ACRP Challenge: Airport Management and Planning

L.E.N.D. - Low Energy Navigation Device

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<u>Executive Summary</u>

In this proposal, a team of four undergraduate students at the Penn State University's Engineering Leadership program has taken on ACRP Challenge 4.9, *Innovations to Accommodate the Aging Passenger Demographics in Airports*. The team proposes a solution to provide navigation assistance to senior passengers who have difficulty navigating unfamiliar spaces. Currently, airport passengers download mobile phone applications to assist them while they navigate an airport terminal. After conducting extensive field research and a thorough literature review, the team discovered that some of these applications were challenging to use and may cause difficulty due to smartphone incompatibility and technological illiteracy in seniors. Our solution will use a pre-programmed handheld navigation device, The L.E.N.D., that directs passengers through the airport to their destination using Bluetooth Low Energy Beacons. The team has thoroughly analyzed the potential industry impact of the L.E.N.D. through cost-to-benefit ratio analysis, a formal risk assessment, and conducting interviews with project stakeholders and experts. After a thorough analysis, the team concluded that our proposal is feasible, s business potential, and will make an impact at airports. By using this device, airports can empower older passengers and reduce the stress associated with making their flights. In light of the COVID-19 pandemic, fewer passengers feel comfortable with traveling by air; an associated goal of the project is to draw this more hesitant group back to air travel in a safe and ethical way while making them feel more comfortable with airport terminals. In addition to the confidence the device instills in passengers, the extra downtime passengers will have due to more efficient travel will give them more time to spend money, creating significant revenue and profits for airports.

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Problem Statement and Background

The senior population in the United States is projected to dramatically increase over the next few decades. By 2034, the number of children below 18 is projected to be less than the number of citizens above 65 (Older People Projected to Outnumber Children for First Time in U.S. History, U.S. Census, 2018). This growing demographic will become a more sizable portion of airport clients; if these problems are not addressed, airports may lose this generation of passengers and additional revenue. Along with this increase in clients, seniors may have issues with standing for extended periods, light to moderate walking, and difficulties manipulating objects (WHO, 2018). In addition to these issues, older passengers are also affected by sensory disabilities such as poor eyesight and hearing loss (WHO, 2018). Navigating airports can be taxing to someone in an unfamiliar setting; difficulty understanding directions or signage in an airport compounds this problem further and can cause undue stress. An increasingly overlooked barrier with the elderly population is with technological literacy and navigating online apps and sources. Only 53% of seniors over 65 have a smartphone, which may make certain resources unobtainable under stressful situations (Pew, 2019). Not only would a smartphone-based navigation solution be ineffective, but this lack of experience with technology can be frustrating when accessing information over the internet or at information centers.

Airports have implemented numerous solutions to address problems associated with fatigue and navigation. High fatigue activities in an airport are caused by walking long distances and carrying heavy luggage. To ameliorate this issue, airports have installed walkways and provided motorized carts and wheelchairs for those with constant fatigue. Similarly, escalators and elevators ease fatigue induced from climbing stairs. Customer support staff help senior passengers with fatigue through baggage carrying and pushing wheelchairs to their destinations.

Many airlines offer transportation services to their gates upon request forty-eight hours before their departure. Free Wi-Fi services in airports enable passengers to use their smart devices to find paths to their destination (Mein et al., 2014). Moreover, designated help desks and kiosks are available to answer questions and guide passengers experiencing disorientation. Finally, all airports are required to provide signage and message boards that lead passengers to their destinations. While these solutions help seniors, not being informed about assistance options for health-related issues such as poor sight and hearing make it difficult for them to use these solutions (WHO, 2018).

The project aims to assist older passengers in navigating through airports without experiencing high fatigue. The solution should be cost-effective in installation and maintenance, simple to use for those not as technologically literate, and readily available and accessible for the senior population. If the solution is not cost-effective, there is little chance that airports will try to implement a risky idea with no proof of concept or significant monetary incentive. Because seniors may lack technological literacy, any solution implemented must be simple so that anyone can fully utilize the solution. Finally, the solution should be easily advertised within the airport. Solutions are only effective if they are well-known; therefore, any solution should be visible and accessible in an airport while being advertised to seniors throughout the terminal.

Summary of Research

Airport Literature Review

Seniors in America face issues related to fatigue and wayfinding when traveling through airports. A Rose, Thorn, Bud activity, adapted from the LUMA Institute, was employed to generate potential research areas, and begin research into several aspects of this problem (LUMA Institute, n.d.). During this activity, two to three potential research areas were generated, and their positive aspects (Rose), negative aspects (Thorn), and insights for each idea (Bud) were identified. The activity generated nine ideas, further categorized into navigation, wheelchairs, kiosks, and A.D.A. compliance.

Airports and airlines must satisfy numerous rules and regulations to be A.D.A. compliant. These relate to kiosks, wheelchairs, wait times, and video walls. Twenty-five percent of airport kiosks need to be A.D.A. compliant (Transportation Department, 2013), which needs to be a design consideration for future projects. Furthermore, the screens need to be between 15 and 48 inches in width and have resources such as closed captions for hearing or vision impaired people. Additionally, help desks must be available when A.D.A.-compliant kiosks are unavailable. In addition to kiosks, wheelchairs must be stowed on planes free of charge to assist passengers. Some potential solutions could be limited due to the rules and regulations imposed by government bodies, and these factors will affect what services are allowed in the solution phase of the project.

Navigating an airport and providing accurate ticket information to senior passengers is especially challenging. Because of this, the team considered ticket handling as an area of research to assist navigation and ease wayfinding; ideas considered including directions on tickets to aid the elderly in wayfinding to their destination gate. However, most passengers today prefer using electronic versions of tickets over traditional paper tickets (Rice, 2014). Most tickets distributed worldwide are virtual, and their rate of adoption is increasing; as of 2007, more than 84% of tickets are distributed electronically around the world (Austen, 2007). Additionally, the rules and regulations regarding manipulating tickets would hinder the effectiveness of the design challenge and make the implementation of a potential solution extremely difficult.

Airports and airlines must comply with numerous wheelchairs and guided assistance regulations. The team researched wheelchairs to better understand the solutions that were already in place to assist seniors, who can become tired from carrying heavy baggage and walking between destinations. Airlines are required by law to provide wheelchairs to those who need them (U.S Department of Transportation, n.d.). Additionally, there are weight requirements for wheelchairs based on the airline, further restricting design solutions (Morris, 2020).

Kiosks are often spread across airports near airline check-in counters, shopping areas, and even food courts. The team researched the possibility of integrating wayfinding systems into kiosks to either print or display directions to the destination gate. While the kiosks implemented by airlines exist to help passengers check into airports, the kiosks implemented by airports serve other purposes, such as ordering food, asking for help, and navigating through the airport terminal. Smaller airports usually have airline-operated kiosks exclusively and no airport-operated kiosks because of limited passenger volume. Kiosks are highly programmable, which makes them very suitable for navigation, and a kiosk-based solution could be technologically feasible while being visible to seniors. The team concluded that, of the four research categories from the airport literature review, kiosks and wheelchairs had the most potential after weighing the benefits and pitfalls of each area.

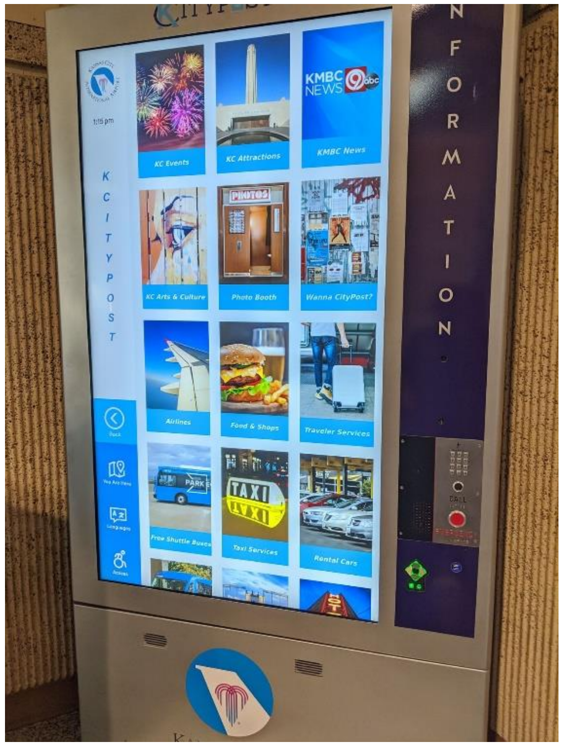

Figure 1: An information kiosk with a complex user interface.

Airport Field Research

Field research was conducted at the University Park Airport to gain a real-life perspective on the design project and obtain additional insight into how older passengers would navigate an unfamiliar airport environment. First, an immersion technique, described by the LUMA Institute, was conducted to gain firsthand knowledge of the situation. This research technique, known as a "Walk-a-Mile Immersion," focuses on the experience from the consumer point of view while noting changes that could improve the wholistic customer experience (LUMA, 2012). This activity involved a wheelchair requested from the airport beforehand and weighted luggage and bags to simulate how a passenger would navigate through the airport with these items in tow. Through this activity, insight into the limitations and proficiencies of modern wheelchair design was directly observed. The research activity also highlighted how the airport's facilities could be improved for a passenger in a wheelchair. Other aspects of the airport toured to look at improving the wheelchair design include an observation of the kiosk systems in place at the airport, seating arrangements, and baggage claim areas.

In addition to physical assistance, the team observed the effectiveness of virtual solutions to wayfinding at airports. Team members each chose an airline and downloaded their respective mobile phone applications to see what a passenger with a smartphone would have to experience. Because of different phone models, some apps were downloaded faster than others, which would further increase frustration for passengers who do not have the latest technology. Once downloaded, the applications had a variety of menus and options for airports that were challenging to navigate and had small text that may be difficult to read for passengers with vision impairments. This test was another indication that there were shortcomings with the existing solution in terms of ease-of-use for seniors and effectiveness while highlighting a gap in the market for a simpler navigation-based solution.

For a passenger in the wheelchair, the flight kiosks provided by different airlines had a screen angle that limited visibility and some buttons and screen components were too far to reach. However, in the ADA-compliant kiosks, passenger amenities such as an audio port and lowered screen helped with visibility and reduced confusion. The research was recorded about these changes for future use if the design challenge were to trend towards a kiosk-based solution.

Figure 2: Team members at the University Park Airport conducting the "Walk-a-Mile Immersion" field research project.

Interaction with Airport Operators and Industry Experts

To aid in the research of the design challenge, two professionals from the airline industry were contacted: James Meyer, Executive Director of the University Park Airport (SCE), and John Greaud, Commercial Aviation Lead at Barge Design Solutions. In addition to calls with these two individuals, email questionnaires to industry experts were also used, with one of these requests being Dr. David Byers, President of Quadrex Aviation.

James Meyer

The team's discussion with Mr. Meyer helped narrowed the scope of the design solution. Using his years of experience managing the University Park Airport, he gave key insights into the relationship that airports have with airlines as well as the roles and responsibilities that are shared between them. Through the interview, Mr. Meyer thoroughly defined which problems are handled by airlines and airports; the airlines provide direct help for senior passengers while the airport itself focuses on navigation inside the terminal. Also, Mr. Meyer explained that older passengers request assistance upon purchasing tickets or 24 hours in advance and their requests for wheelchairs and other forms of assistance are handled by individual airlines instead of terminals. This was critical to the development of the project since the team now knew which organization or business to approach for design solutions. Since airports are not as involved in fulfilling the wheelchair needs of passengers, the scope of the design solution was further narrowed to the development of wayfinding solutions to help passengers navigate to their destinations.

John Greaud

Mr. Greaud discussed the differences between wayfinding structures such as signs and symbols, electronic or physical maps showing location, and FIDS (Flight Information Display Systems) that show passengers which gate their flight will be departing from. He explained that, in terms of displaying information to passengers, less is more; providing too much information to passengers can overwhelm some passengers and could aid in confusion. One idea presented was using boarding pass information as a method of identifying locations for passengers to travel. Mr. Greaud stated that almost all airlines use exclusively digital boarding passes because of the immense savings on paper products and the simplification of a complex process. He also emphasized that the solution should be impactful and function correctly all the time and be extremely effective. Before the conclusion of the interview, Mr. Greaud recommended research into safety risks associated with a kiosk system, especially with the possibility of overcrowding vital junctions of the airport.

David Byers

Dr. Byers was instrumental throughout the brainstorming phase, giving feedback on design solutions and issues these solutions can create. He discussed the durability solutions that would be required to have in high traffic areas and current solutions in place today. His extensive knowledge of airports was helpful to understand solutions that have been put in place in the past and how they functioned in an airport setting. In addition, he identified many of the current wayfinding issues in American airports today and advised the team to choose a solution that was technologically complex in a simple package Something Dr. Byers gave us great insight on was safety risks, which allowed us to really analyze our final solution to ensure that it would meet safety standards. At the conclusion of the interview, Dr. Byers gave some insight towards the cost-benefit analysis and said to focus on these areas when designing the solution and drafting the report. Overall, Dr. Byers provided exemplary assistance throughout the report and freely provided his expertise in a seamless and collaborative experience.

Point-of-View Statement

We met Mr. Meyer, the airport operator of the University Park Airport (SCE). We were amazed to learn that airlines provide help directly, while airports focus on navigation. It would be revolutionary if a technologically simple, cost-effective, and accessible wayfinding solution be provided to help elderly passengers get to their destinations.

Problem-Solving Approach

Problem Formulation and Background Investigation

A series of activities were completed to narrow down which design challenge would be completed and how to frame the chosen challenge in the appropriate context. Exploration into which design challenge prototype would be the most hands-on was discussed and the feasibility of creating a physical prototype was considered. After all the data was factored and collected, the decision to help senior passengers navigate airports would be the most appropriate and accessible design challenge to replicate and investigate under real-world conditions. After the design challenge was chosen, it was delved further into using the *Frame Your Design Challenge* worksheet from the "Field Guide to Human-Centered Design." In this activity, particular focus was on the constraints of a potential solution; these areas included the implementation costs of the proposed solution, low technological literacy among seniors in America, and the issue of bringing awareness to the solution. Therefore, the problem was framed into the following design question: "In what ways can assistance be provided to the elderly population in navigating airports while being cost-effective, technologically simple, and easily accessible?"

To further understand the design challenge and gain perspective on viable solutions, a detailed understanding of usable infrastructure at airports and possible issues with solutions was required. Through conversations with airport staff and industry experts, aspects of the project were discovered that would add to the efficiency and cost-effectiveness of the solution, such as using boarding passes and the presence of pre-constructed kiosks. The Q.R. code present onboarding passes contains information about the gate and flight for the passenger and could be used for navigation purposes. Navigation-based kiosks are already present at airports and use flight data from terminal computers to display information; if this resource could be used legally and effectively, design solutions could be integrated into kiosks and decrease the cost of the solution. Also, problems were discovered that the design solutions would have to work around; these include maintaining the flow of traffic in the terminal, changing the infrastructure of terminals, and the technological literacy of some senior passengers.

Brainstorming Approach

Before brainstorming solutions, multiple mental exercises were performed to get into the mindset of the problem and target audience group. These exercises were retrieved from the "Field Guide to Human-Centered Design" by IDEO which was developed to focus on the communities who will be served and create solutions rooted in people's actual needs. One of the first activities done was "Share Inspiring Stories," which helped team members resonate with the senior demographic. During the research, the team interacted with different stakeholders, and sharing these stories with each other gave key insights into what this demographic needs.

From these stories, many important insights were made about the target audience of senior passengers. One of the most important insights was that even if there are resources for senior passengers, there is no guarantee they will use them correctly or even use them at all. Often, senior passengers do not know of solutions already in place, and they often are hesitant when voicing their needs. This insight played a key role during problem-solving, as there was a shift from using kiosks to also incorporating the device at counters that could be given to senior passengers. This change would help with informing passengers of our solution's existence and ensure seniors use the solution in its entirety. Following these activities, a "Top Five" activity was performed that allowed team members to share the most important themes of the project. Some of the themes identified were knowledge of a solution, ease of use, prevention of backlogs or bottle-neck points, and rate of turnover. Upon identifying these themes, the next exercise involved the creation of insight statements to connect the themes and focus on the targeted demographic prior to brainstorming. Some of the core insights used for brainstorming are listed below:

- Ease of use is the defining characteristic of whether elderly passengers will utilize our solution.
- If a solution processes customers too slowly, the system will create a backlog in the queuing line and obstruct airport walkways.
- Deciding between modifying existing solutions or a brand-new solution allows us to brainstorm more topics in a variety of fields.
- Implementing both physical and software solutions into a kiosk gives passengers more options to choose from.

After identifying themes for the project, the team began brainstorming potential solutions with set rules for engaging each other, such as speaking one at a time and accepting outlandish solutions in the preliminary stages of the project. These rules for brainstorming created an inviting environment for members and increased the quality and quantity of feasible ideas. In addition to these rules, mental breaks were taken when group morale drifted. This allowed everyone to produce new sets of ideas when brainstorming resumed. During the brainstorming session, some solutions seemed more effective than others. For instance, help buttons could be placed at regular intervals to request assistance or a virtual robot as a kiosk to aid passengers. Eventually, a "creativity slump" was reached, during which ideas seemed to be forced and linear, such as a conveyer belt transportation system for passengers. However, more innovative and creative ideas were generated after breaks and adherence to the brainstorming rules. One idea generated showed promise as a feature or as a solution; after passengers scan their boarding passes at kiosks, a map would be displayed on the screen and print a physical map with detailed directions that seniors can use as a guide. Alternatively, the kiosk could dispense a buzzer that would point passengers in the right direction as they travel. The brainstorming session ended in a plethora of ideas that were further structured and organized into a cohesive document.

Affinity-Clustering and Bull's-eye diagramming, two LUMA strategies, were also used to categorize and narrow down ideas. During the Affinity-Clustering activity, four large boxes were drawn on the whiteboard, and ideas with similar themes were grouped up into one of those four categories: Q.R. codes and their application, AR/VR, wayfinding, kiosk design, and scanning/retrieving data from databases. During the Bull's-eye diagram activity, three concentric circles labeled primary, secondary, and tertiary were illustrated on the whiteboard, and ideas were placed based on their relative importance. Themes that best aligned with the goal were placed at the center of the bull's-eye diagram. Upon completion of both activities, five ideas were generated, all of which seemed equally effective solutions. These solutions centered around the use of an intuitive kiosk that by scanning a boarding pass and using predictive algorithms based on time, location, and flight the desired directions could be displayed. Additional concepts like navigation displayed on the floor, printing physical maps with the directions, and the use of handheld buzzers that point passengers in the right direction was also generated.

Stakeholder Feedback

Senior family members from the team's extended family were contacted throughout the project, as their insight into the design challenge's stakeholders was extremely relevant and impactful. One grandmother of a team member appreciated the navigation kiosk design developed. When asked whether she preferred the screen-only navigation method or floor-based navigation method, she said she would prefer to have some floor-based navigation component implemented with the kiosk. As she said "A line on the floor would be wonderful! It would feel like there was someone there helping passengers through the airport!" Another family member interviewed appreciated the buzzer system and recommended that the solution have speech recognition for added simplicity. The stakeholder also mentioned that she especially liked this solution because of its reusability and commented that passengers may prefer color coding for different destinations, such as bathrooms or dining experiences.

In addition to grandparents, an industry expert in that aging population was contacted. Dr. Byers, President of Quadrex Aviation, provided a unique perspective on the design challenge because of his experience both designing terminals and as a passenger in terminals new to him. Dr. Byers took particular interest in the concept of the modified kiosk and recommended adding reinforcers when someone is navigating the terminal correctly and before the passenger scans again for directions. A concept that Dr. Byers thought paired well with the kiosk is the use of interactive floor signs that guide passengers to their destination. He suggested that the markers could not only be on the floors but could also aid navigation on walls. One concern discussed was the material being used as a floor marker must be extremely durable and resistant to wear since floors receive heavy foot traffic and cleaning. The next concept shared with Dr. Byers was printing maps using the boarding pass of the passenger. An area not previously noticed was that passengers who would use maps at the airport would have their boarding pass printed at the airport. Since these are the same people that receive their boarding pass printed, they could also have their custom map printed at the same time. The last concept shared with Dr. Byers was a buzzer that individuals could be handed that would point them in the right direction. Dr. Byers was particularly interested in this idea and advised on the feasibility of the solution. Since the devices would be simple, he explained the idea's potential for cost-efficiency and predicted the devices could operate with an RFID signal. Another design choice for the solution would be tactile feedback for an additional layer of immersion. Since the device would have similar operations as a smartphone, an app could be developed for other passengers to use their phones instead of an airport-provided device. However, his main concern with the buzzer solution was the distribution of the device and ensuring that the devices were deposited at the airport for reuse and not lost or unknowingly stolen.

Technical Aspects

Solution Selection

There were five solutions generated by the end of the "Imagine" phase of the project: printing maps through a kiosk interface, displaying maps on kiosks, wayfinding using a buzzer-like device, navigating using wall-based illumination wall-based navigation, and navigating using images of landmarks through a kiosk interface. Team members ranked each of the five solutions from favorable to unfavorable and explained their reasonings and opinions during an activity to understand team preferences and points of view. Through this discussion-based activity, the team realized the landmark-based solution was vague and complicated and that the display-based solution was simplistic and uncreative. The team decided to unanimously disregard both ideas because they served better as features in other solutions rather than solutions themselves.

Decision Matrix

The remaining three solutions were evaluated in a six-criteria decision matrix shown below in Table 1.

Table 1: Evaluation of solutions through the decision matrix

Criteria	Kiosk Printer	Buzzer-Based	Wall-Based
User-friendly/simplicity	8	7	7
Reliability (low failure rate)	4.5	8	9
Feasibility	9	9	4
Widescale adoption	3.5	7	8
Innovativeness	4	8	7.5
Safety	10	8	10
TOTAL	39	47	45.5

Initially, there were eleven criteria, out of which the members selected the six most suitable ones. The team decided to select the buzzer-based solution as the final solution because it scored the highest on the decision matrix. Additionally, the buzzer-based solution was both highly innovative and feasible. On the contrary, the kiosk-printer solution had high feasibility but low innovativeness. The wall-based solution had high innovativeness but low feasibility, primarily due to the lack of walls near certain areas in airports.

Rapid Prototyping

Figure 3: Initial rapid prototype

The main goal of the prototyping phase was to obtain immediate feedback on design concepts to make incremental improvements over the prototyping phase of the project. The first rapid prototype shown is a model of the small handheld navigation device. Its primary purpose would be to show the direction a passenger needs to travel to reach their gate. One of the concerns about this prototype from stakeholders was that the device did not have enough features. The group decided to add buttons to the device, and the corners were rounded to make the device more comfortable to hold. Additionally, the screen would be made green rather than black due to the widespread stakeholder appeal for the contrast provided by the green background. Another design factor to be determined was how many additional buttons and features the device would have during the following steps.

Figure 4: Secondary iterations of the rapid prototype

To simplify the user experience and account for their technological literacy, the team decided that the devices would have two buttons: one for directions to bathroom facilities and one to the passenger's gate. In addition to the buttons, the device was given the name "Low Energy Navigation Device", or L.E.N.D. Overall, feedback from users and experts was widely favorable towards the final rapid prototypes shown below. Multiple stakeholders appreciated the simplicity of the two-button design and the explicit directions of an arrow pointing passengers in the right direction. Additional feedback from an in-person meeting with senior relatives and a 3D printed prototype yielded additional information, such as having buttons for eating establishments or rental car areas. Also, the senior family members appreciated the large text and arrow design of the prototype and were particularly impressed at the simplicity and versatility of the solution.

Figure 5: Prototype concept art for the final design of the L.E.N.D.

Figure 6: Final Prototype C.A.D. Model in SolidWorks and 3D printed device

Final Prototype and Summarization of Technical Aspects

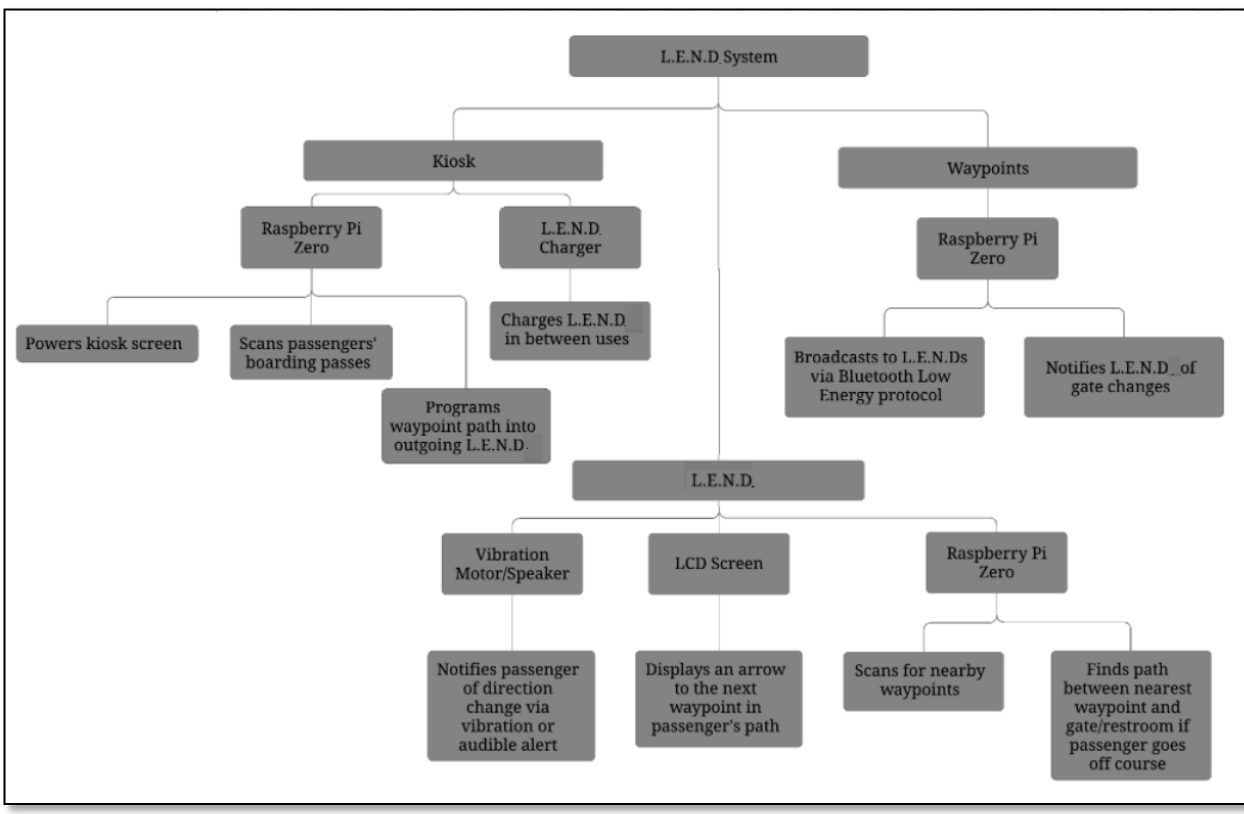

Figure 7: Function decomposition of the L.E.N.D

Using the feedback from multiple rounds of rapid prototyping, the team developed the final prototype of the L.E.N.D. system. Outlined in the functional decomposition above, the L.E.N.D. system incorporates kiosks for passengers to receive L.E.N.D.s, the devices themselves, and Bluetooth Low Energy beacons to enable navigation. Upon arrival at the airport, older passengers will have the opportunity to receive a pre-programmed L.E.N.D. free of charge either from the check-in counter or L.E.N.D. kiosks distributed around the airport. By default, the device will point to a passenger's gate, but using the restroom button will direct the passenger to the nearest bathroom, afterward which the gate button will put them back on their original path. Any gate changes to a passenger's flight will be broadcast to the L.E.N.D., and their path will subsequently be updated to the correct location. Both a C.A.D. model and a 3D printed prototype have been included below. In addition, a commercial demonstrating the L.E.N.D.'s benefits have been included as part of the final prototype and can be accessed in the Q.R. code on the cover page of this report and has also been included below. Not only is the commercial informative and lighthearted, but the specific style of the commercial is modeled from advertisements typically seen on television shows that are popular with older populations.

Figure 8: L.E.N.D. Commercial filmed by team members

The L.E.N.D. works by using Bluetooth Low Energy (BLE) beacon technology that sends out message data and other information. For this application, these waypoints provide approximate location information to the L.E.N.D. along with other waypoints placed at strategic locations throughout the airport. These waypoints will be used to construct an undirected graph of the airport. At the beginning of the airport experience, a passenger would scan their boarding pass Q.R. code with a scanner built into the kiosk holding the L.E.N.D.s. Using the obtained information, which includes the flight and gate number of the passenger, the kiosk will perform a breadth-first search of the waypoint graph and determine the shortest path between the kiosk and the passenger's gate. This path will then be programmed into the passenger's L.E.N.D. With each waypoint around the airport projecting a unique identifying frequency, the handheld unit will select which waypoints are on the path to the airport and which signals to ignore. After the user receives the L.E.N.D, the screen will display an arrow pointing in the direction of the first waypoint along the path. Once the user approaches 5-10 feet from this first waypoint, the device will signal to the user with haptic feedback and visual cues that the L.E.N.D. is changing towards which waypoint the device will point. This process repeats until the user approaches their destination, in which the waypoint will signal to the passenger to have the device returned. If the passenger goes off their given path, then the L.E.N.D. will identify the waypoint closest to the passenger and plot a new path to their destination.

Safety Risk Assessment

While safety is important in all design endeavors, the L.E.N.D. is designed to assist a population with possible health problems making safety in the L.E.N.D. system's implementation in an airport paramount. Per the F.A.A.'s mission "to provide the safest, most efficient aerospace system in the world.," a safety management system or SMS has been developed for the L.E.N.D. system (Federal Aviation Administration, 2019).

To create this SMS, the five phases for safety risk management outlined in F.A.A. AC 150/5200-37, Introduction to Safety Management Systems for Airport Operators, were employed, including:

1. describing the system
2. identifying hazards
3. analyzing the risk in terms of likelihood and severity
4. assessing the risk and
5. controlling the risk

The team determined each identified hazard's likelihood and severity and included a plan to mitigate or reduce the risk associated with that hazard in the table below. Both industry experts and senior stakeholders were consulted to develop potential hazards associated with using the L.E.N.D. The likelihood of each hazard was then rated on a scale of frequent to extremely improbable using this feedback. The severity of the hazard was then rated on a scale of catastrophic to minimal. Finally, using the risk matrix from the Safety Management System Manual (see below), the risk of each hazard was calculated. With this risk determined, mitigation solutions for each hazard were developed to lower the hazard level.

Table 2: Table describing risk levels based on likelihood and severity

Likelihood \ Severity	Minimal 5	Minor 4	Major 3	Hazardous 2	Catastrophic 1
Frequent A	Low	Medium	High	High	High
Probable B	Low	Medium	High	High	High
Remote C	Low	Medium	Medium	High	High
Extremely Remote D	Low	Low	Medium	Medium	High
Extremely Improbable E	Low	Low	Low	Medium	High* / Medium

*Risk is high when there is a single point or common cause failure.

Table 3: Table describing likelihood and severity of L.E.N.D. implementation

Hazards	Likelihood	Severity	Mitigation Practices	Result
Lower Situational Awareness while using the L.E.N.D.	Remote (C)	Hazardous (2)	Provide sound / haptic feedback to notify passengers of a direction change	C2→ E2
Dropping the L.E.N.D.	Remote (B)	Hazardous (2)	Incorporate a lanyard into the device to prevent passenger drops	B2→D2
Battery Life of Waypoints	Probable (B)	Major (3)	Power waypoints using AC power from the wall outlet	B3→E3
Loss of L.E.N.D. from Airport	Probable (B)	Minor (4)	Upon arrival at the location the device will remind people to return it at the gate	B4→E4
Changes in Gate Location	Probable (B)	Minor (4)	Gate changes will be broadcasted to the device to automatically update a passenger's path	B4→B5
Turnover Rate of L.E.N.D. Distribution	Remote (C)	Major (3)	Lower time spent at the kiosk through boarding pass scan instead of user inputs	C3→E3
Battery Malfunction and Overheating	Extremely Improbable (E)	Catastrophic (1)	Quality batteries will be used and casing strong enough to withstand falls can mitigate battery punctures	E1→E3
Battery Depletion of L.E.N.D.	Extremely Remote (D)	Major (3)	Batteries will have a large enough capacity to last throughout the day and charge while in kiosks	D3→E3
High Risk	Medium Risk		Low Risk	

Project Impacts/Cost-benefit

Cost/Benefit Analysis

The total cost to bring this design concept to life has been considered below in Tables 14-10. Following the estimated cost are the benefits that this design solution would bring to airports in Table 9. The first phase of design cost, shown in Table 4, Research & Development (Alpha) is related to the work done for this design competition. The student efforts put forth have consisted of a team of 4 working around 8 hours each per week over a 12-week span.

Table 4 Research & Development (Alpha)

A. Research & Development (Alpha)				
Item	Rate	Quantity	Subtotal	Remarks
Labor - University Design Competition				
Student Efforts	$25/hr.	384	$ 9,600	4 students - 96 hrs. ea.
Subtotal			$ 9,600	
Note. This table was adapted from Guidance for Preparing Benefit/Cost Analyses (Byers, 2016)				

The following phase of design cost, shown in Table 5, Research & Development (Beta) is related to the cost of fully bringing the design concept to life. The cost of development has been considered by comparing the cost to similar services. The largest cost has been calculated to be Software Development; on average, this category falls around $50,000 to $250,000 to design and develop a custom application.

Table 5: Research & Development (Beta)

B. Research & Development (Beta)				
Item	Rate	Quantity	Subtotal	Remarks
Labor - Academic R&D				
Student Efforts	$50/hr.	160	$ 8,000	Input from team
Software Development				
Programmer	$ 100,000	1	$ 100,000	Full Development of Service
Testing	$ 25,000	1	$ 25,000	Testing installs/fees
Expenses				
Prototyping Materials	$ 5,000	1	$ 5,000	Cost of testing materials
Software License	$ 750	1	$ 750	
Subtotal			$ 138,750	
Note. This table was adapted from Guidance for Preparing Benefit/Cost Analyses (Byers, 2016)				

The next phase of design cost, shown in Table 6, is related to the actual cost of producing and installing the design solution into an airport. For comparisons to real-world costs and figures, the numbers used in the report reference the Baltimore/Washing International Airport (BWI), a mid-sized airport that serves domestic and international passengers on the East Coast. Much of the installation cost is related to the number of L.E.N.D.s required for the airport. This number is calculated from the estimated number of passengers using the device daily and how many times the device can be reused daily. Using BWI as a benchmark, the number of passengers is determined by taking the total daily departure passengers at BWI, 37,000 (BWI, 2017), and factoring in that 16.5% of Americans are seniors (Statista, 2021). This produced an estimated daily passenger figure of approximately 6,000 uses of the L.E.N.D. The daily reuse rate was calculated by taking the busy hours of 8 AM to 5 PM totaling 9 hours and dividing that by the average check-in to the departure time of 3 hours. By assuming that an airport's daily traffic is primarily generated during these busy hours, one device can be used 3 times per day. Since such a conservative number is used, the number of devices calculated is more than enough to support heavy traffic during high-volume time periods, such as holiday seasons or over the summer.

Table 6: Production and Install Cost

C. Production, Marketing, & Distribution (Based on BWI airport)				
Item	Rate	Quantity	Subtotal	Remarks
Labor - Manufacturing, Sales, & Installation				
Marketing	$ 20	100	$ 2,000	4 students - 96 hrs. ea.
Hardware Install	$ 1	10000	$ 10,000	Installing hardware in the airports
Expenses				
LEND Devices	$ 50	2500	$ 125,000	6,200 Passengers daily / 3 uses per day
Gate Drops/Waypoints	$ 300	75	$ 22,500	75 Gates Total
Ticket Counter Boxes	$ 300	34	$ 10,200	68 Counters, 1 box per 2 counters
Kiosk Dispensers	$ 500	17	$ 8,500	17 Counter Sections
Transport Carts	$ 500	6	$ 3,000	Max 6 Transporters at a time
Waypoints	$ 15	25	$ 375	Intersections & Bathrooms
Subtotal			$ 181,575	
Note. This table was adapted from Guidance for Preparing Benefit/Cost Analyses (Byers, 2016)				

The final phase of design cost, shown in Table 7, is related to the ongoing yearly cost of providing the L.E.N.D. service to passengers. Most of this ongoing cost is from the salaries of additional workers that would make the devices available around an airport. While these are additional costs towards the project, these jobs provide economic benefits to the surrounding community, since the system would provide 12 new jobs paying a livable wage of $16 dollars/hour. Additionally, the solution would also create one additional high-paying skilled job for the maintenance and support of the L.E.N.D. system.

Table 7: Ongoing Cost

D. Operations & Maintenance				
Item	Rate	Quantity	Subtotal	Remarks
Labor - Personnel & Technical Support				
LEND Transporters	$16/hr.	26280	$ 420,480	Rate of return: 86 devices/hour
Onsite tech support	$30/hr.	2080	$ 62,400	Addition person to IT/Maintenance Staff
Expenses				
Electricity	$5/hr.	8760	$ 43,800	Calculated based on engery usage of all kiosk
LEND Repair/Replacement	$ 25,000	1	$ 25,000	5 year life span on average
Subtotal			$ 551,680	Yearly Operating Cost
Note. This table was adapted from Guidance for Preparing Benefit/Cost Analyses (Byers, 2016)				

To account for Overhead & Profits, an additional 25% has been added to the cost shown below in Table 8. Overall, the estimated 3-year cost from R&D to operations for an airport like BWI is approximately $2.5 million.

Table 8: 3-year Summary of Cost

Cost Summary (BWI Airport for 3 Years)				
Item	Rate	Quantity	Subtotal	Remarks
Cost				
Development	$ 329,926	1	$ 329,926	Tables A, B, and C
Operations & Maintenance	$ 551,680	3	$ 1,655,040	Table D
Overhead & Profits, 25%	$ 82,482	1	$ 82,482	Development
Overhead & Profits, 25%	$ 137,920	3	$ 413,760	Operations
Total Cost			$ 2,481,208	Total 3-year cost
Note. This table was adapted from Guidance for Preparing Benefit/Cost Analyses (Byers, 2016)				