Airport Cooperative Research Program: 2022-2023 Design Competition

Airport Environmental Interactions – Increasing Energy Efficiency

Infrared Beam Sensor System for Escalator and Moving Walkway Power Consumption Reduction

January 2023 – May 2023

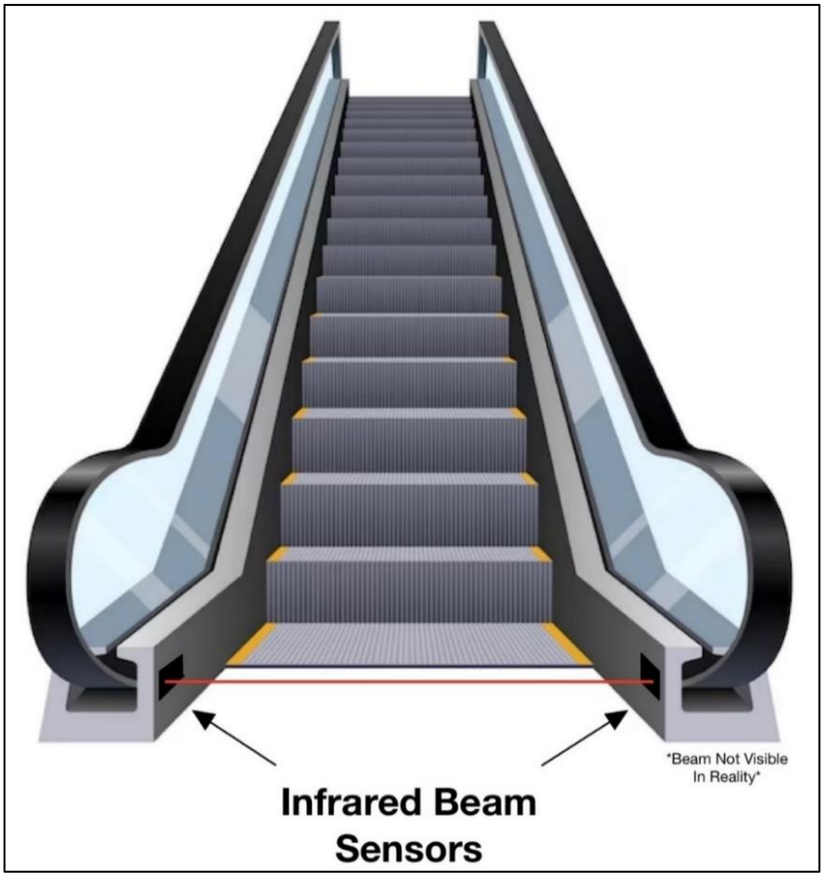
The Pennsylvania State University

Faculty Advisor:

- Abbie Canale

Undergraduate Team Members:

- Collin Price, cap6065@psu.edu
- Joshua Christ, jxc2214@psu.edu
- Taylor Pierce, tkp5284@psu.edu
- Victor Yang, vqy5025@psu.edu
- Abby Chang, acc6087@psu.edu



Executive Summary

This report will outline the design developed by five undergraduate engineering students at The Pennsylvania State University to improve energy efficiency within airports by using sensor technology for escalators and people movers. After conducting research and interviewing stakeholders, the team used a decision matrix to select a solution of utilizing infrared beam sensors to detect the presence of people on escalators and people movers to reduce the energy consumption of airports. Escalators and people movers currently run at full speed, regardless of the presence of people, which is not energy efficient. During the research and interview phase, the team found that airports do not proactively adopt more sustainable infrastructure because it is often not worth the cost or disruption of operation to do so. These insights allowed the team to develop a list of criteria for the solution. Extensive research was conducted on possible sensor technologies that could be used for the solution, which were analyzed through the lens of the required criteria. The team presented the prototype to electrical engineers who provided feedback that led to the team improving the prototype and developing a feasible implementation plan. The solution integrates an infrared beam sensor at the start of the escalator or people mover with a microcontroller system. The escalator will run at a reduced speed until the sensor is tripped, it will then increase to its normal operational speed, where it will operate until a predetermined time has elapsed. If the sensor is activated again within that time, it will continue to operate at full speed. The speed of the escalator will be controlled with a microcontroller and variable frequency drive. The implementation of the solution is straightforward and minimally invasive, requiring minimal modifications to existing infrastructure. Critical risks were analyzed and mitigated. Most risks identified cause little disruption to airport operation, and none cause injury to patrons. Based on the team's cost-benefit analysis, the solution proves to be extremely cost

effective, with significant cost savings even for busy airports. After analyzing the solution's risks, costs, and benefits, the team has determined that using infrared beam sensors to improve the energy efficiency of escalators and people movers is a safe and cost-effective method to improve the sustainability of airports.

Table of Contents

Executive Summary 2

Problem Statement and Background.. 5

Summary of Literature Review 6

Team's Problem-Solving and Design Thinking Approach to the Design Challenge 9

Summary of Stakeholder Feedback.. 10

Solution Selection 12

Prototype Description and Process.. 16

Safety Risk Assessment 20

Projected Impacts of Team's Design and Findings 24

Cost Benefit Analysis.. 24

Conclusion.. 31

Appendix A.. 32

Appendix B.. 34

Appendix C.. 35

Appendix D.. 36

Appendix E 37

Appendix F... 41

Problem Statement and Background

Airports are a critical key in modern infrastructure. Some airports see millions of travelers a year, while in other places, airports are really the only existing infrastructure. As such, the energy challenges of airports are unique and varied. In a world moving toward more renewable energy and still grappling with long term supply effects of the global pandemic, recognizing methods for improving airport energy efficiency are ever important. Similarly, as critical infrastructure, an airport’s energy supply must be secure and resilient.

Airports need new solutions that improve energy efficiency. An average airport uses 19.7 kilowatt-hours of electricity and 34.7 thousand Btu of natural gas per square foot annually. This energy is a large portion of the operating costs of the airport, sometimes as high as 10%-15% of total operating cost (*Airports*). This non-renewable energy also causes a massive carbon footprint, which is very harmful to the environment. By increasing energy efficiency, airports can not only cut down on their average operating costs, but they can also limit the negative impacts that they have on the environment.

As airports age, newer technology is becoming available to increase energy efficiency of airports. One area that could be improved is that of escalators and moving walkways. Many airports rely on a system of escalators and/or moving walkways to assist travelers with moving around the airport. Because this system is constantly running at full power, it uses large amounts of energy, even when there is no foot traffic. Infrared sensor technology can be used to decrease energy consumption during down times in airports of all sizes. This sensor technology can be used to determine the times when escalators and moving walkways don’t need to be running at full power. Therefore, energy consumption within the airport terminal can be decreased.

Summary of Literature Review

As part of preparing to make recommendations for airports to follow, several reports of effective energy use reduction projects from other airports around the globe were reviewed. In particular, *Energy Reduction in Airports* covers projects at four different airports (Choufani, 2016). At the Hong Kong International Airport, engineering teams implemented intelligent sub-monitoring of temperature zones to cater cooling loads more properly with demand and pumping preconditioned air to planes while parked at the airport. In Norway, airports used recycled woodchips to burn for heat, and stored chilled water at night for use during the day. In Galapagos, the airport design is fundamentally green – no terminal temperature control, skylights on the roof, and a purely mechanical baggage handler.

When is an airport truly considered sustainable? According to Gurgit Wood's "What makes a sustainable airport?", although a majority of CO2 emissions are produced by aircraft, ground operation's efforts to be more sustainable can still make a difference (Wood). An airport doesn't have to achieve zero net emissions to be considered sustainable. Sustainability in airports can come from many different places. Whether that be renewable energy, different infrastructure designs, or something else, airports can find many ways to increase their sustainability. It is possible for an airport to increase sustainability without damaging nature or any existing biodiversity. These more sustainable approaches can also be more beneficial to the employees, communities, and travelers that exist around the airport.

According to the *Federal Aviation Administration's (FAA)* Website, most of the greenhouse gases emitted from airports are caused by gasoline and diesel fueled airport vehicles, and non-renewable energy sources used to power airport infrastructure (Airport). One way the FAA suggests reducing energy consumption includes improving building insulation and climate control within the terminals. In addition to reduced costs, airports can receive financial compensation from renewable energy cooperatives. Tax exemptions along with other federal and state incentives give airports additional incentives to increase use of clean energy.

As airports take measures to increase their sustainability and energy efficiency, a standard must be developed to ensure that airports are taking active measures to improve their infrastructure. Effective use of the PEER standard will help airports develop a plan to improve the sustainability of their facilities (Moore 2021). The PEER Standard is composed of four areas: reliability and resiliency, energy efficiency and environment, operational effectiveness, and customer contributions. Currently there are no PEER certified airports in the United States, however, airport facilities in other countries that have been built to the PEER standard have shown good results in the areas of sustainability, energy efficiency, and cost savings.

As the project narrowed in scope, the team performed research on different types of sensors to identify which could be appropriate for the selected final prototype. Below is a list of different sensor types and a summary of the findings.

Wi-Fi sensing uses Wi-Fi signals to detect human activity. Since most people in an airport use cell phones, computers, or other devices that utilize Wi-Fi signals, this technology would be able to sense the presence of people and movement in or out of an area. Due to its nature, this technology would be best suited for an ambient application.

Infrared beam sensors are composed of an infrared beam emitter and receiver. The emitter produces an infrared laser that is invisible to the human eye but can be detected by the emitter. The sensor can detect human activity when the beam between the sensor and emitter is broken. This sensor is best utilized for interactive applications since it works in close proximity.

Video counting technology uses a combination of video capturing devices and computer algorithms to detect and count people. Existing video infrastructure such as surveillance cameras placed throughout the terminals can be used. Computer algorithms are then used to detect the amount of people seen in the video footage.

Floor pressure sensors are floor/carpet tiles that detect human activity by sensing when pressure is applied to them. Similar technology has been utilized in the healthcare industry for inpatient care. The tiles can be placed into existing floor areas seamlessly, however, due to the relatively high cost per area, this technology is best suited for interactive applications.

Radio sensors detect sources of RF signals transmitted in the environment to detect human activity. Due to the amount of electronics present in the airport, RF signals are generated and propagated throughout the facility. Using this technology, the signals can be analyzed and used to detect the presence or movement of people.

Daylight sensors work in conjunction with a buildings lighting system. By detecting the brightness levels of the outside environment, the amount of energy used for indoor lighting is adjusted to take advantage of natural lighting. Currently this technology is seen in many buildings with large amounts of windows.

Passive Infrared Sensors detect infrared radiation from humans. It is capable of detecting individuals who are in both standing and moving states. As a result, data collected by the sensor can be used to track the number of people in an area and the number of individuals leaving and entering the area.

Team's Problem-Solving and Design Thinking Approach to the Design Challenge

The team's first brainstorming session used the brainwriting method, which offers the opportunity for many ideas, from grounded to extremely idealistic. This method begins with every member of a team taking five minutes to think of possible solutions. To generate as many solutions as possible, every member will write down any ideas or thoughts that come to mind. After the five minutes are up, each member will read through all the ideas that were generated and pick two to three favorite solutions. All the ideas conceptualized throughout this process stemmed from either increasing green energy use or energy efficiency within airports.

One theme that was discussed during this brainstorming session was the idea of focusing on low-impact, high-value upgrades and retrofits to existing airport systems. The theme was attractiveness and feasibility of implementation, tying in proven solutions from other sectors and adapting them to airport needs. Some key ideas emerged included improving jetway insulation, speed adjustment sensors for moving walkways and escalators, and reduction of lighting, especially during airport downtime.

Another theme that was discussed was implementing systems that could allow energy generation in airports, increasing self-sufficiency. One idea that was discussed within this theme was based on a trash incinerator in Switzerland that produces electricity and steam from burning trash. In other words, an airport would use trash generated by everyday traffic to power the terminal. Other ideas included incorporating technology that could generate electricity from human activity within airports, developing plans to help airports replace aging infrastructure with newer, more efficient options, and using sensors to reduce electricity consumption.

After the brainstorming session, improving energy efficiency within airports was the common theme. The idea of implementing a trash incinerator system similar to the one in Switzerland seemed like a promising idea at first. However, when considering the overall cost effectiveness and ease of implementation, it became clear that a smaller, simpler system would better align with team goals.

Ultimately, this brainstorming session pointed to the use of sensors within airports to reduce unnecessary energy consumption as the most viable solution for increasing energy efficiency within airports. These sensors would be used to decrease the overall energy consumption. They would detect areas and times of high traffic to decrease energy outputs from many different systems within the terminal such as escalators, people movers, and lighting when demand for these systems drops.

Summary of Stakeholder Feedback

Despite the numerous positive effects of reducing an airport's energy consumption and greenhouse gas emissions, there are several obstacles airports face when achieving these goals. The team met with Chris Babb who works with Landrum & Brown, a private company that investigates airports’ environmental impact across America. He is tasked with finding ways for airports to reduce energy consumption as well as designing plans to install green and renewable energy sources locally at airports.

When speaking with Chris, he stated the largest obstacle when updating outdated infrastructure to new, more sustainable infrastructure is cost. It is not financially reasonable to simply replace outdated infrastructure if these systems are still operating to the airport's needs. For instance, it would not make sense to replace all perfectly operational gasoline- and dieselpowered luggage carriers and plane taxis with newer electric vehicles. Though in the long run it would be cheaper to operate these vehicles, the airport is still essentially wasting money by discarding working equipment. One way Chris suggested to overcome this obstacle is to plan ahead, so that as these outdated systems fail, airports can gradually replace these systems with new and more suitable infrastructure, instead of all at once. Though this might take a long time to achieve full use of more efficient infrastructure, it is a better course of action to balance finances with suitability. Based on this insight, the team decided that a possible solution would have to be easy and inexpensive to implement. Airports would likely reject ideas that would require a major rebuild of any working systems, so devising a solution that would just be an addition to preexisting infrastructure or a gradual update to outdated infrastructure became a priority for the team.

The team also met with Andrew Kleit, a professor of energy and environmental economics at the Pennsylvania State University. Similar to Chris Babb, Professor Kleit also emphasized the idea that airports will not want to spend money to improve a system that already works, especially since clean energy solutions are more expensive to install and maintain. He discussed how more energy efficient systems might require a technical expert, so the airport might need to hire someone specifically to handle energy efficiency. Despite the financial costs, he recognized there could be some financial benefit to transitioning to cleaner energy. An energy efficient system could be designed so that the fluctuating price of electricity throughout the day can complement the operation of the system. This could still help energy efficiency efforts while saving the airport money by buying less electricity during times of higher cost. Even with this potential benefit, Professor Kleit still stressed the idea that many people underestimate the difficulty and costs of managing energy efficient systems. This information caused the team to prioritize low-cost solutions that would be simple to install and maintain.

Later on in the project process, the team received feedback from two other experts. By this time, a rapid prototype had been created and the team was looking for possible improvements or areas of concern with the solution concept. The team spoke with a team of electrical engineers from BL Companies, Robert Zygmunt and John Prete. After hearing about the concept for the rapid prototype, they informed the team about variable frequency drives. These devices can be used to change the speed of motors without changing the voltage that the motor requires. This results in no extra stress being added to the motor because it would run on the same voltage consistently. These devices are not cheap, but still provide a strong return on investment for this solution. Based on this feedback, the team decided to implement variable frequency drives into the proposed solution. The electrical engineers also mentioned some other ideas, like using a passive infrared sensor, which uses thermal imaging to detect people in a general area. These ideas would be great for future exploration. However, at this point in the project, the team had chosen a different sensor to implement and time constraints prevented their new suggestions from being explored.

Solution Selection

After the scope of the project was narrowed to the use of sensors for reduced energy consumption, additional research was conducted on different types of sensors. Sensors were scored based on criteria determined by prior research and stakeholder feedback. Each sensor (apart from daylight) was evaluated in both ambient and interactive applications. Ambient settings encompass a large area such as an airport room or hallway. Interactive applications are ones that involve immediate response to human activity such as escalators and people movers. Research on these sensor types is listed above in the Summary of Literature Review.

Below is a list of all criteria utilized to assess potential sensors.

Ease of implementation is important as airports are generally unwilling to undergo modifications to infrastructure to accommodate new technology without very strong reasoning. If the technology can utilize or be added to existing systems, it would be easier to implement and more appealing to airports. If the system is difficult to implement, it would be less desirable for airports to implement.

Efficiency is another important factor to consider when designing a solution. The goal of this team's project is to reduce energy consumption in airports, and the best way to do that is an efficient design. A design could be great in all other areas, but because the focus is energy efficiency, it's important to take into consideration just how efficient each design solution is.

Versatility determines how well this design can be applied to different settings. Ultimately one of the best solutions is one that could be implemented in many different types of airports. Whether this be small or large, isolated or popular, an efficient solution is one that could be implemented in any case.

The accuracy of a sensor is an essential aspect of its ability to serve its purpose. A sensor needs to be reliable in its readings and avoid unintended operation. The level of accuracy required is variable between situations or applications, but an optimal solution consists of a sensor that provides precise and reliable readings.

Certain types of technology are much more complex than others and may require someone with specialized knowledge to operate. More basic sensors can be maintained and repaired by someone with an average level of general technical knowledge. More complicated sensors might be so specific and niche that a typical maintenance worker would not know how to work with it. If an airport needs to employ someone with this specialized knowledge, this will make the sensor system more expensive to implement and maintain.

Another important factor to consider for any solution is the downtime of installation: for how long will a given solution cause respective system to be out of operation, and how long will it inconvenience customers. While the cost of the labor is already included in installation cost, the downtime itself can be worth considering.

Finally, the team evaluated each system by longevity or potential maintenance costs. A solution is ineffective if it creates more maintenance work than money it saves, so the team considered how long these systems typically last, and how the airport environment may affect this.

	Criteria									
	Ease of implementation	Efficiency	Cost of installation	Cost of operation	Versatility	Accuracy of sensor	Specialized Knowledge	Time of installation (downtime of existing system)	Maintenance/ Longevity	
Solution Options	Rating									Total
Wifi sensors	8	7	5	9	8	8	5	9	6	65
Infrared beam counter	7	5	5	9	3	3	7	6	5	50
Video counting	9	8	7	8	9	5	8	8	8	70
Pressure sensors in floor	6	4	4	8	6	6	8	6	6	54
Radio sensors	7	7	8	8	7	5	8	9	7	66
Daylight sensor	8	7	8	8	7	7	9	9	5	68
Grid-EYE sensor	8	7	8	8	8	7	9	8	6	69

Figure 1 - Ambient Prototype Decision Matrix

	Criteria									
	Ease of implementation	Efficiency	Cost of installation	Cost of operation	Versatility	Accuracy of sensor	Specialized Knowledge	Time of installation (downtime of existing system)	Maintenance/ Longevity	
Solution Options	Rating									Total
Wifi sensors	5	7	5	9	9	6	5	9	8	63
Infrared beam counter	8	8	9	8	9	8	9	7	8	74
Video counting	9	8	9	9	9	5	8	8	8	73
Pressure sensors in floor	8	8	8	8	8	6	6	7	6	65
Radio sensors	8	8	8	9	7	6	6	8	8	68
Grid-EYE sensor	8	8	8	8	8	7	9	8	6	70

Figure 2 - Interactive Prototype Decision Matrix

Prototype Description and Process

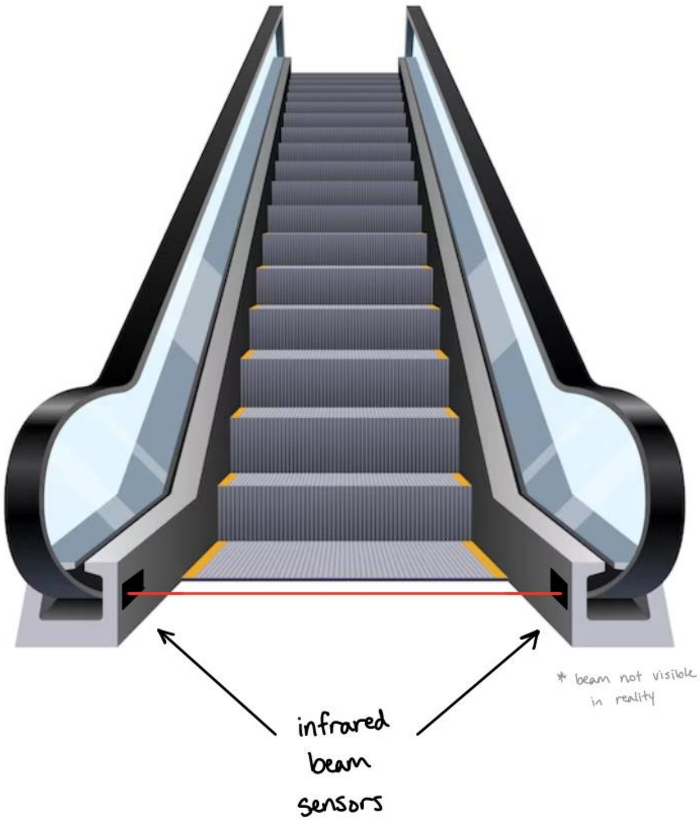


Figure 3 - Sensor Placement on Escalator

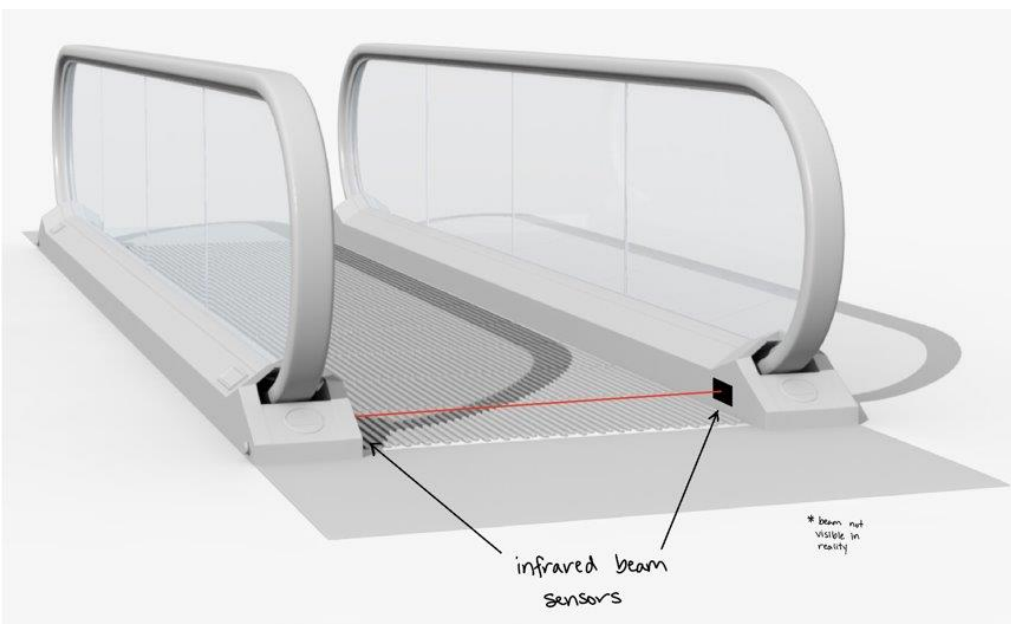


Figure 4 - Sensor Placement on Moving Walkway

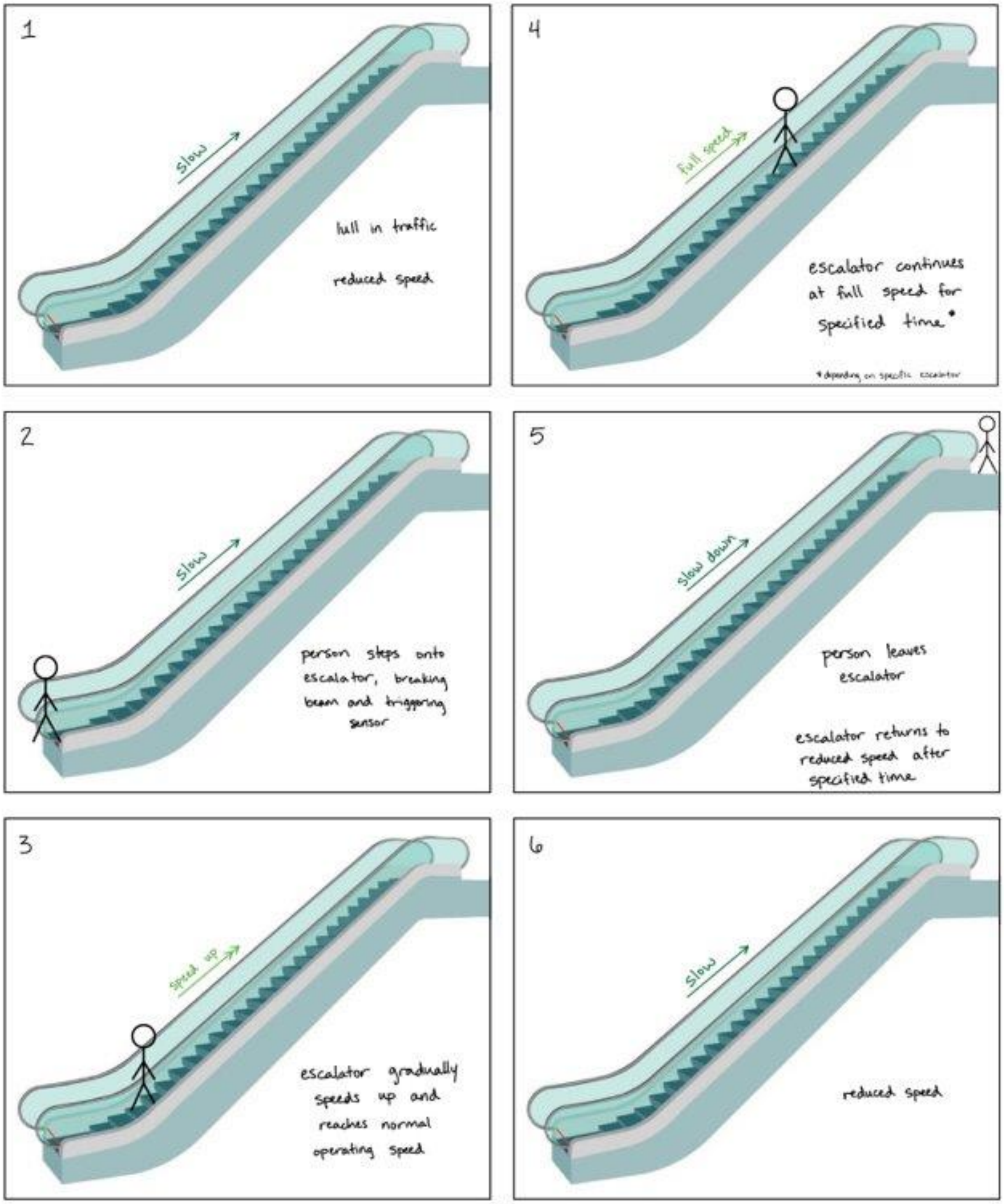


Figure 5 - Prototype Storyboard

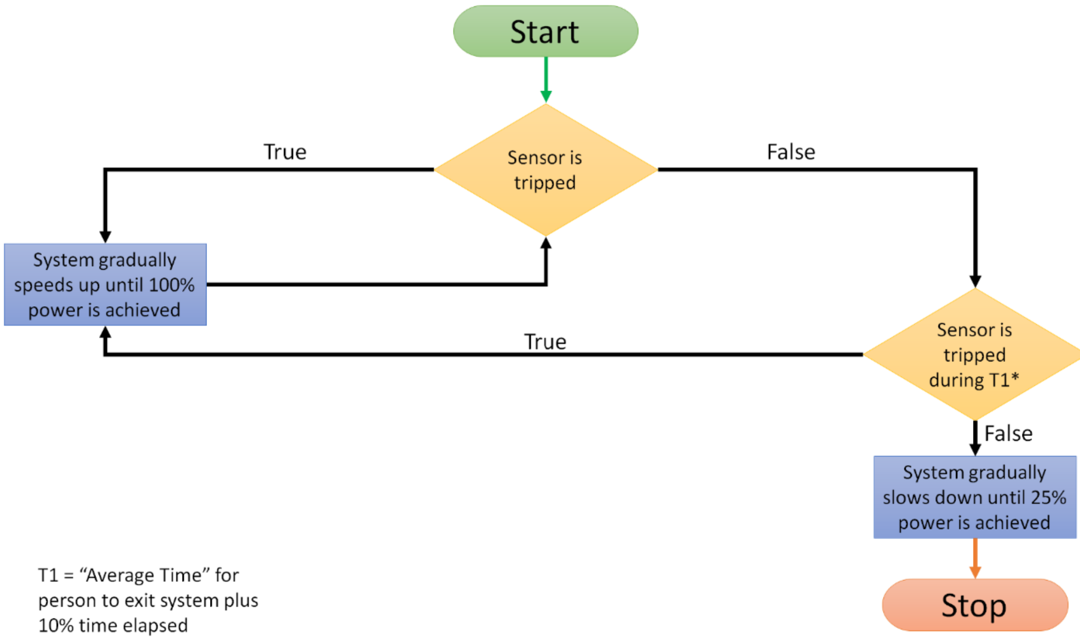


Figure 6 - Programming Flowchart

When patrons walk up to the escalator, an IR sensor system mounted before the steps will detect that it has been broken, and feed that data to either a preexisting control system or a new micro controller.

As shown by the flowchart in *Figure 6 - Programming Flowchart*, the system starts by determining if the infrared sensor is tripped. The system defaults to its idle speed or about 25% power when the system is first initialized. If the sensor is tripped, the system will gradually increase in speed until 100% power is achieved or normal operating speed. The system will then loop back to determine if the sensor is still being tripped. Once the sensor is no longer being tripped, an internal timer will begin. The length of this timer [T1] is the time it takes for a person using the system to exit the system plus an additional 10% of the elapsed time. If during time T1 the sensor is tripped, the timer will reset, and the system will continue to gradually increase in speed until 100% power is achieved. If 100% power is already achieved, the system will remain at 100% power. If time T1 elapses and sensor is not tripped, the system will gradually decrease in speed until 25% power is achieved. The system then returns to its idle state of 25% power until the sensor is tripped again and the loop will restart.

This system does not include a full stop. Instead, the system will move at about 25% of its normal speed. This was chosen rather than a stop because a stopped escalator or people mover conveys a broken system and people will be less likely to use it, which may cause frustration. This way, travelers will still feel as though they're able to use the escalators or people mover but energy consumption will be reduced when they're not needed.

The speed of the escalator is changed using a variable frequency drive (VFD). VFDs can control the speed of an AC motor by adjusting the frequency of the electric input. Escalators may already have a VFD installed with their control system. If the escalator does not have a VFD installed, one will be installed for the system to interface with the escalator to adjust its speed. VFDs are composed of three primary systems, the interface, controller, and AC motor. Data from the sensors would be transmitted to a microcontroller, which interfaces with the controller of the VFD which in turn adjusts the speed.

Safety Risk Assessment

Safety Management Systems (SMS) are utilized to identify and mitigate risks that could become hazardous to airport operators and the public. As a part of a "pro-active approach to safety", risks are carefully evaluated and addressed until they are completely resolved or reduced to an acceptable level (Federal Aviation Administration, 2023, 1-3). The team listed the potential risks to the proposed solution and ranked them based on severity and likelihood.

According to the FAA Safety Management System Manual, safety risk management identifies potential risks and ways to reduce those risks, as well as develops strategies to address existing safety issues (Federal Aviation Administration Air Traffic Organization, 2022). To assess the safety of the proposed solution, the team evaluated the results of the risk assessment matrix rankings and developed mitigation strategies for each potential risk.

		Severity				
		Minimal (1) Insignificant operation disruption	**Minor (2)** Some operation disruption	**Major (3)** Substantial operation disruption	**Hazardous (4)** Possible injury / significant operational disruption	**Catastrophic (5)** Probable injury / major operational disruption
Likelihood	**Frequent (5)** Once/Week	Moderate(5)	High (10)	High (15)	Severe (20)	Severe (25)
	Probable (4) Once/Month	Moderate (4) **1,2**	Moderate (8)	High (12)	Severe (16)	Severe (20)
	Remote (3) Twice/year	Low (3)	Moderate (6) **4**	High (9)	High (12)	High (15)
	Extremely Remote (2) Once/2 years	Low (2)	Moderate (4) **3**	Moderate (6) **5**	Moderate (8)	High (10)
	Extremely Improbable (1) Once/Decade	Low (1)	Low (2)	Low (3)	Moderate (4) **6**	Moderate (5)

Figure 7 - Risk Assessment Matrix

	Potential Risks	Likelihood	Severity	Overall
1	Sensor False Positive	Probable(4)	Minimal (1)	4
2	Sensor False Negative	Probable (4)	Minimal (1)	4
3	Sensor Physically detaches (Flush)	Extremely Remote (2)	Minor (2)	4
4	Sensor Physically detaches (Protruding)	Remote (3)	Minor (2)	6
5	Sensor Electronic Disconnect	Extremely Remote (2)	Major (3)	6
6	Escalator accelerates too quickly	Extremely Improbably (1)	Hazardous (4)	4

Figure 8 - Potential Risks associated with Risk Matrix

Sensor false positive and false negative are two of the potential risks identified. A sensor false positive is if the sensor detects a break in the infrared beam when nothing actually passed through the beam. Similarly, a sensor false negative is if the sensor does not detect a break in the infrared beam when someone did pass through. Both of these risks were considered to have probable likelihood and minimal severity. A false positive reading would result in the escalator or moving walkway running at full speed for longer than necessary, which is what most systems operate at normally without the proposed solution. A false negative reading would result in the escalator running at the reduced speed even with people on it, causing the people to have to wait on the escalator longer. Since these consequences would not cause injury or much operational disruption, these risks were considered acceptable. Mitigation strategies include ensuring the beam sensors are positioned and aligned correctly during installation and including a clear hard cover to protect the sensors. These covers would have to be included in regular janitorial cleaning so that any collected dirt or grime would not interfere with the beam.

A third potential risk is if the sensors detach from the escalator or moving walkway due to physical impact from people or luggage. This risk was considered to have remote likelihood and minor operation disruption. The sensor would be strongly secured onto the base of the escalator or moving walkway, so this possibility has low probability. If it were to happen, the sensor would need to be reattached and this would require maintenance personnel to come and fix it. A mitigation strategy that was included in the final design included using a mounting plate with rounded edges. This would allow the sensor to sit tighter and more securely to the escalator base, which would decrease the impact of physical collision and reduce the chance that impact would result in breaking the sensor and mounting plate off. With this improvement, the design was assigned an extremely remote likelihood and minor severity.

There could potentially be an electronic disconnect between the sensor and the variable frequency drive (VFD) or the VFD and the motor. This would only occur if the sensor wiring was installed incorrectly or poorly. This is why it was assigned extremely remote likelihood. However, if it were to happen, the sensor would need to be reconnected and reinstalled, which would require electricians or other trained personnel, so it would have major severity. A preventative measure for this risk would be ensuring installation quality assurance checks.

Another potential risk is if the escalator accelerates too quickly. This proposed solution manipulates the speed of an escalator, making it go from a reduced speed back up to its normal operating speed, so it is possible that the escalator would speed up too quickly. This could cause people to lose their balance and potentially fall. Due to the potential injury, this risk was assigned hazardous severity. However, this possibility should not occur if the system is programmed correctly and the connection between the components is intact. The magnitude of acceleration could be customized to each airport or even escalator, depending on the customer's requests, but it would not exceed the American Society of Mechanical Engineers guideline of a maximum acceleration of 1 ft/s^2 (Escalators, 2023). Because the acceleration would be controlled by the program, it has an extremely improbable likelihood.

The risk assessment matrix and potential risks demonstrate that this proposed solution has moderate risks involved and those potential risks can be mitigated using various preventative measures.

Projected Impacts of Team's Design and Findings

Cost Benefit Analysis

The team's solution uses an infrared sensor to detect the presence of an airport patron at the entrance to a moving walk, or escalator and take the device from a reduced or energy saving speed to full power. This solution is designed to help reduce power consumption of idle escalators and moving walks. Because this solution is based on energy savings, the primary benefit is a reduction in cost. This solution relies on a purely economic calculus: does this solution save more than it costs to implement? The team performed a cost benefit analysis to determine solution viability of the solution.

Cost	**Subtotal of TOTAL ESCALATOR year 0/installation internal costs**					$ 24,070.00				
Cost	**Lifetime support internal costs**						$ 3,001.00	$ 3,001.00	$ 3,001.00	$ 0.30
Cost	**Subtotal, internal cost**					$ 28,615.00	$ 3,001.00	$ 3,001.00	$ 3,001.00	$ 37,618.00
Cost	**Overhead & profit, 25%**					$ 7,153.75	$ 750.25	$ 750.25	$ 750.25	$ 9,404.50
Total Cost	**Sales price and annual technical service fees charged to airport: internal cost + markup**					**$ 35,768.75**	**$ 3,751.25**	**$ 3,751.25**	**$ 3,751.25**	**$ 47,022.50**
Airport Authority benefits										
Benefit, tangible	Airport operations	Reduced kilowatt hourly usage, 50% dow	$ 0.86		87,600.00	-	75,555.00	75,555.00	75,555.00	226,665.00
Total Benefit	Airport operations					**-**	**75,555.00**	**75,555.00**	**75,555.00**	**226,665.00**

Figure 9 - Basic Cost Benefits

Figure 9 - Basic Cost Benefits shows a full cost benefit breakdown for a sample medium sized airport with 10 escalators. Because this project has both fixed development costs and variable installation costs, it is important to note that the benefits the solution is a stronger choice for larger airports.

The below section is a breakdown of the rationale behind costs and benefits of team solution.

Infrared Sensors:

Basic Infrared Sensors cost $7 per pair. Nicer sensors are liable to cost more, but for this application, the most basic sensors are generally appropriate.

Mounting Plate + Hardware:

Upper ceiling assumption based on price of 3D printing and Self-Tapping Screws is 5 dollars per mount, with 2 total mounts for system. Given the relatively limited scale of this solution, 3D printing is probably the correct choice even for larger implementations, as opposed to having a mold made for the plastic sensor housing.

Microcontroller:

Price based on Arduino UNO Price from Amazon.com, just under $30. While the National Instruments MyDAQ was used for the prototype, a Arduino UNO is a more appropriate solution for full scale implementation.

VFDs:

Price based on higher end 10 hp VFD Pricing of 1000 dollars, while this can vary wildly based on individual motors in airports, this was chosen in attempt to overestimate the associated cost.

Installation Downtime:

Total time from Electrician Labor Estimate and Contractor Labor combined, approximately 15 hours. The cost of this time is intangible and hard to estimate, but 10 dollars per hour felt like an appropriate, if a little high, assignment of value to the downtime.

Maintenance:

Assuming the system undergoes bimonthly maintenance checkups of 1 hour each, 6 hours of time are accounted for. The estimated hourly pay rate for maintenance work is $50 per hour, so the total cost is $300 per escalator annually.

Electrician Labor:

Electrician labor cost was estimated at $70 an hour, with 12 hours estimated for installation. While this is higher than electrician pay rates, parent company profits must be factored into what electricians are actually paid. These sensors aren't difficult to install, so about 3 hours worth of electrician labor per escalator were accounted for, plus another 9 hours for electrician labor to install the VFD. 12 hours at $70 an hour gives $840 in total electrician labor.

Contractor Labor:

Contractor labor cost was estimated at $70 an hour, with 3 hours estimated for installation. While this is higher than contractor pay rates, parent company profits must be factored into what contractors are actually paid. The sensor mounts were designed to be easy to install, the team accounted for about 1 hours worth of Contractor Labor per escalator, plus another 2 hours for contracting labor to install the VFD. 3 hours at $70 an hour gives $210 in total contractor labor.

Programmer Labor:

Programming labor was estimated at 80 dollars an hour. As with both the contractors and electricians, this is an inflated rate. Programmers would have the responsibility of programming the microcontrollers to receive input from the sensors and change the speed of the escalators for certain time intervals. The team accounted for 15 hours worth of work to program the system initially, and then 2 hours worth of work per escalator to input the custom dimensions and other device specific logistics. 15 hours at $80 an hour gives $1200 in programmer 'setup' labor, and 2 hours per escalator gives $160 per escalator.

Power to Run (Annual):

The power to run the infrared sensor is based on the manufacturer's listed 5 Volts at 10mA and the National Average Energy Cost of $0.23 per kwH. Calculations below:

5V * 10mA = 0.05 W

0.05W = 0.00005 kwh * 23¢ /kwh * (24 hours per day * 365 days a year) = 10¢

Therefore, each year the IR Sensor costs $0.10 to run for a year.

Student Labor:

Student Labor hourly rate of $25 per hour given by ACRP project. Number of hours given by internal project Gantt chart. $25 hourly pay rate for 125 hours is $3125. This is a fixed development cost.

Prototyping Materials:

1 kg 3D printer filament: $20

myDAQ: $200 (discounted from PSU EE Supply Room)

Airport Operations Benefit:

Escalator energy savings based on assumption of escalator used 50% of the time, escalator running at full power during use and 33% power when not in use, giving total energy savings of 33% of prior consumption. This is a somewhat convoluted calculation, the process is listed below.

Power used at full speed: 11.25 kwh * 0.5 time fraction = 5.63 kwh

Power used at idling speed: 11.25 * (1/3) = 3.75 kwh, 3.75 kwh * 0.5 time fraction = 1.87 kwh

Total Power used after sensor: 5.63 + 1.87 = 7.5 kwh

Power Saved: 11.25 - 7.5 = 3.75 kwh

3.75 kwh * 23¢ /kwh * (24 hours per day * 365 days a year) = $7555.55 per escalator

Payback Ratio and Solution Scalability

While the above case is based on a 50% cycle assumption, the team determined it may be useful to determine what 'reduced power time' rate would be the bare minimum required for a 3 year payback period. Due to the nature of this solution, benefit is only present when patrons do not use escalators or moving walks. As such, the team calculated the bare minimum break even usage time for a 3 year payback period. In other words: what percentage of the time must an escalator be unocteamcupied for this solution to payback its cost in 3 years? This metric was dubbed the 'Payback Ratio', and is explored more below.

For this calculation, the required energy savings over the three year payback period was set equal to the cost, and then the above calculations were done in reverse to get a time fraction that the system must operate at to have the savings equal the cost. This percentage started at 22% but quickly drops below 10%, a number reasonably achievable in even the busiest airports, especially considering their minimal traffic in graveyard hours.

Cost / Benefit Analysis and Payback Time Calculation

Customer: Airport with 10 escalators
Product: Infrared Sensor Escalator/Moving Walkway System
Time frame: Three (3) years

Type	Phase	Item	$/hour	$/unit	Hours or Units	Year 0	Year 1	Year 2	Year 3	Year 1-3 Subtotal
Cost	Product & Installation	Infrared sensors		$ 7.00	1	$ 7.00	$ -	$ -	$ -	$ -
Cost	Product & Installation	Mounting plate + Hardware		$ 5.00	2	$ 10.00	$ -	$ -	$ -	$ -
Cost	Product & Installation	Installation downtime*		$ 10.00	15	$ 150.00	$ -	$ -	$ -	$ -
Cost	Product & Installation	Microcontroller		$ 30.00	1	$ 30.00	$ -	$ -	$ -	$ -
Cost	Operation	Maintenance	$ 50.00		6	$ -	$ 300.00	$ 300.00	$ 300.00	$ -
Cost	Product & Installation	VFD		$ 1,000	1	$ 1,000.00	$ -	$ -	$ -	$ -
Cost	Product & Installation	Electrician labor	$ 70.00		12	$ 840.00	$ -	$ -	$ -	$ -
Cost	Product & Installation	Contractor labor	$ 70.00		3	$ 210.00	$ -	$ -	$ -	$ -
Cost	Product & Installation	Programmer labor (Custom to escalator)	$ 80.00		2	$ 160.00				
Cost	Product & Installation	Programmer labor (Initial Programming)	$ 80.00		15	$ 1,200.00	$ -	$ -	$ -	$ -
Cost	Operation	Power to run (Annual)		$ 0.10	1	$ -	$ 0.10	$ 0.10	$ 0.10	$ 0.30
Cost	Research & Development	Student labor	$ 25.00		125	$ 3,125.00	$ -	$ -	$ -	$ -
Cost	Research & Development	Prototyping materials		$ 220.00	1	$ 220.00	$ -	$ -	$ -	$ -
Cost	**Subtotal of FIXED year 0/installation internal costs**					$ 4,545.00				
Cost	**Subtotal of PER ESCALATOR year 0/installation internal costs**					$ 2,407.00				
Cost	**Number of Escalators implemented**					10				
Cost	**Subtotal of TOTAL ESCALATOR year 0/installation internal costs**					$ 24,070.00				
Cost	**Lifetime support internal costs**						$ 3,001.00	$ 3,001.00	$ 3,001.00	$ 0.30
Cost	**Subtotal, internal cost**					$ 28,615.00	$ 3,001.00	$ 3,001.00	$ 3,001.00	$ 37,618.00
Cost	**Overhead & profit, 25%**					$ 7,153.75	$ 750.25	$ 750.25	$ 750.25	$ 9,404.50
Total Cost	**Sales price and annual technical service fees charged to airport: internal cost + markup**					$ 35,768.75	$ 3,751.25	$ 3,751.25	$ 3,751.25	$ 47,022.50
Airport Authority benefits										
Benefit, tangible	Airport operations	Reduced kilowatt hourly usage, 50% dow	$ 0.86		87,600.00	-	75,555.00	75,555.00	75,555.00	226,665.00
Total Benefit	**Airport operations**					-	75,555.00	75,555.00	75,555.00	226,665.00
For this project, it would be useful to consider what cycle time yields CBA = 1			$0.18		87600.00		15,674.17	15,674.17	15,674.17	47,022.50

Figure 10 - Full Cost Benefit Analysis, 10 Escalators

Figure 10 - Full Cost Benefit Analysis, 10 Escalators shows the team's full cost-benefit analysis for a 10-escalator airport. The assumption for the profit is the 50% duty cycle level, and the bare minimum break-even calculation is included too.

Payback Ratio:

$$\text{(Annual Energy Savings per Escalator)} \times \text{(\# of Escalators)} \times \text{(\% of time Escalator runs at reduced power)} = \text{Total Cost}$$

Figure 11 - Payback Ratio Formula

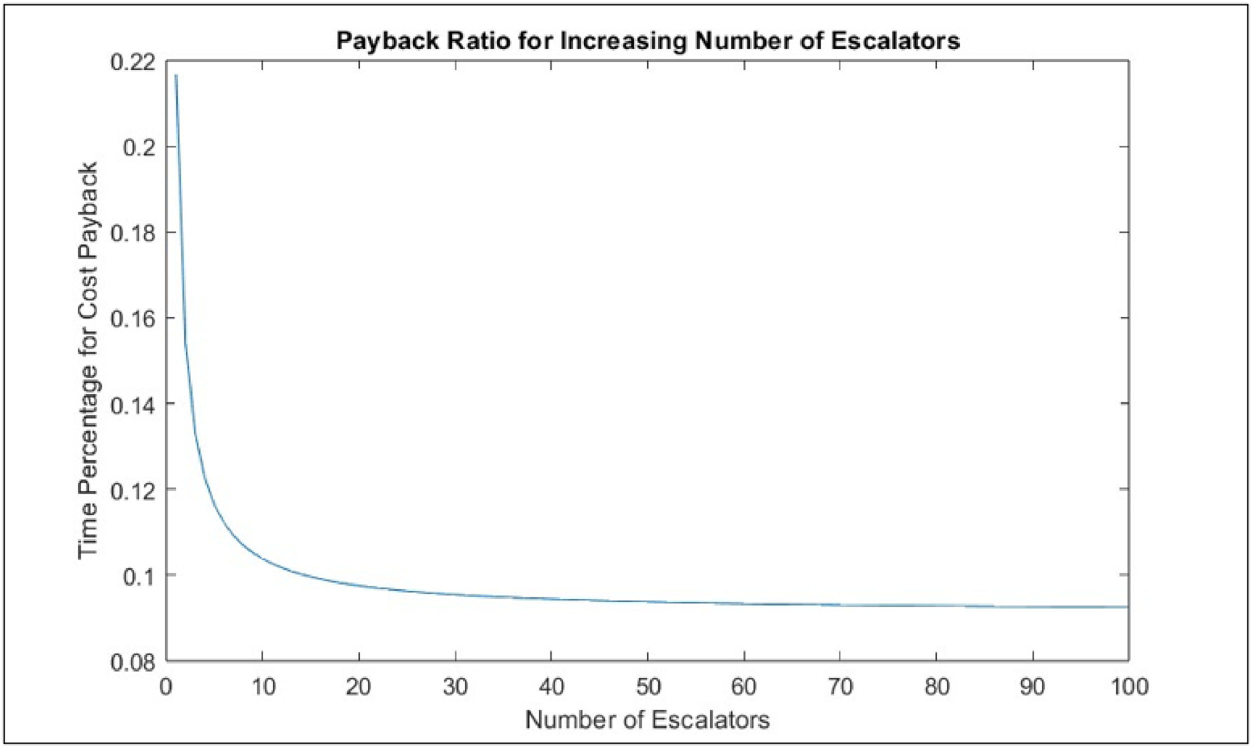


Figure 12 - Payback Ratio vs. # of Escalators

Using MATLAB, the team evaluated what this percentage would be for an airport with any number of escalators or moving walks. *Figure 12 - Payback Ratio vs. # of Escalators* shows a plot of Number of Escalators vs. Break even time fraction: Given a certain number of escalators, what time percentage would the escalator need to run at reduced power for cost to equal benefit in 3 years?

Scenario	Savings in 3 years
5 Escalators at 50% time at reduced power	$86,964.00
10 Escalators at 50% time at reduced power	$179,610.00
15 Escalators at 35% time at reduced power	$170,250.00
25 Escalators at 25% time at reduced power	$174,210.00
50 Escalators at 20% time at reduced power	$354,110.00

Figure 13 - Example Saving Scenarios

Figure 13 - Example Saving Scenarios above shows a few realistic scenarios for airports and what the expected savings in 3 years might be for those scenarios.

Conclusion

Airports are a critical piece of modern infrastructure and enable the global lifestyle and economy of today. However, many were built decades ago and were not designed with sustainability in mind. Opportunities for updating airports to reduce energy consumption and increase sustainability have a lot of viability. Using emerging technology, energy consumption of many different airport systems are ripe for improvement. This solution focuses on using infrared beam sensors to detect patron traffic on escalators and activate them accordingly. By operating at reduced speed when not in use, significant energy and cost savings are possible, with no patron risk or operational disruption.

Appendix A

Student Information

Collin Price

- Penn State University
- Email: cap6065@psu.edu

Josh Christ

- Penn State University
- Email: jxc2214@psu.edu

Taylor Pierce

- Penn State University
- Email: tkp5284@psu.edu

Victor Yang

- Penn State University
- Email: vqy5025@psu.edu

Abby Chang

- Penn State University
- Email: acc6087@psu.edu

Advisor Information

Abbie Canale

- Penn State University
- Email: aes5356@psu.edu

Appendix B

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

Appendix C

Alumni Mentor

- James Corson
    - Senior Reactor Systems Engineer, U.S. Nuclear Regulatory Commission

Stakeholders

- Chris Babb
    - Senior Managing Consultant, Landrum & Brown
- Andrew Kleit
    - Professor of Energy and Environmental Economics, The Pennsylvania State University
- Robert Zygmunt
    - Senior Electrical Designer, BL Companies
- John Prete
    - BL Companies

Appendix E

<u>Student Perspective</u>

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

Yes, the Airport Cooperative Research Program provided a meaningful learning experience for our team. Throughout the duration of this project, our team learned and improved valuable skills such as leadership and teamwork. These are both important skills that will help us both now and, in the future, and being able to utilize these skills over the course of a few weeks was extremely helpful.

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

Our team ran into challenges with finding stakeholders whose expertise would be relevant to the scope of our project. Because of this, it was difficult to get real world input and determine how feasible our solution was. We were relatively far along in our project, and we had only been able to talk to 2 stakeholders. However, we were able to overcome this challenge by reaching out to our coach who was able to connect us with electrical engineers from BL Companies. By overcoming this challenge, we were able to gain valuable insight into our project as we became introduced to Variable Frequency Drives, a type of motor that's essential in order to implement the solution that we came up with.

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

In order to develop our hypothesis, the first action our team took was to do a brainstorming session in which we all came up with possible solutions within the scope of energy efficiency. The brainstorming method we used was called Brainwriting, and it consisted of everyone coming up with as many ideas as possible within a short amount of time before we shared the ideas as a team. Once we decided that we wanted to use sensors to increase energy efficiency within airports, we developed two design matrices to decide which specific solution we wanted to use. One design matrix focused on ambient solutions that were for wider areas in the terminal. The second design matrix focused on interactive solutions which were more close-range solutions. After developing multiple categories that we would rank these solutions with, we were able to narrow our solution to a few viable ideas. After a team discussion, we ultimately decided on using infrared beam counters on escalators and moving walkways in order to increase energy efficiency because it would be the most feasible solution within the timeframe that we had.

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

Yes, participation by industry in the project was meaningful and useful. Although we struggled at first with finding good stakeholders, the information that we gained from them was extremely valuable. We were able to gain valuable insights that helped us to determine our project direction as well as some flaws that were present in some of our first prototype solutions.

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

Throughout this project, our team learned valuable communication skills, leadership skills, and teamwork skills. As we worked through this project, we learned the importance of each of these skills as we put them to practice. These skills and knowledge are all important for succeeding in entry in the workforce or to pursue further study because there will be many times in our futures as engineers where we will be working in teams. It's important to learn to work well in a team dynamic because it will help us succeed in team environments in the future.

Faculty perspective

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

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

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

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

3. What challenges did the students face and overcome?

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

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

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

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

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

Appendix F

Airport Carbon Emissions Reduction. (n.d.). Federal Aviation Administration. Retrieved February 15, 2023, from https://www.faa.gov/airports/environmental/air_quality/carbon_emissions_reduction

Airports. Business energy advisor. (n.d.). Retrieved February 15, 2023, from https://ouc.bizenergyadvisor.com/article/airports

Cianca, E., De Sanctis, M., & Di Domenico, S. (2017). Radios as Sensors. *IEEE Internet of Things Journal*, *4*(2), 363–373. https://doi.org/10.1109/jiot.2016.2563399

Choufani, E. E. (2016, December). *Energy Reduction in Airports*. CIBSE - chartered institution of Building Services Engineers. Retrieved February 17, 2023, from https://www.cibse.org/media/pngijmy2/energy-reduction-in-airports-2016-1.pdf

Conte, D., Foggia, P., Percannella, G., Tufano, F., & Vento, M. (2010). A Method for Counting Moving People in Video Surveillance Videos. *EURASIP Journal on Advances in Signal Processing*, *2010*(1). https://doi.org/10.1155/2010/231240

Escalators and Moving Walkways. Sacramento Municipal Utility District. (2023). Retrieved April 9, 2023, from https://smud.bizenergyadvisor.com/article/escalators-and-moving-walkways#:~:text=Almost%20all%20of%20the%20electricity,hp%E2%80%94are%20the%20most%20common

Evans, P. (2020, April 25). *Variable Frequency Drives Explained - VFD Basics IGBT inverter*. The Engineering Mindset. https://theengineeringmindset.com/variable-frequency-drives-explained/

Federal Aviation Administration. (2023). Advisory Circular 150/5200-37A, *Safety Management Systems for Airports*. Retrieved from https://www.faa.gov/documentLibrary/media/Advisory_Circular/150_5200_37A_Part_139_SMS.pdf

Federal Aviation Administration Air Traffic Organization. (2022). *Safety Management System Manual*. Retrieved from https://www.faa.gov/air_traffic/publications/media/ATO-SMS-Manual.pdf

Jost, D. (2019, July 29). *What is an IR sensor?* FierceElectronics. https://www.fierceelectronics.com/sensors/what-ir-sensor

Lauterbach, C., Steinhage, A., & Techmer, A. (2012, March 1). *Large-area wireless sensor system based on smart textiles*. IEEE Xplore. https://doi.org/10.1109/SSD.2012.6198101

Shen, Y.-L., & Shin, C.-S. (2009). Distributed Sensing Floor for an Intelligent Environment. *IEEE Sensors Journal*, *9*(12), 1673–1678. https://doi.org/10.1109/jsen.2009.2030650

Shetty, A. D., Disha, B, S., & K, S. (2017, July 1). *Detection and tracking of a human using the infrared thermopile array sensor — "Grid-EYE."* IEEE Xplore. https://doi.org/10.1109/ICICICT1.2017.8342790

Vodovozov, G. (2022, December 20). *What Is Wi-Fi Sensing? - Definition, Applications, Benefits*. Nami.ai. https://nami.ai/blog/what-is-wi-fi-sensing/#How_Does_Wi-Fi_Sensing_Work

Wood, G. (n.d.). *What makes a sustainable airport?* Arup. Retrieved February 15, 2023, from https://www.arup.com/perspectives/what-makes-a-sustainable-airport

Zotos, N., Pallis, E., Stergiopoulos, C., Anastasopoulos, K., Bogdos, G., & Skianis, C. (2012, July 1). *Case study of a dimmable outdoor lighting system with intelligent management and remote control.* IEEE Xplore. https://doi.org/10.1109/TEMU.2012.6294730