSA more quickly, the percentage of Pre TSA participants will rise. The fingerprint scanner would be beneficial globally and already had a huge impact on the mobile phone industry. If airports would apply the same technology to their own systems, there would be guaranteed customer satisfaction with security, along with shorter lines due to the lack of necessary identification checks.

The additional amount of lines before the scanning process could vary depending on the location of the airport. Perhaps, in larger, more prominent cities, the "frequent flyer" line would be greater. In more touristy and vacation locations, the "liquid/electronic free" line might be greater because passengers tend to leave those items behind. Airports can adapt the improved model according to the demographics of their location. Along those lines, in places where the handicap percentage is low, then, the amount of "special needs" lines would be less, etc. However, the additional lines focused specifically on characterizing people would overall be useful because that would allow faculty to be specialized in a specific area, rather than generally educated. This would be especially helpful in larger cities, where airport workers encounter an array of people. Say, if a worker specialized in children under 7, that worker will be skilled to work with children and families in a more productive manner if they were to work with families, special needs, and other types of passengers. Overall, the improved model takes into consideration several types of cultures along with personal features of passengers, and can be adapted accordingly.

## 6. Policy / Procedure Recommendation

The new policy recommendations are as follows. First, an agreement must be made with airlines that allows rewards customers to also be TSA pre check. This will increase the already 45% of passengers in the TSA pre check program and thus customer throughput will increase due to faster fingerprint technology in the TSA pre check lanes. Second, managers must push the concept of the right worker for the right customer. Officers will be trained and encouraged to accommodate a specific type of traveler. Thus, the procedure recommendation is that officers understand the passengers they are working with and thus act accordingly. I.e. if an officer is working in the special needs/ children lane they know that they may need additional aide. On the contrary an officer working in the express lane would understand that passengers are in a hurry and will thus stay out of their way and simply direct traffic through security.

# 7. Conclusion

## 7.1 Strengths and Weaknesses

As North Carolina A&T State University, Greensboro, NC mentions in a case study, a concept to consider is, will future passengers continue to feel safe if the improved model allows for a quick pass through? This of which was not thoroughly implemented in the improved model, considering that the objective was to generate a better model for customer satisfaction for queuing.  The improved model does not improve the technological system for checking for the security of the travelers, rather, allows for an efficient process from one point to another. Although safety technology is not directly improved, the passengers may “feel” safer due to evidence that states “persons are most comfortable when associating with persons from their own background”[6] (The Social Psychology of Groups). Although security lanes are not determined by ethnicity, by grouping similar travel styles, customers will relate to those around them and feel safer. For example, parents with children in the Special needs/ children lane will feel at ease that most of the other passengers are also parents with children. In addition, by categorizing lanes by travel style, slower passengers will not hold up those in a hurr□□□□□y as much because they will not be in the same security lane.

## 7.2 Future Improvements

The future model will consider technology aspects because the new model does not consider technological improvements. Since the categorization of lanes will change depending on the demand, the signage for each lane should be a screen that can readily change from “Rewards Members” to “Special Needs/ Children,” etc. Furthermore, there will also be an estimated wait time at the bottom of each screen so customers can weigh their lane options very easily.

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