The Wheels-Up Solution

A comprehensive solution to providing smart-transportation throughout the airport for disabled passengers

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1 Quad Chart

Purdue University Wheels-Up Solution

FAA Challenge
Smart Airport Student Competition

Problem Statement:

A lack of regulation and innovation has led to the need to improve the air teavel experience of passengers with mobility constraints.

Technical Approach:

+ Discovered and defined problems with airport disability accomodations through background research

+ Formed design criteria from identification of stakeholder needs

+ Derived constraints from required functionality of proposed all-in-one wheelchair

+ Appraised and improved physical design through digital means using computer-aided design and finite element analysis

+ Confirmed design feasibility with autonomous prototype and computer-aided simulations

Key Findings

+ Most disabled passengers find the current traveling situation egregious

+ Using one method of transportation around the airport can lead to time and operational cost savings

+ An autonomous all-in-one wheelchair is feasible and affordable with current technology

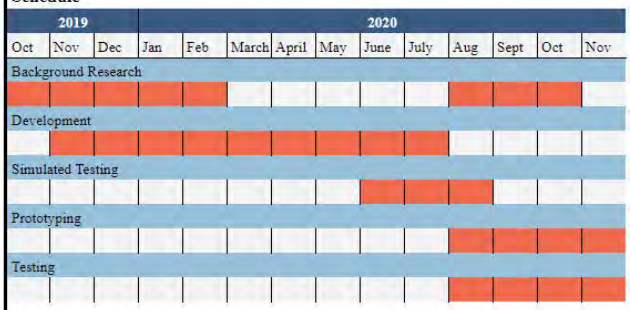
Potential Benefits

+ Reduced boarding times for disabled passengers

+ Reduced terminal traffic without current mobility solutions

+ Simplified and dignified airport experience for disabled passengers

Schedule



Cost

$9,223 per unit

2 Executive Summary

The FAA has tasked students and faculty at the collegiate level to draw on their knowledge to improve commercial air travel through the use of smart technologies in the airport. This report showcases an innovative new mobility device for physically disabled air travelers which is intended to enhance their experiences in the airport. Developed by Purdue University students, this new wheelchair design and system allows for fluid movement throughout the airport and airplane using inexpensive technologies available today. The design team kept passenger accessibility, security, and experience the focus throughout the development of this wheelchair.

The United States has 30.6 million people that have difficulty walking, climbing stairs, or use mobility devices such as a wheelchair or walking cane [1]. This number is growing rapidly with the aging population in the United States. In addition, airports in the U.S. must accommodate international travelers from around the globe that may also require assistance. Being able to create an enjoyable experience for all travelers will become a growing barrier to the United States' continuing improvement in the commercial aviation industry.

Developing an accommodating system for all physically disabled travelers which provides a world-class traveling experience requires complex considerations. It is important to allow passengers to have a customized experience at the airport by allowing them to summon assistance when needed, easily obtain navigational assistance, and remain comfortable regardless of travel duration. It is also important to allow airports to easily manage the new system regardless of the airport's scale. Managing these competing considerations is a challenge not yet solved by current solutions.

The design team worked diligently on a new mobility device to meet the needs of a physically disabled passenger. This electric wheelchair can autonomously navigate through the airport or give the user turn-by-turn navigation to the desired gate. The chair incorporates an interface that allows the user to request assistance, change their route, and obtain updates about their flight. It also allows the user to directly board a plane by manipulating the wheelchair width to fit in the airplane aisle. The device's ability to change widths reduces boarding time and replaces the need for costly aisle chairs. To manage the system, the team designed a database outline and website that would organize all assistance requests and maintain fluent communication between the airport, airline, and passenger. The team has designed and tested a working computer model of the chair as well as a model for the database and website.

By accommodating all travelers who need assistance in the airport in a more effective manner, our team believes that the airport experience will be more efficient and enjoyable for physically disabled travelers within the United States. Under the Code of Federal Regulations (CFR), airlines are ultimately responsible for the passenger experience (including disabled passengers) and the assumption is that the free market will solve this problem. It has not. With a redesigned wheelchair and the leadership of the FAA, implementing this new mobility solution will propel the United States into becoming a prime example of accessibility and equality around the globe.

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4 Background

The FAA Reauthorization Act of 2018 was congress's first step to push the FAA in a new future-forward direction for commercial air travel. In this report it was made clear that airports in the United States needed to start implementing future technologies to keep up with other countries around the globe that were and are expanding their commercial aviation networks rapidly. Smart airport technologies help loved ones reunite, connect the business world, and bring exotic vacations to life in an ever more efficient manner. While airports help millions to travel around the globe every day, inadvertent and unintentional boundaries are being set by lack of accommodation and accessibility for the physically disabled. It is important for airports to take a holistic view of all passengers and their concerns during their travels in order to provide an equally enjoyable travel experience.

There have been many attempts at providing solutions to allow for accessible and comfortable air travel for all passengers, over the years. These solutions have all worked within the given requirements laid out by many sources. The Code of Federal Regulations (CFR) provides requirements for operators to follow in order to provide an equal traveling opportunity to passengers with disabilities [4]. The Airport Disability Compliance Program (ADCP) also intends to ensure that passengers with disabilities have the same services provided to them that any other traveler would have [3]. The Americans with Disabilities Act (ADA) is yet another document that seeks to provide a comfortable and manageable experience for disabled people in buildings around the United States including airports [2]. These documents lay a framework for airline operators to follow when they are providing any service to disabled customers.

Some physically disabled travelers require more assistance than other passengers and airlines are required by the regulations discussed above to help provide this assistance. Airlines commonly hire contractors to provide these services in the airport. These contractors use tools that are common across all airports in the United States to aid in the transportation of disabled passengers. Examples of these tools include the common airport wheelchair, aisle chair, and the airport buggy (Figure 3). All these tools are commonplace in today's airports and serve specific purposes for the physically disabled passengers. For example, the buggy helps to transport passengers who cannot walk long distances without assistance, while the aisle chair allows passengers with limited or no mobility in their lower extremities to board a plane and move to their seat with assistance. While the tools above are helpful in transporting disabled passengers, they are all very different from one another and are dependent on the contractors to provide the experience for the passengers. With many contrasting transportation methods and varying levels of experience and training possessed by contractors, passengers' experiences can vary widely from one another.

(a) Common Wheelchair [5]

(b) Aisle Chair [9]

(c) Airport Buggy [7]

Figure 3: Common Current Mobility Solutions

Within the airport and on the aircraft, the contractors provide enplaning, deplaning, and connecting services for the airlines' passengers as required by law. However, when a situation arises in which the passenger was mistreated or in which proper regulations for the operator were not followed, hired contractors provide a means for the operator to misdirect media and other passengers' attention toward the contractor and not themselves [11][8]. It is important to shed light on the scapegoating that airline operators use in order to circumvent damaging public relations. The origin of the mistreatment of physically disabled passengers can be traced back, in part, to the service people that are working with the disabled customers coming through the airport. Service members are often underpaid and ill-trained leading to a larger percentage of passengers being improperly cared for, inferior public relations for the airline, and a higher turnover rate for the workers [8][12]. In a recent study conducted it was found that nearly 62% of travelers with some sort of disability found their service at the airport either "poor" or "very poor" [13]. These figures can be confirmed by the team's independent study where 60% of respondents said that they are dissatisfied with airline and airport accommodations and treatment. These results are egregious for any market segment of paying customers and attention should be given to these passengers as such.

The number of physically disabled passengers in the market is growing in the United States. In 2012 it was stated that the United States had 30.6 million people who had trouble "walking or climbing stairs, or used a wheelchair, cane, crutches, or walker" [1]. These numbers are just a reference for disability today. Looking ahead it can be seen that there will be many more Americans who will need some type of help getting around the airport. In the next 40 years, the number of Americans over the age of 65 is expected to nearly double from 52 million to 92 million[10]. Based on the fact that about two-thirds of people over 65 need some type of assistance in their daily routine, it can be seen that the number of people requiring assistance in everyday life will increase by 77% over the next 40 years [6]. These numbers only consider the aging population in the United States and not customers who may need assistance for other reasons. This increase also does not take into account the number of foreign travelers that may need assistance. All of these passengers will need some type of help when traveling. In order to create a better and more enjoyable traveling experience for disabled passengers, mobility issues must be prioritized. Solving the mobility issues in the airport today can improve the physically disabled passengers' experience tomorrow. The solution proposed in this report will allow airlines and airports to more easily fulfill their obligations to all passengers while also improving the experience of the passenger. Overall, an improved mobility system will empower the physically disabled and create a more enjoyable and consistent air travel experience.

To prepare for the future of physically disabled commercial aviation, a mobility solution must be versatile. The solution must service all passengers who need it which will vary from older customers with walking canes to young customers who have limited mobility in their lower extremities. The solution must also be conditioned to fit seamlessly into today's infrastructure in order to obtain quick acceptance in airports around the country while also following all regulations set by respective governmental departments. In order to be successful, the solution must provide everyone, even those without disabilities, with a more enjoyable and efficient experience at the airport. To meet all the criteria that have been set forth and all the constraints set upon the solution, a systematic design method was used to create a holistic solution.

5 Project Description

5.1 Design Overview

In order to create a comfortable airport experience for physically disabled passengers and to provide a seamless trip from arrival to departure, the team developed an innovative wheelchair and a compatible management system. The overall approach began with research, which influenced design decisions, and ended with testing and physical prototyping of the solution. Through background research and distribution of a survey, the team solidified an understanding of the problem and its' current solutions. The technical research on materials and manufacturing of a physical chair guided computer-aided design (CAD) of the chair throughout the design process. Finite Element Analysis (FEA) allowed the team to determine whether the wheelchair design met stability and structural criteria. The complicated task of creating an autonomous prototype required the creation of a specialized team to code and build the vehicle using a combination of free software and inexpensive hardware. This contributing team accomplished this task in just 3 months.

5.2 Concept

The overall framework consists of an autonomous wheelchair fleet, an informational database, and a website. This framework is henceforth referred to as the "Wheels-Up" solution.

(a) Fully Rendered Expanded Wheelchair (b) Fully Rendered Compact Wheelchair

Figure 4: Wheels-Up Wheelchair Design

5.2.1 Physical Wheelchair

The Wheels-Up wheelchair took extensive development and testing with input from every team member. The criteria used to decide our final wheelchair design include maneuverability, compactibility, comfortability, structural stability, cost, weight, and autonomy capabilities. Our final design focused on all of the criteria but specialized in a certain few.

The most important aspect of our design, which separates our concept from any current design, is the ability to manipulate the width of the wheelchair to allow direct access to the airplane. Our final design can manipulate its standard 23-inch wheelbase to a 15-inch wheelbase which is able to maneuver any commercial airplane aisle. Our design accomplishes this with a split chassis connected by two load-bearing linear slides and one electrically-powered scissor jack. The scissor

jack offers excellent mechanical advantage and allows a small motor to operate the jack with little required power. Besides the chassis, the chair's seat and armrests must also compress to 15-inches. To do this, both the seat-cushion and seat-back have one 14-inch middle section. The seat-back has two 4-inch side sections which fold behind the seat while the seat-cushion has two 4.5-inch sections that fold under the seat.

A main area of concern with the split chassis design is structural stability. The stability starts with the base of the chair. On the interior of the base, an aluminum frame supports the seat and distributes the load to the two linear slides, the scissor jack, and the axels (see Figure 5). The linear slides bear the most bending stress from the split chassis and the scissor jack provides additional structural rigidity between the two halves. Surrounding the chassis interior is a shell made of KYDEX® plexiglass (the same plastic that is used in Aircraft pull-down trays). The insulative, durable, and scratch-resistant plastic will cover and protect the aluminum frame and all electrical and mechanical components of the chassis. Connected directly to the rear of the base on both sides are the main seat-supports. These aluminum supports connect the base to the seat and give the wheelchair significant structural rigidity. All structural components that handle loads were tested using Finite Element Analysis (FEA), see Section 7.1.

Figure 5: Chassis Structural Configuration

Figure 6: Mecanum Wheels

In order to improve maneuverability, our design includes four mecanum wheels, Figure 6. When positioned correctly, mecanum wheels allow for zero-degree turns and lateral movement. Using these wheels, the Wheels-Up wheelchair will be able to traverse any tight turns in an airport or airplane. Mecanum wheels were chosen over omni-directional or traditional wheels because they provide resistance to lateral motion on an incline (unlike omni-wheels) and provide zero-degree turn capabilities (unlike traditional wheels).

Designing a comfortable chair is an important requirement considering the passengers could be spending long periods of time sitting in it. This requirement is even more challenging with a chair that downsizes. When the chair is expanded, there is an 8 to 9-inch gap between the split chassis. This gap would not be comfortable underneath the seat, so we came up with a design that covers the gap and maintains support throughout its different configurations. Beneath the seat, bridging the gap between the split upper chassis, is a section of compressible hexacell support material (see Figure 14). This support material maintains its strength and rigidity under the vertical load of the passenger even when it expands horizontally, and can compress laterally to less than an inch.

Our electric design requires substantial power to propel the chair at speeds of up to 5 mph. Two rechargeable lithium-ion battery rated at 24V for 10Ah supply this power. The batteries are housed within the aluminum base, below the passengers feet. This placement lowers the chair's center of mass and will allow for a max range of 10 miles.

In order to make the final design compatible with current technology, we incorporated easy controls for our users. The right armrest includes all controls to operate the wheelchair. Buttons control autonomous settings and a joystick controls steering similar to other powered wheelchairs today. The left armrest includes a 6.2" x 3.1" touchscreen display that allows the passenger and staff members to interact with the chair. The screen will have a travel information section that will display the current location on a map of the airport (see Figure 19). The travel information section will also have information on bathrooms and food in the airport for the passenger as well as navigational assistance to their gate (see Figure 20). To secure the wheelchair and ensure that no one except the intended user operates it, the display has a scanner that scans passports and/or boarding passes. With this, the passenger can simply scan their boarding pass and the chair will take them to the desired gate. This function requires that the wheelchair be in communication with the airport and airlines in real-time in order to account for any gate changes.

5.2.2 Database & Website

To organize and house all pertinent information about the wheelchairs and the customers who need a wheelchair, a database will be used. The database consists of three main tables. A table is a collection of rows where every row contains the same set of columns. The three tables in our database are the customer information table, the wheelchair information table, and the airport information table. All three of these tables use both common and unique IDs in order to track customer and wheelchair data between them. This data is then fed to a proprietary website where it is used to create reports and give detailed real-time information about the wheelchairs and the customers using them or in need of them.

The Customer Table includes all the information of a specific user of a wheelchair (see Figure 27). Information in this table will be collected when the customer buys a ticket for his or her trip. Using a back-end tie-in for multiple airline operators' websites will allow for a smooth and secure process for both the airline and the customer. The information that will be collected from the operators' websites includes a customer's name, date of birth, contact information, departure and arrival airports and gates, and level of need or priority. The customer's name, contact information, and date of birth will be used for verification when checking out their respective wheelchairs at the airport. The contact information also serves the double purpose of reminders and notifications for the customer that may be sent prior to their flight to give them more information on where they can find their wheelchair upon arrival. Departure and arrival information is to be used for the arrival airport and airline to make sure that a wheelchair is available and ready for the customer when he or she lands. Finally, the column that houses the priority level serves the purpose of helping staff members discern who is in the greatest need of a chair, if chair numbers are limited, and how much assistance they might need from a service member during their travels. All of this information is collected and stored in an effort to keep the user's experience efficient and enjoyable throughout their journey. The Customer Table is referenced using a primary key which is titled ID Number. The Customer ID is a unique six-digit ID for each user that aligns with their information.

An additional table was created for the wheelchairs to help organize and keep track of all of the wheelchairs (see Figure 27). The wheelchair table includes all of the information about a specific autonomous wheelchair. This includes the wheelchair's power level, the amount of time in service (denoted by hours), the wait time for a customer, the airport the wheelchair is located in, and the location of the chair in the airport. The power level and amount of time in use are meant to be

maintenance indicators in the table. This will help keep track of the wheelchair's overall health and projected lifespan so that accurate replacement timelines can be made by airports. The location of the wheelchair will be a reference for the website so that it can display relevant information to those that use it. On the other hand, the wait time for a customer will be directly applied for scheduling of arriving flights and departing flights so that all chairs are in use as much as possible and so that people are not stuck waiting on the plane for a wheelchair to show up. The location of the chair inside the airport serves the purpose of making sure that all chairs are in the areas they should be in and will allow for easy assistance if it is requested by a customer. Like the users in the Customer Table, each autonomous wheelchair is referenced using a primary key titled Wheelchair ID. Each wheelchair being used will have a unique identification number that will be used to reference the wheelchair in the database.

In order to bring these two tables together, a final table was constructed for the airports (see Figure 27). The ID Number from the Customer Table and the Wheelchair ID from the Wheelchair Table act as a primary key. The primary key in the airport table was created so that all the specific customer information is aligned with the wheelchair that they are using. This allows for information to be known about the location of the customer in the airport, their level of need, and when/where they will be departing from to name a few items.

In order to keep all of this data compact and usable the team has designed an interactive, web-based, tracking system that will allow for customizable functionality for the end-user i.e. airport or airline. With background integration and prescripted APIs, we can allow a user-friendly and easy access management system to be formed. This website will require a login given to customers who have the wheelchairs at their airport (see Figure 31). The website can be accessed from anywhere by the proper users and will include dual authentication using text messages in order to ensure that the site is secure. The information will then be displayed in an ordered manner that allows the airport to track and monitor each chair at any given time. The sheets will be exportable and analysis of data will be continuous and live so that status is always constant.

Airport operations and airlines will obtain information from the database through a website via an application programming interface (API). The database will be created using a relational database management system (RDBMS), and the website will be implemented using a web application framework. The API will be using Amazon Web Services cloud computing platform with its API Gateway product.

5.2.3 Autonomy

In order to improve the efficiency of operation in the airport, the Wheels-Up wheelchairs incorporate autonomous navigation. An array of sensors including a LiDAR sensor, four ultrasonic sensors, two wide-field cameras, an accelerometer, a gyroscope, and a GPS sensor feed data to the wheelchair's on-board navigational computer for processing.

The goal of autonomy is to allow for the wheelchair to move freely throughout the airport without needing a staff member to propel it or guide it. Navigationally, the wheelchair will be similar to current robotic vacuums. All wheelchairs operating in the same airport will map the terminal to create a static map of the airport, including landmarks. This will allow for the wheelchairs to have a constant sense of position and potential obstacles in a changing environment. The sensors

on-board will help to avoid collision with dynamic obstacles. This includes construction in the airport, other passengers, and everyday obstacles like luggage. If the passenger takes manual control of the wheelchair using the joystick at any time, the autonomous features will be turned off. This will revert the wheelchair back to standard joystick controls until the passenger chooses to return back to autonomous mode using the touchscreen.

The wheelchair will also have a special mode for boarding the plane. When in the plane boarding mode, the LiDAR will keep the wheelchair straight while the cameras monitor the seat number to make sure the chair arrives at the desired aisle. With the help of on-board staff, small changes by one row or multiple rows can be made to ensure that the passenger is in the right position before the they are comfortably transferred to their seat. The chair can then be instructed to return up the aisle once the aisle is clear of boarding passengers.

The autonomous features of the wheelchair allow for additional streamlining of disabled passenger transportation. A simple follow-feature allows a physically disabled passenger to follow their companion and also allows for many wheelchairs to be used in tandem to create a wheelchair train. This feature allows for group-travel of disabled passengers going to the same gate or area. The chair that is leading could also be controlled remotely by a staff member using a wirelessly connected computer. This "train" transportation method serves to replace the large airport buggies with more slender and maneuverable wheelchairs.

Avoiding dynamic objects in any environment is an challenging task. Active algorithms make use of all on-board sensors to travel from one GPS way-point to the next. If obstacles remain in the path after attempting to avoid them, the wheelchair(s) will emit a low pulsing tone that will serve to alert but not displease other passengers. See Section 7.2 for more information on the team's autonomous prototype.

5.3 Concept of Operations

5.3.1 Concept of Physical Chair Operations

Athena, a Wheels-Up wheelchair at Miami International Airport, starts its day plugged into the charging port. As soon as the airport opens, Athena unplugs and waits for its first assignment. Once Athena receives a new passenger assignment from the airport, it will move in its compact mode to the desired location of the user. Athena makes its way through the narrow hallways and through security into the drop off area of the airport. It then expands and politely waits for Jane Doe.

Athena meets Jane Doe at the drop off location and then proceeds to meet her requests. If Jane wants Athena to go to a certain location automatically, Athena will use its sensors to guide it through the airport to the location of Jane's choosing. If Jane touches Athena's control stick Athena politely stops and hands manual control to Jane waiting until its autonomy is needed again. Once Jane is ready to board the airplane, Athena enters into the jet-bridge. Athena warns Jane that it will be contracting and slowly adjusts its width to fit within the airplane aisle. Athena reminds Jane to put on the lap belt provided and then moves in compact mode down the aisle with Jane. After Jane is helped out of the chair Athena returns down the jet-bridge and back to its charging station, or becomes available for another passenger to use.

After a long day of transporting passengers, Athena makes its way back to the charging station and waits to be plugged in. Athena delivers a report of the day's activities to the server for analysis and monitors its own systems for anything that may have gone wrong during the day.

5.3.2 Concept of Assistant Operations

John Doe works at O'Hare International Airport as a wheelchair assistant. When John gets to work, he logs into his iPad and clocks in. John has a section of the airport that he and other assistants work to ensure proper maintenance and care of wheelchairs and passengers. Early into his shift John walks over to the charging portal and ensures that all chairs are clean and charging.

Not long after, John received a notification that a passenger needs assistance with their wheelchair. The iPad shows John where the passenger and wheelchair is and shows that there may be something wrong with the right front drive wheel. As soon as John gets to the chair he greets the passenger and checks the reported issue with the front drive wheel. It appears that there is a piece of trash stuck in the wheels axle. After removal John tests the chair with the passenger and ensures that they are comfortable before marking the issue as resolved.

Over the next few hours, John responds to other issues and cleans chairs as needed. Most of his day is dedicated to moving around the gates in his region and ensuring that the chairs are running properly. After lunch John needs to complete his training for the week. On the iPad, John is given the opportunity to complete his video training about how to properly transfer and take care of passengers in the Wheels-Up wheelchairs. After his training is done for the day John can get back to servicing people and tending to chairs. When needed, John helps transfer passengers into their plane seats and takes care of intermittent maintenance issues that arise during the day.

5.3.3 Concept of User Operations

Jane Doe is on her way to visit her grandchildren for winter holiday and is excited to see them for the first time in six months. Jane booked her flight a few months in advance to get the best fare possible. When booking, she knew that the airport was going to be too big for her to travel by foot and so she decided to opt for wheelchair service. When buying her ticket, she marks her assistance needs as a 3 since she is traveling alone.

Jane receives a text message 6 hours before her flight reminding her of her scheduled assistance and encouraging her to arrive 90 minutes before her flight based on the airport traffic. She arrives at the airport two hours before her scheduled flight. From her mobile device, Jane clicks the texted link to signal that she has arrived at the airport and is ready to be helped to her gate. After a very short wait in the loading area, her Wheels-Up wheelchair makes its way to her. Finally arriving at Jane's car, the wheelchair expands to allow Jane to sit in it and emits a tone to greet her. After Jane is settled into the chair, she scans her boarding pass QR code and the chair chirps to let her know it knows who she is. Jane presses the "Take me to my gate" button on the home screen and relaxes as the chair slowly moves toward the security line. Being in the Wheels-Up chair allows Jane to go through a designated line for disabled passengers and their companions. After clearing the security checkpoint, the chair prompts Jane to confirm she wants to go to her gate.

Being nervous for the flight, Jane needs to use the restroom. Jane selects "Choose another destination" and selects "Bathroom" from the list of places on the touch screen. She then taps the "Automatic Navigation" button and relaxes as the chair takes her to the restroom nearest her gate. Once to the restroom the chair navigates to the handicap stall and allows Jane to proceed. Once Jane has finished she moves back into the chair and selects the "Navigate to my gate" button from the home page. The chair once again navigates slowly to the gate. At the gate, the chair parks near the front desk to wait for the boarding process to begin.

When the boarding starts, Jane presses the "Start Boarding" button on the touchscreen. The chair navigates to the jet bridge door and moves toward the plane. Once down the ramp, the wheelchair warns Jane that it will be contracting. She is encouraged to put on the lap belt and then prompted to press "Start" when she is ready. Jane hits start and the chair contracts slowly to 14 inches. Jane must adjust to stay balanced on the chair but the slow nature of contraction allows her to do this easily. Once the chair is in its fully contracted state, Jane is prompted to press the "Take me to my seat" button. She presses this button and the chair moves into the plane and navigates to her chair. The flight attendants are instructed to help Jane if instructed and when she gets to her seat Jane is helped out of the chair and into her seat by the attendants. Now in her seat Jane's chair backs up down the aisle and she relaxes waiting for the other passengers to board.

5.4 Implementation of Solution

5.4.1 Design Assumptions

During the design process there were certain assumptions made that guided large design decisions. In designing the wheelchair and delay time reduction, excess wheelchair users were not accounted for per flight. For example, if a particular flight had 10 wheelchair users, the time and cost statistics were not considered due to the unlikely event that the outlier occurs. Additionally, aside from product and website upfront cost, uneven maintenance costs were not considered due to the lack of relevant statistics and unpredictability of the cost. In terms of physical wheelchair maintenance, market research yielded a loose maintenance schedule estimation that can be found in the "Lifecycle" section. Due to the specific and protected nature of the disabled travel community, there is not an abundance of statistics available to the public, therefore there were assumptions and estimations made for costing and timing.

This design was formulated with an intention of making travel for wheelchair users easier to encourage them to fly more often. This was done with the assumption that the problems that disabled passengers experience are large enough that the community will welcome a more technological and innovative solution. Furthermore, this is a two-way solution, meaning that it is intended to apply for departure and arrival experiences. This wheelchair is not designed to fly with the passengers, rather it is kept at the airport and provided to passengers either arriving at the airport or deplaning. Due to the assumption of the wheelchair not flying on the plane, weight was not as heavily considered when designing the chair and choosing materials. Also, it is assumed that this wheelchair design will be cleared to access and navigate through the jet bridge and onto the plane while boarding and deplaning. Regarding the website, it was assumed that there will be different levels of access for different website visitors (i.e. passengers, airport management, airlines, etc.). This in turn prompts the creation of user login and appropriate credential checks.

5.4.2 Lifecycle

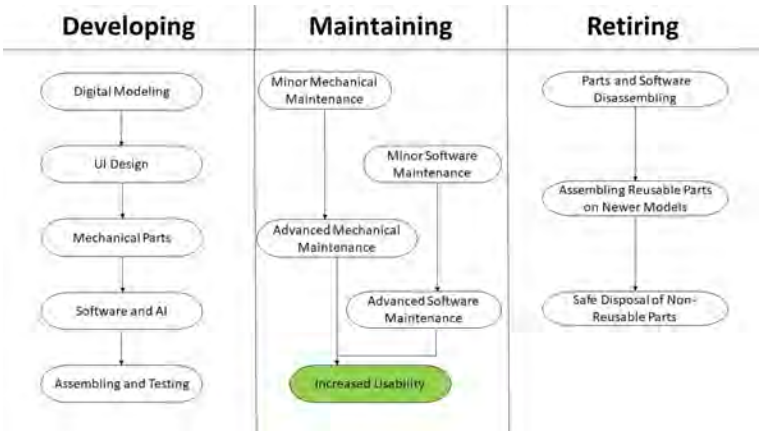

Figure 7: Product Lifecycle Graphic

The following protocols detail the maintenance schedule of the proposed wheelchair. Traditional wheelchairs have a usability span of approximately five years according to Numotion. To increase the usability span of this autonomous wheelchair, the design team proposes that the wheelchair undergo advanced maintenance once every six to twelve months . Advanced maintenance includes fully replacing or repairing mechanical parts such as the wheels, armrests, and seat material as well as composing new software and user interfaces that will improve user experience . The design team also proposes that minor maintenance should be done every month or whenever such maintenance is urgent. Minor maintenance includes checking or replacing any loose nuts or bolts on the wheelchair, heavy sanitation, and updating software and user interfaces that produce any bugs or inconsistencies. With these maintenance plans, the design team hopes to expand the usability span of the wheelchair to more than ten years.

5.4.3 Cost Comparison

In order to examine the feasibility of the Wheels-Up Solution, the team determined the cost of wheelchair production and implementation and compared it to the cost of current solutions. The team needed a baseline for which it could compare its costs to. This baseline was chosen as the top 50 airports in the United States, by traveler count. Using numbers provided by independent researchers and the United States Census Bureau, it was determined that about 1.86% of travelers were physically disabled and would need a wheelchair in the airport.

Taking this number of 1.86%, we then estimated how many passengers would be disabled in a given airport based on the traffic for each airport. With the number of disabled passengers in a given airport, the team examined the peak hours of operation. The peak hours of operation were found to have a passenger flow of 3.8% of the passengers of the day. The peak flow was then applied to the peak month of August which handles 9.6% of the total travelers for the year. All of this information lead to the calculation of the peak numbers of disabled passengers for the top 50 airports.

After estimating the maximum number of disabled passengers that would travel through an airport during the day our team could then examine the value of the current solution and the Wheels-Up solution. This examination revealed that the Wheels-Up solution was over 400% more

costly than the current solutions including airport buggys, aisle chairs, and wheelchairs. This high percentage is a direct result of the engineering that went into our solution and the value provided by the autonomous features of the chair.

Although the Wheels-Up solution is more costly when looked at from a strictly material and purchasing perspective, the Wheels-Up solution provides a costing benefit when staffing is compared. As a result of the Wheels-Up solution being fully autonomous, our team predicts a reduced need for third-party contractor staffing by up to 50%. In this scenario, a staff for Wheels-Up could help 24 people in a shift where as a staff member who works with the current solutions today could only help 12 people a shift.

Overall, when staffing costs and value of the two systems is compared, the Wheels-Up solution provides a total reduction in cost of 36%. This number is a very rough estimate of savings mostly provided by the staffing cost reduction and does not account for maintenance on either system. Ideally the two solutions would be tested in an airport to determine the staffing needs for Wheels-Up and whether or not the staffing could indeed be cut by 50%.

All sources and information about the costing calculations can be found in the Excel workbook attached.

5.4.4 Website Cost

The Wheels-Up solution's digital portion is made up of three components: mobile and website front end, integrated Amazon Web Services, and backend database. The cost for the front end consists of the domain name of the website (ex. WheelsUp) and the website and mobile content. We expect the yearly cost of this component to be around $20.00. The cost for the Amazon Web Services include all the AWS products we plan to use in our framework. This includes the Amazon's API Gateway for front and back end communication, Amazon's Simple Storage Service (S3) for website storage, AWS Lambda to process get requests from the website to the database, and Amazon's CloudWatch Logs for website tracking and analytics. We expect the yearly cost for the Integrated Amazon Web Services to be around $4,200.00. Finally, the database cost includes the database instance, email service, storage (GB per hour), and server. We expect the yearly cost of the database to be around $1,500.00.

The security measures we propose for our framework include the Secured Socket Layer (SSL) certificate to move the website protocol from HTTP to HTTPS and the Amazon Cognito user sign-up and sign-in. We expect the cost of the security to be around $23,000.00 per year. Along with the cost of the entire software framework, the total yearly cyber cost will be around $29,000.00.

5.5 Risk Assessment

As with any new technology there are inherent risks to both the users and the people around the users. The risk of someone getting hurt when using the device can be described as minimal as the autonomous features in our wheelchair are meant to be slow moving and cautious. Since the risk is not zero the consequences of this risk must be considered. The following sections examine in more detail certain risks expected with the Wheels-Up solution. The Failure Mode & Effects Analysis walks through each element of the product to better examine failures that could occur. The subsequent sections pertain to the other risks that are not elemental in the wheelchairs design but that should be considered still.

Please click me to download the FMEA for this project.

5.5.1 Social Risk

Navigation error is the major cause of passengers getting lost and may lead to being late and missing a flight. This risk can be refined as the system being outdated and losing internet connection. When an airport updates its facility or a shop decorates, a section of the road may be closed and the wheelchair will need to plan a new route to the destination. If the information stored in the navigation system is outdated, the wheelchair might not recognize the change and go into trouble. False localization may happen when the network connection is weak. Due to the false localization, the wheelchair might collide with obstacles or go to the wrong route. To lower the risks, the navigational system needs to be frequently updated; before implementing the wheelchairs to an airport, the network coverage of all the operating areas should be carefully detected to ensure normal operation.

5.5.2 Physical Risks

The causes of human injury include wheelchair flipping when passing floor gaps or obstacles; collisions between wheelchair/passenger and other people, airport facility, luggage, and another wheelchair. The property damages are either caused by collision between the wheelchair and airport facilities, or passengers belongings falling off during a collision or flipping. In short, interaction between the wheelchair (and its user) and other static and dynamic obstacles may increase the risk of human injury and property damage.

The relative speed between the wheelchair and obstacle is an important factor that affects the severeness of consequences. A lower speed would allow more reaction time to avoid dynamic obstacles, improve the stability when passing floor gaps, and allow passengers experience less impulse when collision or flipping happens. In order to mitigate the risk of serious collisions the wheelchair has included a horn that will let other travelers know when it is nearby. The wheelchair is also limited to a top speed of 4 miles per hour in the airport in an effort to keep any possible collision or flipping from being serious.

5.5.3 Cyber Risks

In addition to physical and social risks, the proposed autonomous wheelchair will have to mitigate potential cyber risks due to the autonomous software and accompanying mobile application. One cyber risk includes not fully protecting a user's personal information presented on the mobile application such as his or her name, flight information, and confirmation number for booking. To mitigate this, the user's information will be stored on a secure AWS (Amazon Web Services) server for a maximum of 30 days after the user's flight has reached its destination.

Another cyber risk includes authentication and authorization. This involves a user using another person's flight information to operate the wheelchair. To mitigate this risk, the user will need to have either a mobile or hardcopy boarding pass given by the official airline and will have to scan the boarding pass to begin operating the wheelchair (see Figure A2). When the user temporarily stops operating the wheelchair in order to use restroom facilities or perform other tasks, he or she will still have to scan the boarding pass to resume operation upon returning to the wheelchair. In

case the user loses his or her boarding pass, the wheelchair will prompt the user to input a 4-digit PIN number to help prevent another user from operating the wheelchair in case he or she picks up the lost boarding pass belonging to the original user.

A third cyber risk includes the wheelchair using the local airport's Wifi to operate autonomously and utilize the functions of the mobile application. Hackers can potentially intercept information stored on the wheelchairs and the mobile application when the device is in the process of connecting to the local wifi. To mitigate this risk, the design team plans to install Anti-malware software as well as use a Virtual Private Network (VPN) to prevent hackers between local wifi-connections from intercepting the data stored in the wheelchair. While these mitigations may not fully eliminate the associated cyber risks, the design team feels that they substantially improve the reliability of the wheelchair and ensure the safety of its users.

We propose using Amazon's Relational Database Service (RDS) to store our database on Amazon Web Services. Amazon's RDS provides features to make our database secure including database encryption using Amazon's Key Management Service (KMS) and granting special permissions for projecting, updating, and deleting data using AWS Identity and Access Management services (IAM). Additionally, we suggest adding security measures for our website to protect user information. These include Amazon's Cognito user login service and a Secured Socket Layer (SSL) Certificate. Amazon Cognito is a simple solution that adds user sign up, sign-in, and access control to our application that allows users to sign up with social identity providers such as Facebook, Google, and Amazon. To keep passenger's information confidential, we propose using the passenger's boarding pass to sign in and view their travel and flight information. The SSL certificate enables encrypted communication between web server and web browser by authenticating the identity of the website and encrypting the data being transmitted. These measures will control user access to the website, and thus control users' interaction with obtaining information from the database. We advocate adding an email server for our database using Amazon's Simple Email Service (SES) which will inform administrators when the database inserts, deletes, and updates information of users, wheelchairs, and airports. This will help database administrators to keep track of what content is stored in the database. Furthermore, we recommend adding security levels (Top Secret, Secret, Classified, Unclassified) for database users. This measure can prevent database users with lower security levels from inserting, deleting, and changing data already stored in the database without permission from the database administrator or from those with higher security level access.

6 Research & Outreach

6.1 Aisle Chair User Survey

This survey was constructed to validate the need for a better solution to help disabled passengers maneuver through airports and inside passenger aircrafts. The Wheels-Up automated wheelchair targets disabled air passengers, a very specific community that is unfortunately not always represented as well as other consumer groups. It is through this survey that we were able to hear directly from our stakeholders and receive personal anecdotes and opinions on the problems and possible solutions for disabled airport travel and boarding chairs.

Due to the impact of COVID-19 and the national lockdown, as soon as the survey process started, it was initially very difficult to effectively distribute the survey with any expectations of

success. But in reaching out to resources such as Purdue University's Disability Resource Center, we were able to be put in contact with people who dealt directly with the relevant community. Over the course of the year we contacted organizations like Joni and Friends who were able to point us to appropriate facebook communities who would welcome input from external researchers. After requesting access and posting on a few accessible travel facebook groups, the survey responses skyrocketed and we were introduced to even more people willing to help. Most notably, the president and founder of the nonprofit organization All Wheels Up, Inc, Michele Campanelli-Erwin, reached out to provide insight on our survey and also asked permission to distribute the survey on her personal facebook page.

The survey is divided into four sections: demographics, closed-ended, open-ended, and likert scale questions. The demographic section covers gender, age, flying frequency, and region. The closed-ended questions deal with aisle chair need, transition, and navigation. The open ended questions deal with possible improvements and inconveniences the user can choose to comment on. Lastly there are two sections of likert scale questions: one that deals with opinions on current methods of accessible travel and the other about boarding chair features. Using the results from this survey we can gauge how our product will help the accessible travel community and what needs our solution can address that the current methods are lacking.

With a total of 127 responses, the survey was a success in collecting data concerning the need for a better accessible travel solution. In analyzing the demographics, the spread was actually relatively even across all categories, providing a diverse perspective for the presented problem. Women outnumbered men at about 63% and the average age per respondent was about 48 years old. Each region of the United States was evenly represented, ranging from 13-18% with international responses at 22%. Interestingly enough, the average number of flights per respondent was about 3 times per year, much higher than expected.

For the closed-ended questions, the results were overwhelmingly clear as to the accuracy of the target audience and the need for a better accessible airport solution. 93% of all respondents require the use of an aisle chair while boarding an airplane which accounts for our primary demographic. Due to the almost unanimous use of an aisle chair among respondents, the corresponding anecdotes and comments on the problems of the current solution can be taken seriously. When asked if the "transition between an airport wheelchair to an aisle chair is a difficult process that needs improvement", over 95% of responses were in agreement. The primary goal of our solution is to eliminate this transition period and allow users to seamlessly board the plane using one wheelchair. Additionally, in a similar question, 90% of users responded that "navigating the airport/aircraft would be easier if only one wheelchair was used for the entire airport experience". This addresses the navigation aspect of the airport experience as our solution also aims to make traveling within the airport/aircraft much easier for users.

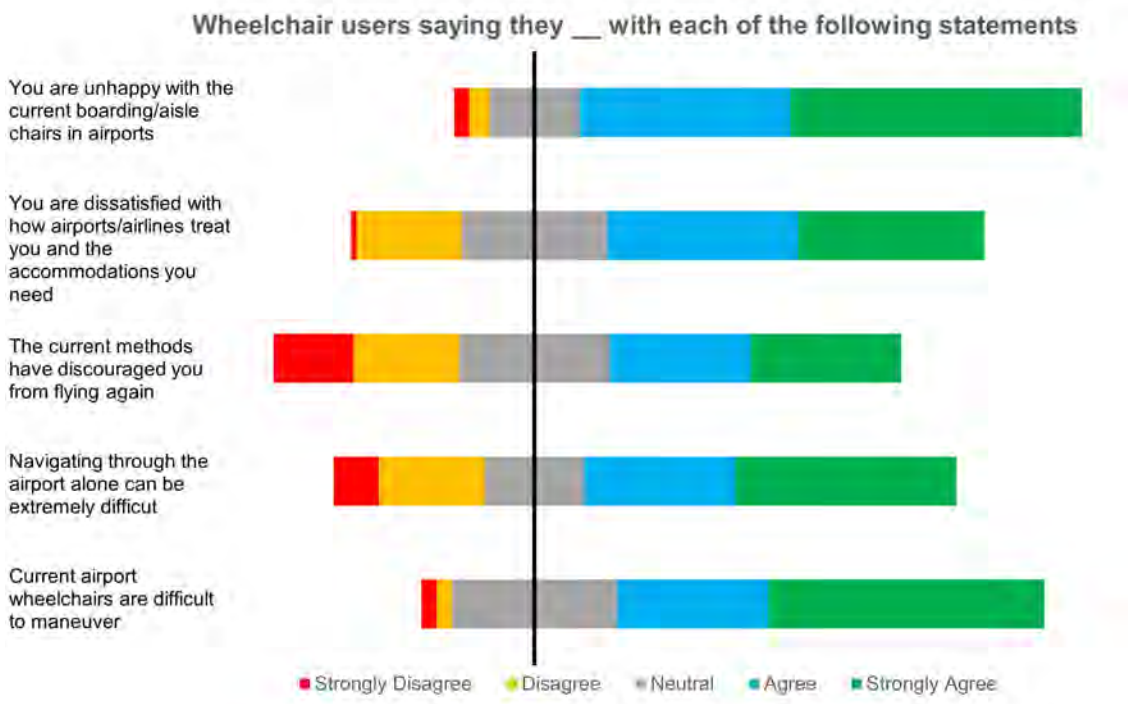

Figure 8: Survey Response of Most and Least Problematic Wheelchair Design Features

In the second Likert-scale section, users were asked to rate design features of current airport aisle chairs from 1 to 5 (1-Most Problematic, 5-Least Problematic). The features included are: comfort, back support, straps, mobility, leg room, ease of use, and ease of wheelchair transfer. The responses were surprisingly split up evenly, with a small average range from 1.79 (ease of transfer) to 2.47 (back support). Ease of transfer from airport chair to aisle chair is one of the main focuses of our project and our responders feel the same way as it was ranked as the most problematic feature of the current aisle chairs. Given that each feature averaged below 3, every feature is important to aisle chair users and none can be ignored.

7 Testing

7.1 CAD Testing

Designing an entirely new wheelchair started with rudimentary concept generation and brainstorming but quickly followed with Computer Aided Design (CAD). Evaluation of the CAD through Finite Element Analysis (FEA) allowed the team to determine whether the wheelchair design met stability and structural criteria. These two digital tools resulted in an accurate appraisal and an optimized design for no cost.

Early decisions on the design were driven by physical intuition. Starting from the limiting dimensions of an airplane aisle, the team set the minimum wheel-base width. From the predetermined width (15 inches), a long wheelbase was created to maintain forward stability and all the mecanum wheels were encapsulated within the base. A modular chassis with narrow supports allowed the chair to compress and the seat flaps to fold underneath the seat. Two telescoping

slides and a scissor jack connect the two halves of the chassis and provide structural stability. The seat-supports, which connect the chassis to the seat, were placed near the rear wheels to provide room underneath the seat for the passenger's legs and small luggage. These factors led the team to the develop a rudimentary model of the Wheels-Up solution.

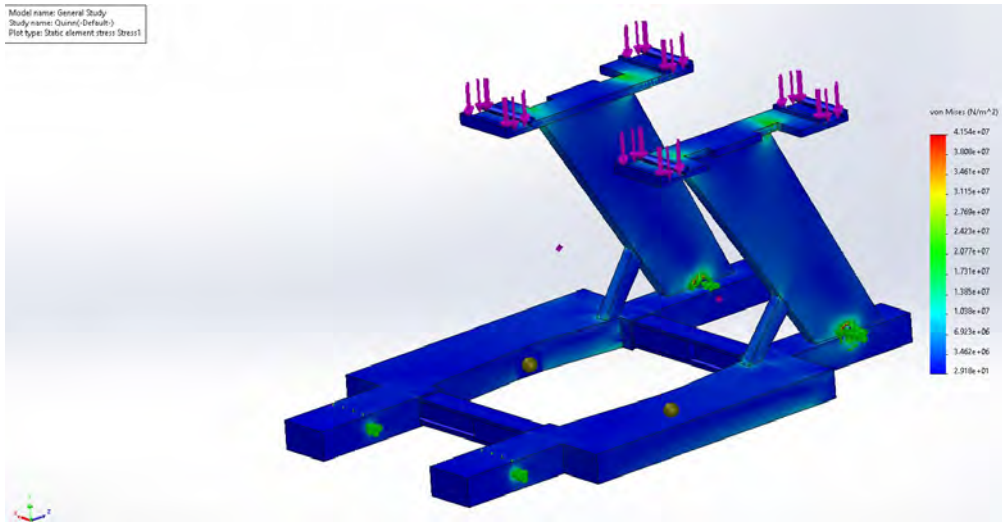

Figure 9: Finite Element Analysis of the split aluminum chassis

Building complexity in the CAD model was a time-intensive process that led to a lighter, less-expensive design. Material properties were assigned to each part to get an accurate approximation wheelchair mass and to allow for structural analysis (see Parts List in the Appendix for details on component materials). Solid bodies were shelled whenever possible, and complex support structures took their place. The best example of this complexity is in the aluminum chassis where the solid interior was replaced with structural ribs (see Figure). All components were put into an assembly to confirm that nothing interfered and that the designed motion of the chair was feasible.

As part complexity increased, structural analysis was needed to verify that the design could handle the maximum loads. The points of failure for the chair were examined through finite element analysis (FEA) in Solidworks. The complex geometry forced the team to examine the screw-jack and chassis independently.

The aluminum chassis was examined under a 400-lbf load applied uniformly to the seat-supports (see Figure). The analysis was done in the fully expanded state (25-inch wheelbase) when stresses on the telescoping slides were a maximum. From this analysis, we determined stress concentrations near the seat-support connection (see Figure) and significant deflection at the interface between the base and the rear telescoping slide. However, the stress and deflection did not approach failure or yield of the aluminum.

The steel scissor jack was examined based on the results of the chassis analysis. The bending stress calculated in the simple beam within the chassis was applied to the jack independently. This analysis pointed out stress concentrations in the expansion screw and expansion screw-holder (see Figure 10) but also confirmed that the jack would not approach the yield stress of the steel.

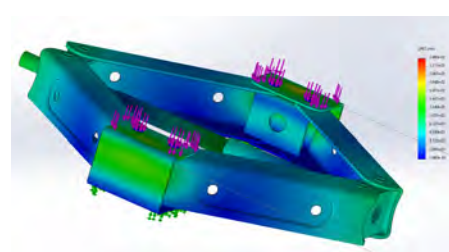

Figure 10: FEA Analysis of the scissor jack

Even though the original FEA did not result in component failures, the team made improvements to the design to limit stress concentrations and large deflections. The seat-support of the chassis interior was given a supporting brace in opposition to the acute angle. The channel interface between the base and the telescoping slides was closed to avoid large deflections. The resulting improvement can be seen in Figure 11. The scissor jack employed c-beam supports in order to withstand greater vertical loads. Moreover, the spindle that is used to rotate the jack, to allow compression and extension of the chair, was reinforced such that the connection points within the jack could withstand greater loads than a traditional scissor jack.

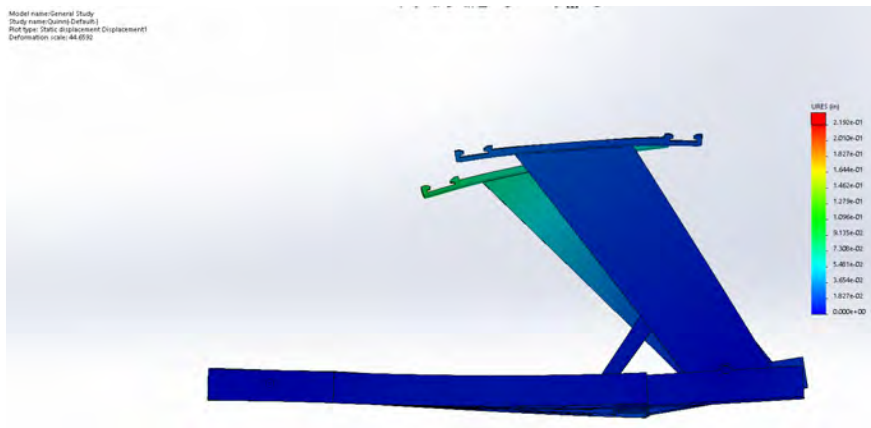

Figure 11: Chassis Improvements resulted in less deflection and less stress

The final results of CAD testing confirmed a maximum load of at least 400 lbs with a safety factor of 6. The structural rigidity of the chair can be certain to withstand fatigue and, with proper maintenance, extend the life cycle of the Wheels-Up wheelchair. The FEA method was discussed with Julio Hernandez, a PhD candidate at Purdue University, in order to confirm the analysis was valid.

7.2 Autonomy Testing

The complicated task of creating an autonomous prototype required the creation of a specialized team to code and build the vehicle using a combination of free software and inexpensive hardware. The team member's all contributed to both the programming and construction of the prototype.

Team Member	Year	Major
Ali Almakhmari	Junior	Aerospace Engineering
Joel Rivera	Junior	Aerospace Engineering
Brandon Dimitri Thomas Skelly	Junior	Aerospace Engineering
Michael Baldomero	Senior	Aerospace Engineering
Tomoki Koike	Senior	Aerospace Engineering

Table 1: Autonomous Group Team Members

In order to autonomously travel to a destination, the Wheels-Up solution must visualize and interact with the world around it. To do this, the on-board computer must make use of an array of

sensors including a LiDAR sensor, four ultrasonic sensors, two wide-field cameras, an accelerometer, a gyroscope, and a GPS sensor. These sensors allow for dynamic mapping of the airport to better understand the dynamic airport environment. Google's indoor maps for large airports were used for proof of concept in this regime.

To avoid obstacles and objects in the airport, the autonomy group created an algorithm using Python. Two raspberry pi 3s were used as on-board computers to process data from the myriad of sensors, and Open Computer Vision (OpenCV), a package within Python, was used to utilize the on-board cameras. Text recognition was also built into our robotic operating system in order for the autonomous Wheelchair to check that it had indeed arrived at its target destination.

The autonomous group is continuing to develop the prototype and refine the autonomous algorithms. Footage of their progress will be a keynote in the final presentation.

7.3 Challenges and Mitigation

When designing the Wheels-Up solution many physical challenges needed to be overcome. Some of the largest challenges included designing a contracting wheelbase that was functional with a passenger on board and fitting a stable wheelchair in a narrow airplane aisle.

Our solution also needed to overcome certain cyber risks to be a viable solution to the problem at hand. Some of these cyber risks overcome included protecting personal data and an unsolved challenge of working with airlines to create a cohesive system of wheelchair requesting and returning.

Other challenges were overcome as well. For one, market research was protected by paywalls making estimation of costs and consumer habits harder to predict. This information was available but we did not have the resources to access it. Cost estimation of the wheelchair was also challenging to derive as we needed to cost parts individually instead of as a system that would be scaled. This drove our cost up.

One final area in which we had challenges in was in public outreach. It was very difficult to engage the appropriate community to answer the survey and provide relevant feedback regarding the current methods of using aisle chairs. Many resources and contacts were explored but it took a very long time to arrive at an adequate amount of responses. The particular community is also protected and not usually privy to outsiders in the form of surveys or research participation.

8 Conclusion & Key Findings

8.1 Impact Statement

To quantitatively examine the users experience Wheels-Up has focused on reduction of boarding time as a benefit for both airlines and passengers. The average boarding time of a 200 passenger plane ranges anywhere from 20 to 25 minutes. Using video documentation and first hand accounts, Wheels-Up has determined that the average time to board is 4.9 minutes for someone in a wheelchair. The average time to transfer from a regular wheelchair to aisle chair is on average about 1.4 minutes.

Wheels-Up has estimated a total transition time of 30 seconds from full wheel mode to aisle mode. This estimate provides a collapse speed of of an inch every second. Using this estimate and the numbers gained above from previous data, we can say that Wheels-Up would reduce the total boarding time by about 35%. When compared to the maximum observed time to transition to Aisle Chair we can see that the user's reduction in transfer time would be about 86%.

Looking now at the airline time savings we see that with a transfer time of 30 seconds, the overall board time is reduced by 10% which is cascading with multiple wheelchairs boarding a plane. It should be noted that all of this data was gathered from current traveler's personal experience. Although this gives an accurate depiction of timing Wheels-Up would like to point out that this experience was mostly documented by travelers who were with a companion or were in very good shape. Transfer time results may be assumed to increase if the user is older or less capable than those personal experiences gathered in Wheels-Up research.

The Wheels-Up automated wheelchair will have a positive impact among passengers traveling through airports across the United States. First, there will be less dependence on wheelchair staff and other passengers to operate the wheelchair manually because of its autonomous components. This will allow for a more comfortable and relaxed experience for both the passenger operating the wheelchair and his/her companions. Also, social distancing measures will be better maintained by both the passengers and staff at each airport as a result of the autonomous travel. Second, the wheelchair provides both an easier and more convenient experience for their occupants in terms of boarding and deplaning aircraft. There will be less staff needed at the terminal to assist those in wheelchairs while boarding and deplaning aircraft, allowing for quicker boarding and deplaning transition times. Furthermore, since the wheelchair can adjust its width to fit through passenger aisles on an aircraft, there will be no need for occupants to transition to a different wheelchair while boarding an aircraft.

The mobile application also has numerous benefits. First, wheelchair occupants can request for assistance with a click of a button if needed. This feature can alert wheelchair staff quickly to help passengers in need of assistance with operation or any other problems encountered while using the device. Second, the application allows passengers to receive airport information digitally, including dining and shopping areas, baggage claims, and flight departure and arrival information. This can help passengers by reducing the need to check on departure and arrival screens at the airport because they can obtain flight information through the app itself.

8.2 Conclusion

Airlines and airports have lacked the ability or willingness to fund more valid solutions to the problem of disables air passenger mobility experience. The innovative wheelchair design and comprehensive software management system laid out in this proposal represents a chance for the FAA to step up, take the lead, and solve a great challenge for those among us who are least able to get around. Under the CFR, airlines are ultimately responsible for the passenger experience (including disabled passengers) and the assumption is that the free market will solve this problem. It has not. The triad of FAA-Airlines-Airport Authorities has partnered together in the past to build the world's greatest, safest aviation transportation system on the planet. With a redesigned wheelchair and the leadership of the FAA, the triad can solve this issue and bring physically disabled passengers the experience they deserve.

9 Technical Demonstration

In order to demonstrate the concept laid forth above the team will use a myriad of demonstration materials. In order to demonstrate the manufacturability of the design, the team will be presenting a scaled model of our design 3D printed from plastic. This scaled model will be shown during the presentation video. The team will also be showcasing the work done by the autonomous group via a prerecorded video of the autonomous vehicle moving in an environment. Finally, in order to demonstrate the mechanisms needed for wheelchair contraction and expansion, the team will be using SolidWorks' "Motion Study" software to create a simulation. All technical demonstration materials will be included in the presentation video file that will be submitted on November 17th, 2020.

10 Project Timeline

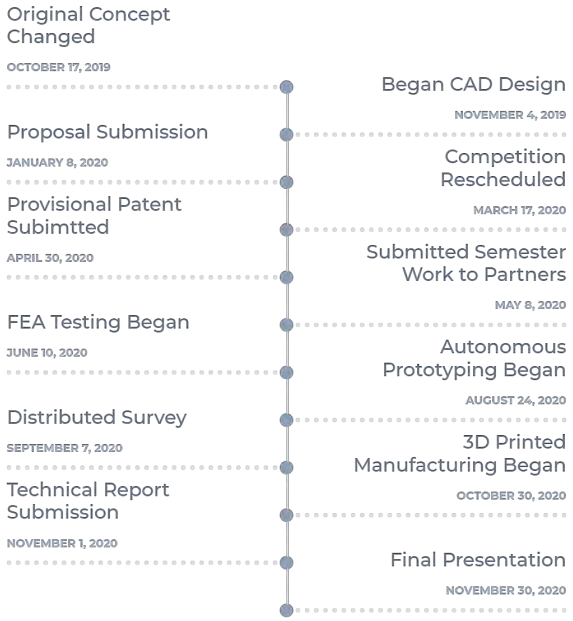

Figure 12: Project Timeline

11 Budget

While this project required hundreds of hours of work, many of the ideas were conceived and simulated using computer models. This meant that the project's design could be iterated without costly prototyping. This in turn meant that the research group was able to do all work for free until prototyping was started. The main prototyping done was 3D printing and autonomous testing. By the end of this project a total of about $25 will have been spent on 3D printing materials and a total of about $500 will have been spent on prototyping our autonomous design. The total cost of the project was relatively small in this manner as we spent just over $525.

11.1 Autonomy Testing Budget

As mentioned previously in this report, our original team created a specialized team that was focused on making an autonomous vehicle prototype. This team needed specific materials and lab space in order to make this prototype. The following table details the ordered parts and their costs along with the total budget of the class.

Part	**Quantity**	**Unit Cost**	**Total Cost**
Drive Motors	4	$13.99	$59.14
Motor Mounting Brackets	4	$11.99	$47.96
Five-Pack Raspberry Pi Ultrasonic Sensor	1	$9.59	$9.95
Raspberry Pi Camera	1	$20.17	$20.17
Raspberry Pi IR Camera	2	$29.99	$59.98
Raspberry Pi Sensehat	2	$34.88	$69.76
Raspberry Pi GPS Unit	1	$16.95	$16.95
Four-Pack Mecanum Wheels	1	$75.60	$75.60
Miscellanious Raspberry Pi Parts	///	///	$98.63
Fasteners	///	///	$14.54
Total	///	///	$472.68

Table 2: Autonomy Prototype Budget

11.2 Acknowledgements

Throughout this entire project the team has received a great deal of support and assistance.

The team would first like to thank Professor Sun and Purdue University for all their support and guidance over the past year. Purdue's support and leadership has allowed the team to use their facilities and continue to meet in-person even during uncertain times.

The team would also like to extend a sincere thank you to all of the private contributions that were made to the autonomous group. Without these donations the team would not have had access to such advanced hardware and could not have developed the algorithms and programs used in this report.

The team would like to thank our industry partners Jeff Tyrcha his enthusiasm and knowledgeable guidance during our competition. A warm thanks is extended to Michele Erwin for reaching out to our group. Her help with research and outreach was invaluable and her passion about airport accessibility instilled confidence in the team.

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13 Appendices

13.1 CAD Parts

Figure 13: Single C-Beam Support

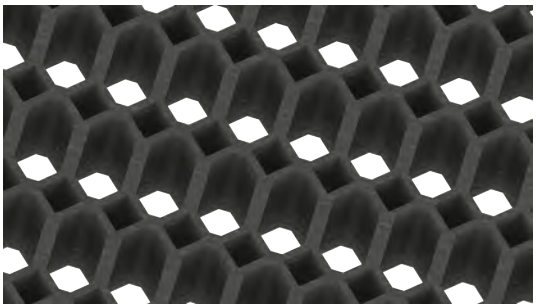

Figure 14: Hexacell Structure

13.2 Mobile Interface Design

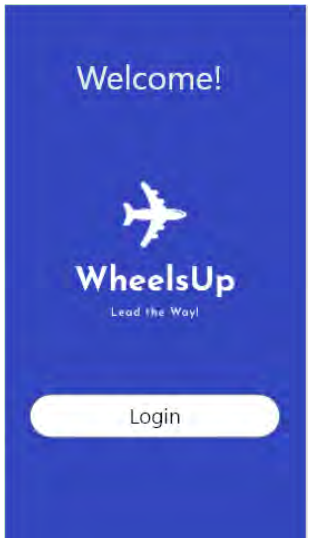

Figure 15: Touchscreen Display Welcome Screen

Figure 16: Touchscreen Display Signaling Passenger to Scan Boarding Pass

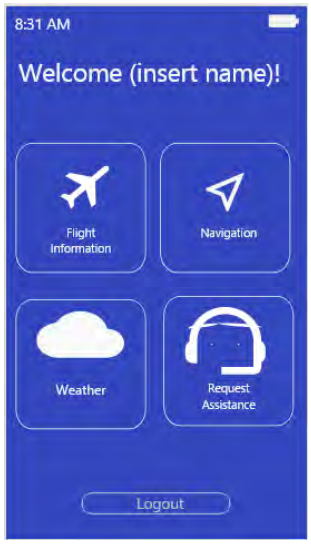

Figure 17: Touchscreen Display of Home Screen

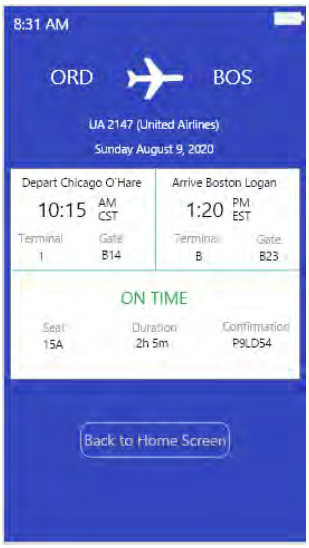

Figure 18: Touchscreen Display of User's Flight Information

Figure 19: Touchscreen Display of Passenger's Current Location in Airport

Figure 20: Touchscreen Display of Navigational Assistance to Requested Destination

Figure 21: Touchscreen Display of Weather Forecast

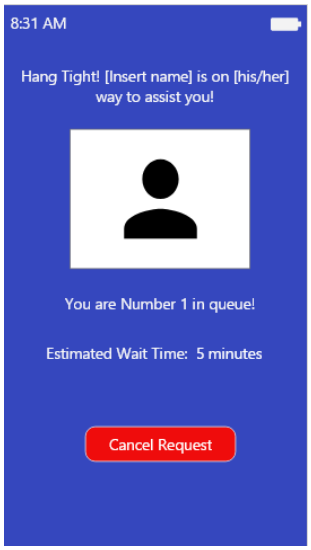

Figure 22: Touchscreen Display when User Requests Assistance

13.3 Tabulated Survey Comments

How would you like to see boarding chairs improve/develop?
Not sure
Simply maintaining the chairs would be a big improvement. I require a headrest since I don't have great neck strength. Multiple times I have been put in an aisle chair that has a broken headrest.
It's more of an issue with the plane. Making the 90 degree turn from the plane door to the aisle is always tricky, especially on small planes.
They are difficult to transfer to and it is very jarring even after the transfer. Also very few planes have options for getting to thThey need to be more comfortable and easier to transfer to and from.
bathroom after you have been boarded.
They need to be more comfortable and easier to transfer to and from.
I would like to see completely eliminated. They are unsafe, uncomfortable and humiliating to use.
Something that doesnt resemble my looking like Hanibal Lectur when im strapped in! If i have to use a transfer chair id prefer something sturdier.
Yes- no arn rest
I wish they could be avoided completely by having some reserved seats near the exits! Baring that, the excessive restraints that are used is cumbersome and embarrassing.
I would love to be able to either stay in my power chair or park it next to me and have it tied down and I transfer to an aisle chair
An easier way to transfer, it can be painful and incompetently done
Some I have been in have been foldable with fabric on top which makes you feel very unsafe and that it will collapse. I always feel like I will loose my balance in the chair until they rip it back - would be nice that they are slightly tailored back so when they put you down for not fighting gravity so much. There aren't any arm rests to hold onto most Ines to stabilise yourself or if there is they are too short to be of any use.
something that raises and lowers so I don't have to try to get over the arm rests
Note: Southwest allows me to take my chair down to row 1 and transfer directly, avoid use of an aisle chair. Would like boarding chairs to be easier to transfer on and off, and be belted and unbelted quickly and securely, without too much hoopla. quickly
I would love it if they were longer. My legs don't stay bent well, so having space for them would be great. Armrests would be helpful. Wider seats would be perfect, but I know that would be harder because of aisle width. Bucket seating too.
Easier to transfer from wheelchair to aisle seat to airline seat
Eliminated, allow space for wheelchair tie downs near front of the plane.
I'm not sure there is a better solution, although the restraint system could be improved. It takes a lot of effort on the part of the airline attendants to get everything correctly into place without injuring the passenger or taking too long I'm not sure there is a better solution, although the restraint system could be improved. It takes a lot of effort on the part of the airline attendants to get everything correctly into place without injuring the passenger or taking too long
Not have to transfer

First- to be able to stay in my own chair. That won't happen- so - better ways to transfer from wheelchair to aisle chair. Biggest problem is getting from aisle chair into plane set.
Would like them to not be needed
Own chair w/lock in place or easier transport to chair w/my personal chair easily accessible instead of cargo
Do you really think any part of the current design is working well? I'm puny (under 5' and about 100lbs) and it's a tight fit for me to be wheeled down aisles and I normally end up with bruised shoulders because there is no protection when the flight crew don't know how to steer. There's nothing stable to grab onto to assist with transferring to the chair, or to keep you stable while the crew bangs you around (accidentally or negligently). The number of transfers is also insane - on to the chair, onto the airplane seat, back onto the chair if you have to go to the bathroom, back to the airplane seat, then onto transfer chair and back to your wheelchair. Why cant thr aisle chair just snap into place as a real chair to decrease the chance of falling by a factor of 4?
since they can't be any wider more padding in the seat and back would be appreciated
Hate being strapped in and feel like luggage
restroom accessibility
It would be nice to be able to get my own manual wheelchair onto the plane and transfer from that to the actual seat plane
Fewer transitions, safer, more independence.
Best solution would be complete elimination with ability to bring personal wheelchair on board plane
better straps, leg supports More leg room for a 6'0. Dimensions are poor. Too narrow
I'd like the boarding team to use hoist or there should be more space to fit the wheelchair - one transfer would be better than two. Plus avoiding the aisle chair would be perfect
Feet don't touch floor/can't transfer to toilet/scary getting off plane on ramp in Cayman Islands
Consistent safety with belts. Sometimes I feel safely strapped in. Other times I get to my seat hoping all the way not to be tipped out.
Better built, larger
The best case scenario would be not leaving my powered chair. Another nice option would be a foundation that helps provide AFFORDABLE flight assistance aids. It would be amazing if the flight attendees that help transfer received training on how to ask about the disability and make sure they are held to a standard when they don't follow.
They need to have a head rest and have adjustable backs. Depending on the individual...some need to sit up extremely straight while others need to recline.
Get rid of them and let me stay in my chair.
It only works bending back and is embarrassing. Need to widen at least part of aisle to let disabled go in on their own chair then transfer!
It would be nice to transfer from my wheelchair directly to the plane seat and avoid the aisle chair, the aisle chair is very narrow and it is hard for the employees to get that aisle over the hump where is some planes have allowed me to transfer directly from my wheelchair to the plane seat and it is a much smoother transition. I hope this is something that happens in the future good luck with your search
Dock to Seat to eliminate transfers
Wider aisle to transfer from own w/c

Very difficult to get from aisle chair to airplane seats. The aisle chairs are often not functional. If you can't sit in first class you are required to make a turn on which becomes even more difficult. I would like to see file chairs withSlightly more room. Even better would be something similar to the eagle lift
Better footplate - always damaged
More like standard wheelchairs.
Less transitioning from chair to seat preferably able to stay in own wheelchair
Be able to stay in wheelchair is the only way I'd fly again
I actually typically don't bother with the chair unless I'm really far back on the plane. I'd rather just crawl. I wish they were easier to maneuver through the plane and more intuitive for the people who assist. Often times it's someone working a lower wage job who hasn't experienced disability or it isn't their first language. So while they're figuring out how to get you in, which color goes to which seatbelt lock, they're really in your personal space and touching uncomfortable areas of your body. I wish the system alleviated the need to do that.
I'm about 240lbs. The chairs are too small which I understand they need to go through the aisle but that also means they are tippy. Maybe adding a stabilizing component to the jetway so then you can transfer on and off while the chair is "docked".
I find the inconsistency troubling when it comes to the dreaded aisle chair. Many are old, many have straps that do not work. Some have foot straps, some do not.
One size does not fit all and they break and injure the passenger. The transfer is awful.
If a boarding chair method is used maybe have color coded seatbelts so it's easier to find which ones attach. It can take up quite a bit of time to find which belts match to secure you in the seat.
Better stability, easier transferring.
Headrest and footrest
Yes, this is why I quit flying!
I don't use them yet, but it would be great to stay in my own wheelchair.
Allow for easier manuvering when it makes the turn from door to aisle.
Be able to move up and down.
keep one on each plane.
ideally boarding chairs should be phased out so that people can stay in their own chairs.
I have only been a full time w/c user for this one year, but my experience with the aisle chairs has been great. Super kind and helpful airline staff. My concern is making the use of the bathroom more accessible. That's the hard trick when someone can't stand at all,
More knowledgeable handlers
I need to be able to stay in my current wheelchair the entire time
It's so tiny. I'm small and I feel like I barely fit. 16x16 seating in wheelchair. Security is a hugs challenge. It hurts to be touched. Even when I tell them, I get a major pat down. Head to toe. Very painful. Carbon fiber and titanium chair. Smartdrive. Place for wheelchair or wheels on plane. Always needs repairs when flying. Being able to use a restroom.
I want them not to exist at all, in other words I want to be able to roll onto a plane in my own chair and be strapped in. 2nd Place would be a chair that I can transfer into easily prior to boarding and not have to get out of once I'm on the plane.
Make chairs standard across airlines

More adjustable
more comfort for the rider; less chance of being dropped by the handlers
Make the aisle wider. Actually the need to be the height is planes seats. As arms can be moved they should be more substantial
More comfort, able to handle tall or obese people better.
Larger size.
Wheelchairs locked at front of plane
More room
Newer ones are too smaell. My feet fall off the footrest.
Easier to use, not depending in people to help me transfer
That they not be necessary for any wheelchair user unable to walk. If you are truly unable to move out of your chair, there's likely a good medical reason as to why staying in your chair during the flight would be beneficial to you (head control, body restraints, pressure sore relief, etc). A person should be able to stay in their chair while on a plane
Make room and tie down to be able to stay in my own wheelchair.
small one for us smaller people
Wider aisles are needed on planes
Arms, headrest, better straps
Weel all the way to my seat.
back and head support, maybe a hoyer available on the airport would be also a good idea
Less awkward. Glide better. Not hit the seats as it moves down the aisle.
I would like to be able to use my own wheelchair or be able to use a more secure system, like the Eagle lift.
have movable arms and cushioned seats
Bring wheelchair on board
Wider and safer. They aren't made with safety in mind.
Allow caregiver or husband to do the transfer from the aisle chair to the airplane chair. Also the aisle chair needs to be more padded
Feel more secure
I would love an aisle stretcher as I can't sit on the boarding chairs so lying down would be so helpful
stay in my chair-seat closer to the front as no space between aisle when being wheeled by the attendantsse
Currently they are a nightmare and totally unsafe. Ive been dropped, bumped, bruised and disrespected being moved from my wheelchair to an aisle chair. Something with arms? Something that you can remain in for the entire flight? Preferably my own chair.ir?
I hate transferring from airport wheelchair to aisle transport chair. And getting up from low seat on chair is very challenging.
Need a headrest
Change the brakes or locking system
Led love to stay in my wheelc
Ideally I would like to stay in my own chair!
Some airline cabin doors are wide enough to fit a wheelchair, which is great but then you can't get to your seat because the aisle is not wide enough, unless there is no first class and you can book and transfer into the front seat.
Pressure relieving seating

Ability to stay in chair for flight
Take my own chair on board
I'd like them removed completely and wheelchair spaces made with secure locking systems as used on trains, taxis and other vehicles.
I would prefer to not have to use one at all and be able to use my own wheelchair that fits my body instead of some narrow uncomfortable chair that I feel like I'm going to fall off of
More ability to have a wider chair and a chair that reclines
However is deemed necessary for everyone to be able to travel
Use my own power wheelchait
I would like airplanes to be configured so that seats can be taken away and replaced with a customised wheelchair instead. If trains and busses can do it, why not aircradt
Anything would be an improvement! Too narrow. Too low.
motorised for the staff pushing them.
The same height as the plane seats. Possible able to transfer straight from my wheelchair.
Go away. They're dangerous and don't provide support.
Lateral and head support
Eliminate them. My manual chair fits into the plane and if I can get the first row I can transfer myself.
Never seen one because none offered
Bigger seat
Size, working seatbelts, trained assistance,
We need to be able to stay in our own wheelchairs.

13.4 Survey Demographic Information

Demographics Data		
Total Responses	127	
Gender	Male	36.8%
	Female	63.2%
Age	Under 21	5.56%
	21-30	14.29%
	31-40	13.49%
	41-50	17.46%
	51-60	22.22%
	61-70	23.02%
	71-80	3.17%
	Over 80	0.79%
Location	Northeast	13.6%
	Southeast	17.6%
	Southwest	12.8%
	Midwest	17.6%
	West	16.0%
	International	22.4%
Flying Frequency	Never	7.14%
	1-2 times/year	42.86%
	3-4 times/year	32.54%
	5-6 times/year	7.94%
	7+ times/year	9.52%

Figure 23: Demographic Breakdown by Percentage

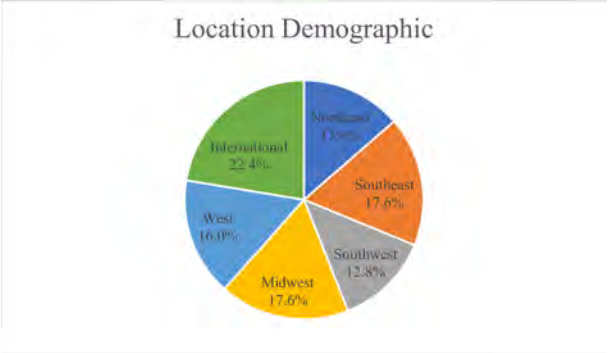

Figure 24: Survey Response Age Demographic

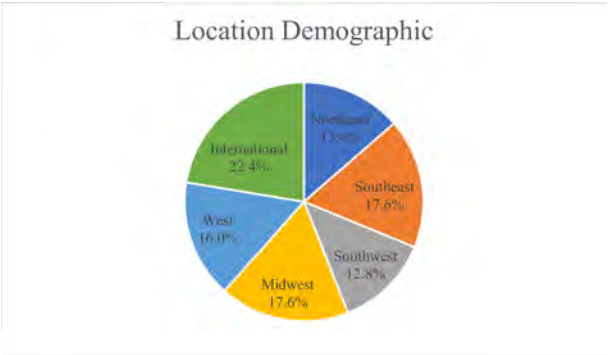

Figure 25: Survey Response Location Demographic

13.5 Survey Graphical Information

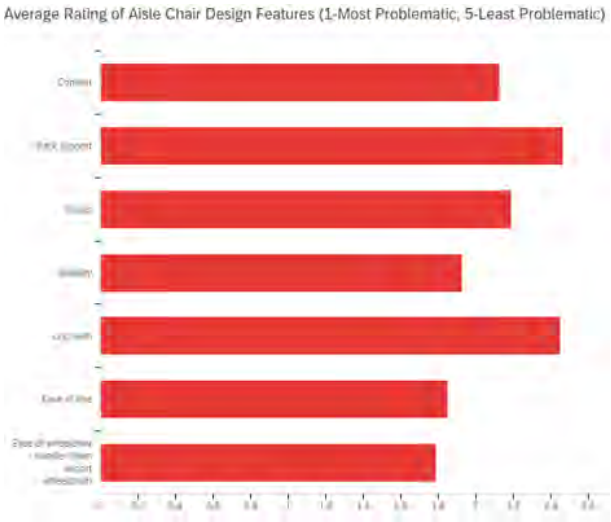

Figure 26: Survey Response of Most and Least Problematic Wheelchair Design Features

13.6 Website & Database System

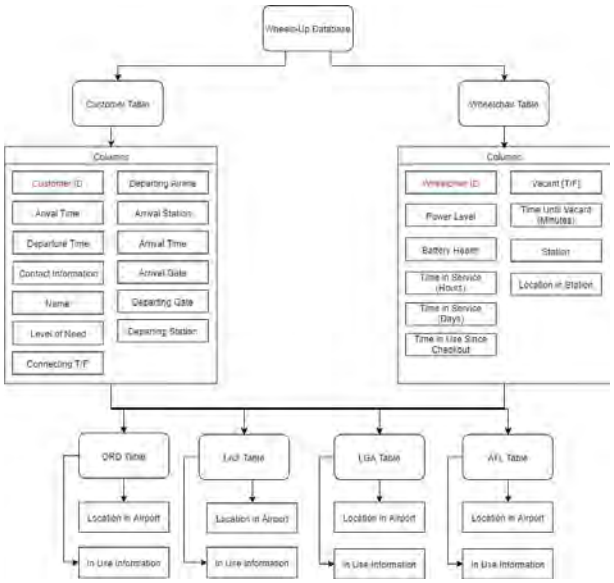

Figure 27: Flow of Data Between Systems

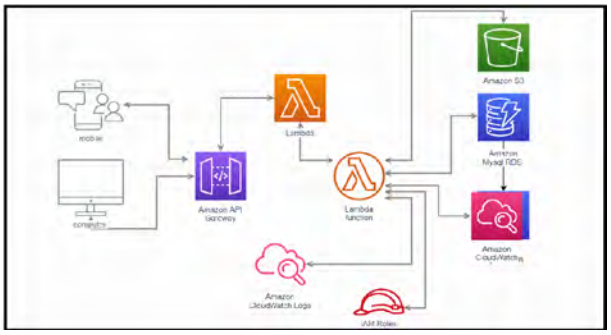

Figure 28: AWS Integration System Overview

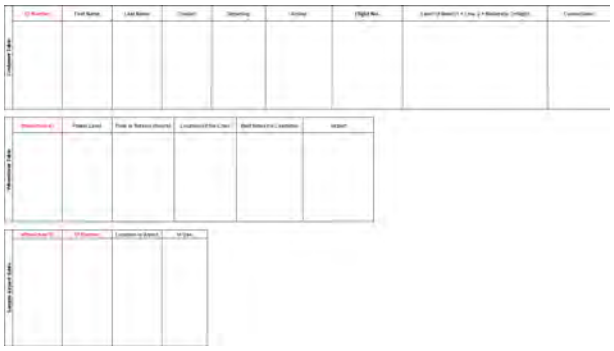

Figure 29: Data Table Structure for Proposed Database

13.7 Mobile Website Design

Figure 30: Mobile Website Home Page

Figure 31: Mobile Website Sign In Page

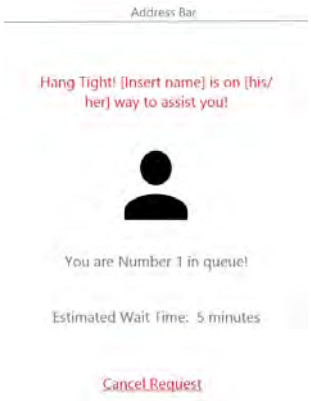

Figure 32: Mobile Website Assistance Page

13.8 Desktop Website Design

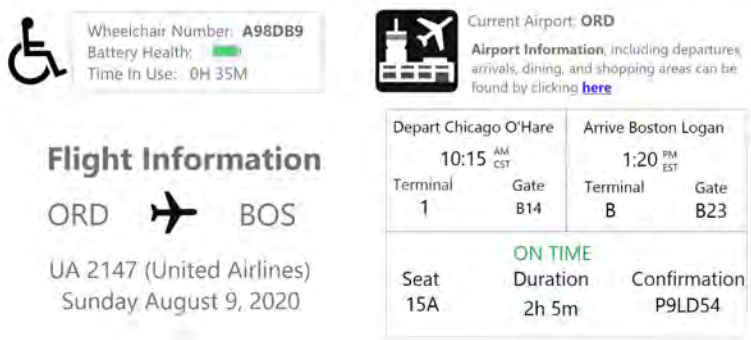

Figure 33: Desktop Website Home Page

Figure 34: Desktop Website Sign In Page