# Reducing Idle Time via Machine Learning

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ACRP Design Challenge: Airport Environmental Interactions

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## Executive Summary

The prolonged taxiing periods for airplanes during ground operations at airports pose significant challenges, including excessive fuel consumption, high operational costs, and environmental impact. This inefficiency, particularly during gate-to-gate or runway transitions, contributes to about 5% of a flight's total fuel usage and is exacerbated in congested airports. To address these issues, an ideal solution leverages innovative technologies and operational strategies. A program utilizing reinforcement learning to optimize taxi routes, reducing unnecessary idling and fuel burn has been developed for this purpose. This approach not only improves operational efficiency and cost-effectiveness for airlines and airports but also contributes to environmental sustainability by lowering emissions. The largest risk with this solution is the risk of the program giving the same path to two flights or a security breach which is mitigated by an air traffic controller override and on-call software developers. The product is used as a tool to help assist air traffic controllers, rather than outright replace them. This program has mainly the upfront cost of software development, with the minimal continuous cost of on-call tech support. The costs along with the benefits of saving fuel, reduced employee stress, and customer satisfaction produce a payback time of about 3 months. Through collaboration with industry experts and rigorous risk analysis, the solution meets safety standards and addresses potential challenges. Overall, the aim is to revolutionize ground operations, making them more efficient, cost-effective, and environmentally friendly.

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## Problem Statement and Background

For airports, extended taxiing periods during ground operations lead to significant fuel consumption, imposing high costs and amplifying environmental degradation. This issue predominantly occurs when airplanes navigate inefficiently from gate to gate or towards the runway, often due to human error among air traffic controllers who rely on radar and radio communications[15]. This inefficiency, unpredictable and varying in duration, can account for approximately 5% of a flight's total fuel usage[2]. Such excessive fuel consumption is costly for airlines and environmentally harmful, increasing emissions at large, congested airports where delays are frequent. Addressing this challenge is essential for reducing operational costs for both airports and airlines and for minimizing the aviation sector's environmental impact. This is a crucial step in the global efforts to combat climate change and reduce pollution.

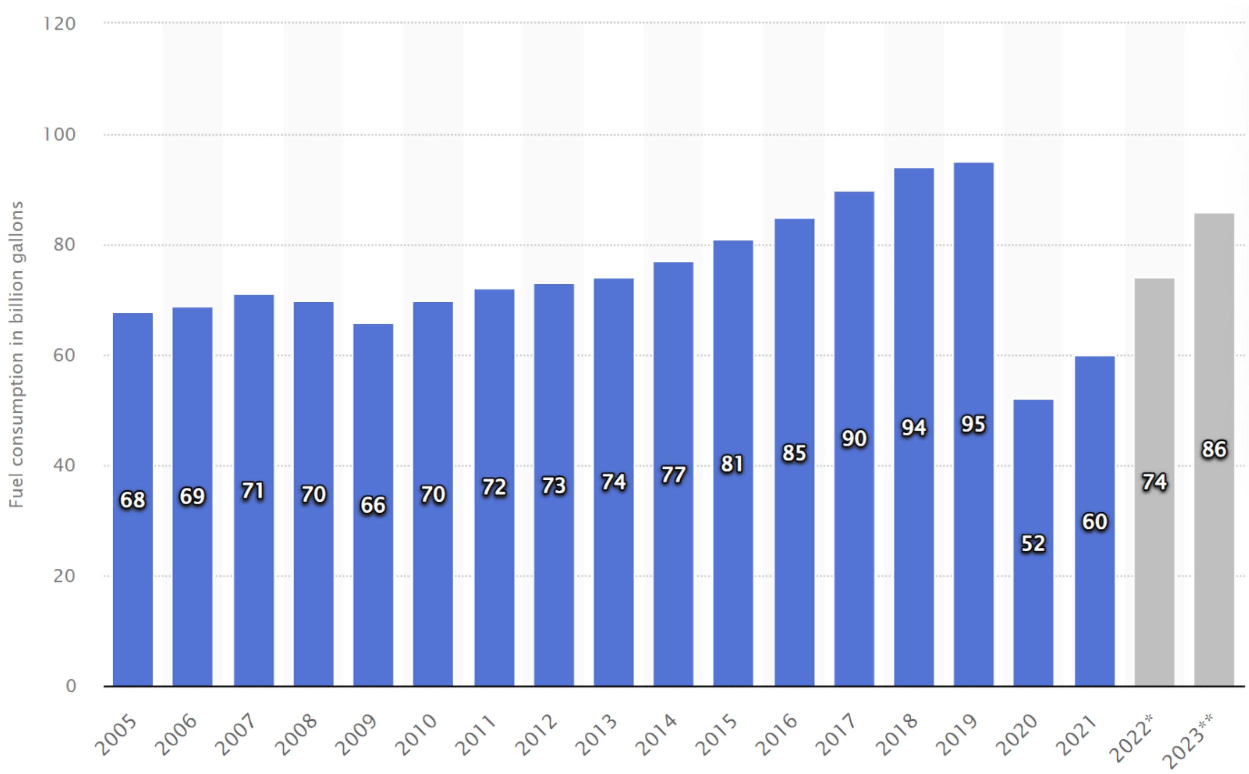
## Summary of Literature Review

Taxi operations can be split up into four different phases: idle thrust, taxiing at a constant speed or brake thrust, perpendicular turn thrust, and breakaway thrust.[3] Airbus has calculated that up to 1000 kg of fuel is unnecessarily spent per flight in the idling phase.[4] Additionally, stops and turns before the takeoff time have a definitive positive relationship with fuel burn.[5] The average taxi time in the U.S. is between 16 and 27 minutes, which accounts for about 5% of a flight's fuel consumption[2]. Importantly, Figure 1 illustrates a notable increase in the number of flights experiencing large taxi-out times between 2006 and 2007, emphasizing the growing challenge of managing ground operations efficiently. Therefore, focusing solutions on the idling and taxiing portion of airplane transportation routes shows promising results for improving fuel efficiency and reducing emissions, especially since the global fuel consumption by commercial airlines increased each year since 2009 and reached an all-time high of 95 billion gallons in 2019 (Refer to Figure 2).[6] Recently, researchers have explored different boarding methods to expedite the gate-to-gate time for airplanes. The research has shown promise in decreasing gate-to-gate time for airplanes by altering the boarding method from front to back to processes like random boarding or by seat.[7] Another recently developed solution is the Aircraft Towing Systems (ATS), an advanced technology system that grounds airplanes to help transport them from gates to runways and then back to gates once they land. It is an automated system that comprises of an electric powered towing cart that uses an in-ground monorail to direct the aircraft. Some of the benefits of this solution include safer taxiing operations as there will be fewer ground collisions and a reduction in fuel costs.[8] However, the cost of implementing this system is extremely expensive as airports would have to remodel runways and gates to install the monorail in the ground.

*Figure 1: Taxi-out times in the United States, illustrating the increase in the number of flights with large taxi-out times between 2006 and 2007.*[9]

| Year | Number of flights with taxi-out time (in min) | | | | | | |
|---|---|---|---|---|---|---|---|
| | < 20 | 20-39 | 40-59 | 60-89 | 90-119 | 120-179 | ≥ 180 |
| **2006** | 6.9 mil | 1.7 mil | 197,167 | 49,116 | 12,540 | 5,884 | 1,198 |
| **2007** | 6.8 mil | 1.8 mil | 235,197 | 60,587 | 15,071 | 7,171 | 1,565 |
| **Change** | -1.5% | +6% | +19% | +23% | +20% | +22% | +31% |

*Figure 2: Total fuel consumption of commercial airlines worldwide between 2005 and 2021, with a forecast until 2023.*[6]



# Approach to the Design Challenge

## Current Approaches

There has been significant research into making the boarding process of airplanes more efficient in order to decrease the amount of time a plane needs to remain in port due to congestion caused by boarding.[10] There has also been substantial research into different taxiing methods for planes. For Example, there was a study that explored the potential of hybridizing conventional electric taxiing systems with electrical energy storage to reduce fuel consumption during ground operations. By using off-the-shelf batteries and implementing various energy management strategies, the research demonstrates up to 72% savings in taxiing fuel[11,12]. There have also been many studies on areas causing the inefficiencies in the plane's movement including inefficient braking and movement.[13]

## Interaction with Industry Experts

To aid in the team's research, the team began to reach out to experts to gain insight. One expert the team interviewed was Felipe Rodriguez, an Adjunct Lecturer at the University of Maryland – Eastern Shore and is also affiliated with the American Associate of Airport Executives (AAAE), the University Aviation Association (UAA), and the Airport Minority Advisory Council (AMAC), on February 16, 2023. Mr. Rodriguez provided a breakdown of gate-to-gate operations and the procedures that occur to prepare an aircraft for its next departure. He shared the new operations being implemented by airports such as creating high-speed taxi ways and updating the current infrastructure in place. Mr. Rodriguez emphasized the adherence to safety regulations for the crew and aircraft when minimizing gate time. Following the interview, he forwarded papers from the Federal Aviation Administration on crew member regulations and airport runway safety initiatives.

**Synthesis of Key Insights:**

The comprehensive review of current literature and insights from industry experts highlight critical inefficiencies in airport taxi operations, notably in idle and taxi times that significantly contribute to fuel waste and increased operational costs. Interviews with experts like Felipe Rodriguez have highlighted the importance of implementing solutions that optimize these operations. Innovations for route optimization and advanced towing systems not only promise considerable reductions in fuel consumption but also aim to enhance overall airport efficiency and safety. These insights pave the way for our Point of View, where we propose a focused approach to redesigning taxi operations at congested airports, aiming to achieve substantial economic and environmental benefits.

**POV Statement:**

After talking to Felipe Rodriguez, the team found that there is a great amount of fuel consumed for ground operations at large airports because of congestion. The team's goal is to reduce gate-to-gate time by developing a new taxiing method to save on fuel costs and reduce emissions at Pittsburgh International Airport.

**Problem Solving Approach:**

The team went through a series of ideation strategies to try to produce numerous unique solutions. In the ideation process one of the large steps is to consider who will benefit from solving the problem and who the solution is being built for. The team decided that the solution that they will continue with will have to mainly benefit the airport and air traffic controllers or the airline company. The solution will most likely benefit both, as well as the passengers, but the solution will be tailored to one group. After considering the groups that benefit from solving the problem, the team found key themes from research and created insight statements from the themes. Pulling out key themes assures that the team knows what the solutions the produce should cover and help solve for. The three key themes the team pulled out were efficiency and environmental sustainability, resilience and adaptability in operations, and a user focused design.

**Brainstorming Approach:**

After fully encompassing the problem and what the team wants the solution to accomplish, the team used multiple brainstorming strategies to devise solutions. The first brainstorming strategy used was SWOT analysis to identify current solutions that may jog new ideas or ideas that alter the current solutions. SWOT analysis identified strengths of what the problem doesn't need to be solved, weaknesses of what needs to be solved the most, opportunities by adding beginning ideas, and threats of current solutions within the problem. The SWOT analysis also allowed the team to further encompass the problem. Then, using what the team came up with from the SWOT analysis, the team members took time individually to come ideate and bring present their solutions to the team the next day.

Coming back the next day, the team used Jamboard to collect all of the individual solutions and collaborate on the solutions. The team then discussed how the team can improve each other's ideas and select the most promising solutions that the team can move forward with. After this, the team reached a creativity slump. The team kept revisiting the old ideas and not adding to the pile. To get out of the slump, the team revisited the themes to see how the proposed solutions fit into them. This helped narrow the number of ideas and add more creative and innovative ideas. The team finished off the brainstorming stage by working through the SCAMPER method. SCAMPER, which stands for substitute, adapt, modify, put to another use, combine, eliminate, and reverse, to alter and narrow the current list of solutions.

After narrowing down the solutions, the team presented two solutions to experts. The two solutions were a machine learning system that plans the routes of planes on the ground and hydrogen powered tow out vehicles. While carrying out research for the machine learning system, it was found that a large use of fuel during taxiing is the stop and go of the planes, as well as turns. Therefore, to reduce fuel consumption, the team identified that it is optimal to reduce the number of times those occur. The machine learning system will not only plan the ground routes, but it also helps plan which runway the planes land on and which gate it is assigned. This solution will help reduce fuel consumption which saves const for the airline companies, but also reduce emissions from fuel consumption. This machine learning system will also help with congestion on the ground. Another solution the team considered is hydrogen powered tow out vehicles, so the planes will use little to no fuel during taxing. The thought of the hydrogen powered tow out vehicles was produced from the current electric powered tow out system. Though the cost of hydrogen is larger than that of aircraft fuel, it would solve the problem of emissions from plane fuel. As the use of hydrogen as fuel increases in the future, costs will decrease. The team considered presenting the solution of a permanent in-ground towing system but struggled with improving this solution significantly enough to make it a new idea. The permanent in-ground towing system solution would also present a very large upfront cost from infrastructure changes.

## Industry Expert Feedback:

To get feedback on the possible solutions, the team reached out to industry experts because they can imagine how the solutions can realistically be implemented into an airport, if it is possible, and any alterations to the presented solutions. The first industry expert the team reached out to was Barry Braton. He explained that many airports are switching to electric ground support vehicles to reduce emissions and fuel consumption. On the idea of hydrogen power, he elaborated that it is not yet cost effective but will likely have a role in the future as hydrogen production costs are reduced by technology. He also emphasizes the necessity of these ideas in airports, explaining that the cumulative fuel consumption of all operations at any large airport is significant. The team also reached out to John Greaud who found that the ideas presented were helpful in saving airline money. He liked the concept of minimizing stopping while taxiing. His feedback on the hydrogen powered tow could bring safety concerns if there is too much ground congestion. He also introduced an electric powered vehicle tow machine already on the market that solves the problem of fuel emissions. Based off John Greaud's statements, the team started leaning towards the machine learning solution. Th hydrogen powered tow machine can be a possible solution more in the future once hydrogen prices decrease and implemented more in smaller airports that have less on ground traffic.

## Prototyping:

The first step of the prototyping process was deciding on one solution to move forward with. The team used a decision matrix to first weigh the importance of environmental impact, resilience to operational changes, feasibility, cost-effectiveness, customer viability, and safety. The team then went through and ranked each possible solution to get a total number that provided the best solution to move forward with. The team saw safety as the largest weight followed by environmental impact and feasibility.

*Table 1: Prototyping Design Matrix*

| | Environmental Impact and Fuel Efficiency | Resilience to Operational Changes | Feasability | Cost-Effectiveness | Customer (Pilots & Passengers) Viability | Safety | Total |
|---|---|---|---|---|---|---|---|
| Weights: | 4 | 2 | 4 | 1 | 3 | 5 | |
| Machine learning | 5 | 5 | 5 | 5 | 4 | 5 | 92 |
| A hydrogen powered towing vehicle | 4 | 3 | 5 | 2 | 3 | 1 | 58 |
| In ground towing system | 3 | 3 | 2 | 4 | 3 | 4 | 59 |
| **Key:** | | | | | | | |
| 1 to 5 (1 being worst, 5 being best) | | | | | | | |

Since the team is more focused on reducing ground fuel consumption for larger airports, the safety aspect of the hydrogen powered tow out vehicle causing more traffic to hurt its total in the decision matrix. The feasibility of implementing the permanent in-ground tow system hurt its total. This led to the decision to proceed with machine learning for optimizing taxi routes to minimize fuel consumption for planes. The team then created a flowchart, which was instrumental in outlining subsequent steps for prototyping. Following this, work began on constructing an airport grid modeled after Pittsburgh International Airport. Subsequently, the early stages of the prototype were initiated based on the developed flowchart and airport grid. After early development, the team decided to show the prototype to some industry experts who gave pertinent feedback. Barry Bratton, an airport management expert, informed that there are other infrequent causes of delay that cannot be easily predicted, such as incidents or mechanical issues that should be considered.

Bratton explained that the most common source of delays is air traffic control which is saturated during peak travel times. He said the largest source of delay was the weather. John Greaud, an expert in airport management, mentioned how if the machine learning program has access to the incoming flight stream and the destination of each aircraft, it will have time to analyze the flow and determine the best routing. Greaud also mentioned how exceptions like mechanical issues and weather delays will impact the flow of planes in and out. Charles Watson, a machine learning expert, said optimization algorithms can be used in conjunction with predictive models to allocate resources more efficiently. By considering multiple factors, such as the proximity of gates to the arriving flight's next departure, passenger transfer times, and the availability of ground support equipment, these algorithms can propose the optimal gate assignments that minimize overall idle times and enhance the utilization of airport infrastructure.

Prototype:

To optimize gate assignments and reduce idle time for arriving and departing aircraft, the team developed an intelligent gate assignment system. This system takes real-time flight data as input (Figure 1), including arrival and departure times, flight numbers, origins/destinations, and aircraft types. The data is parsed and processed by algorithms to make efficient gate assignments while considering potential delays and schedule changes.


```
Arrivals: [{'time': '5:38 AM', 'city': 'Los Angeles', 'airline': 'Spirit 656', 'gate': 'B33', 'baggage_claim': 'L', 'status': 'Arrived'},
Departures: [{'time': '5:00 AM', 'city': 'Charlotte', 'airline': 'American 349', 'gate': 'B36', 'status': 'Departed'}, {'time': '5:20 AM'
```


*Figure 3: The arrival and departure data being parsed into program from Pittsburgh International Airport's Flight Status.*[14]

At the core of the system are two key algorithms. First, it uses Dijkstra's shortest path algorithm to optimize the routing of aircraft from runways to gates and vice versa. By finding the shortest path, it minimizes the time aircraft spend taxiing, reducing overall idle time and fuel consumption. The algorithm considers the airport's layout, including runways, taxiways, and gate locations.

Second, to handle the unpredictable nature of flight operations, such as weather-related delays and early arrivals, a reinforcement learning approach was implemented. This algorithm learns from past data and adaptively makes gate assignment decisions based on the current state of the airport. By continuously learning and updating its strategy, the system can better accommodate schedule changes and minimize disruptions. This reinforcement learning approach was proposed by Mr. Watson during discussions with him on the program's machine learning aspects.

```
Simulating Day 1:

Arrivals:
07:39 AM – Spirit 656 from Los Angeles – Gate B33 – Runway 32 – Status: Delayed 07:28 AM
06:38 AM – Spirit 713 from Newark – Gate B49 – Runway 28C – Status: On Time
06:33 AM – United 1204 from San Francisco – Gate A8 – Runway 10R – Status: On Time
07:10 AM – Southern 227 from Dubois – Gate B41 – Runway 28C – Status: On Time
08:03 AM – Southern 305 from Bradford – Gate B41 – Runway 10R – Status: On Time
07:55 AM – Southwest 430 from Tampa – Gate A1 – Runway 28R – Status: On Time
08:42 AM – Spirit 2370 from Miami – Gate B33 – Runway 32 – Status: On Time
08:55 AM – Spirit 722 from Orlando / Mco – Gate B49 – Runway 10R – Status: On Time
09:42 AM – American 4659 from Raleigh/Durham – Gate B28 – Runway 28L – Status: On Time
10:23 AM – Delta 5245 from New York/LGA – Gate D80 – Runway 28R – Status: Delayed 10:39 AM
09:54 AM – United 1382 from Washington/Dul – Gate A2 – Runway 28L – Status: On Time
09:04 AM – United 4474 from Newark – Gate A10 – Runway 32 – Status: On Time
10:28 AM – American 2310 from Charlotte – Gate B34 – Runway 28L – Status: Delayed 10:28 AM (Holding)
09:25 AM – Delta 5113 from Detroit – Gate D86 – Runway 10R – Status: On Time
10:33 AM – Southwest 3800 from Orlando / Mco – Gate A1 – Runway 28L – Status: Delayed 10:33 AM (Conjestion)
10:22 AM – Air Canada 8921 from Toronto – Gate C51 – Runway 32 – Status: On Time
10:05 AM – United 3617 from Chicago/Ord – Gate A10 – Runway 10R – Status: On Time
10:49 AM – Delta 5597 from Boston – Gate D86 – Runway 28L – Status: On Time
```

```
10:05 PM – Southwest 3696 to Orlando / Mco – Gate A3 – Runway 10R – Status: On Time
10:31 PM – Delta 4821 to Detroit – Gate D80 – Runway 28R – Status: On Time
10:21 PM – United 1539 to Houston / Iah – Gate A10 – Runway 10R – Status: On Time
11:50 PM – United 3224 to Chicago/Ord – Gate A8 – Runway 28R – Status: Delayed 11:50 PM (Waiting for departure)
11:52 PM – American 3296 to Dallas / Dfw – Gate B32 – Runway 28R – Status: Delayed 11:52 PM (Waiting for departure)
10:13 PM – American 3301 to New York/JFK – Gate B28 – Runway 28L – Status: On Time
11:07 PM – Southwest 4361 to Baltimore – Gate A1 – Runway 32 – Status: On Time
11:09 PM – Southwest 2582 to Phoenix – Gate A9 – Runway 32 – Status: Delayed 11:09 PM (Waiting for departure)
11:52 PM – Delta 4435 to Atlanta – Gate D76 – Runway 28R – Status: Delayed 11:52 PM (Waiting for departure)
10:51 PM – Delta 3207 to Detroit – Gate D80 – Runway 28R – Status: On Time
10:42 PM – Southwest 1373 to Nashville – Gate A9 – Runway 10R – Status: On Time
11:50 PM – Southwest 3631 to Chicago/Mdw – Gate A7 – Runway 28R – Status: Delayed 11:50 PM (Waiting for departure)
10:58 PM – Southwest 2760 to Dallas / Dal – Gate A3 – Runway 28C – Status: On Time
11:52 PM – Delta 3980 to New York/LGA – Gate D82 – Runway 28C – Status: Delayed 11:52 PM (Waiting for departure)
11:24 PM – American 3549 to Chicago/Ord – Gate B30 – Runway 28L – Status: On Time
11:52 PM – Spirit 453 to Las Vegas – Gate B33 – Runway 28R – Status: Delayed 11:52 PM (Waiting for departure)
11:55 PM – Southwest 4520 to Orlando / Mco – Gate A3 – Runway 28L – Status: On Time
11:50 PM – Delta 1619 to Atlanta – Gate D76 – Runway 28R – Status: Delayed 11:50 PM (Waiting for departure)
11:52 PM – United 1569 to Denver – Gate A8 – Runway 28R – Status: Delayed 11:52 PM (Waiting for departure)
10:44 PM – Southwest 2356 to Chicago/Mdw – Gate A7 – Runway 10R – Status: Delayed 10:44 PM (Waiting for departure)
11:57 PM – Delta 1922 to Detroit – Gate D80 – Runway 28L – Status: Delayed 11:57 PM (Waiting for departure)
11:50 PM – United 2487 to Houston / Iah – Gate A10 – Runway 28R – Status: Delayed 11:50 PM (Waiting for departure)

Total idle time without ML: 133 days, 22:12:00
Total idle time with ML: 102 days, 13:05:00
Time saved by the ML model: 31 days, 9:07:00
```

*Figure 4: Simulation of flights for a week time of around 360 arrivals and departures per day, saving around a total of 31 days (about 1 month) of idle time, with unexpected delays and early arrivals simulated for 36 percent of the flights to ensure algorithm works.*

The results show that the system can have around 31 days (about 1 month) days of idle time over the week, even with significant schedule perturbations. The combination of Dijkstra's algorithm for optimizing aircraft routing and the reinforcement learning approach for adaptive decision-making creates a solution for reducing idle time and improving overall airport efficiency. As mentioned by Barry Bratton during prototyping phase discussions, accounting for unpredictable changes, such as weather, is crucial for the system's success. The algorithms have been designed with this in mind, ensuring that the gate assignment system can handle a wide range of scenarios.

Looking ahead, new goals have been established to start working on integrating real-time map visualizations for airport taxi routes into the system. This future implementation will provide real time maps with optimized paths from the runway to their assigned gate and vice versa, further confirming a visual representation of the algorithm.

Please see the code here, future iterations will be updated automatically to this version:
https://colab.research.google.com/drive/1mgvnnVowZVr46uZ56gCFiesMHvI-_Ks1

## Risk Assessment

In deciding how to reduce the amount of fuel used during the taxi phase of a flight, the team's priority was safety. In the ideation phase when the expert mentioned how using hydrogen powered tow out vehicles would cause more traffic on the tarmac and safety concerns, the team all agreed to move towards the machine learning path. Even with the current solution of machine learning, the biggest risk is the program being faulty and it provides the same path for two planes, causing either traffic or a crash. The mitigation for this would be to run the program for days before implementing it, so the program learns from itself. There would also be instructions provided to the air traffic controllers on how to catch it when it happens and how to override the command. The program gives the most efficient, but safe, route for the plane to and from the runway and if the air traffic controller sees a problem with the given route, they need to decide on a new path to give to the pilots. The next biggest risk is if an outside person gets into the system and gives routes that would cause traffic or crashes. Safety precautions will be in place to prevent this as much as they can, but if it does happen, once the air traffic controller notices it, they will override the system and give the routes themselves. A software developer will then come in and add extra safety precautions to prevent this from further happening. Many of the other risks, like a power outage or the program failing to give a path, will cause the air traffic controller to take control like mentioned above and give the routes themselves.

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

| Severity/ Likelihood | Minimal 5 | Minor 4 | Major 3 | Hazardous 2 | Catastrophic 1 |
|---|---|---|---|---|---|
| Frequent A | | | | | |
| Probable B | | | | | |
| Remote C | | | | | |
| Extremely Remote D | | | | | |
| Extremely Improbable E | | | | | |

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

| Hazards | Likelihood | Severity | Mitigation | Result |
|---|---|---|---|---|
| The program instructs two aircrafts to take the same path at the same time, causing a crash or traffic | Extremely Remote (D) | Catastrophic (1) | The program runs with reinforcement learning so the longer the program runs as a simulation, the fewer errors happen. Additionally, air traffic controllers will double-check check the route is clear before sending it out to the pilots. If the air traffic controller recognizes a potential crash or increased traffic, the controller can override and send a different route to the pilots. | D1 → E2 |
| A power outage causes the program to stop running | Remote (C) | Minor (4) | The airport's backup generators will kick in and during the outage time, air traffic controllers will decide on the taxi path, even though it might not be the most efficient. | C4 → D4 |
| The program does not find the most efficient path or is not giving any path at all | Extremely Remote (D) | Minimal (5) | The program runs with reinforcement learning so the longer the program runs, the less errors happen. If no path is given the air traffic controllers will take charge and give the pilots a path. | D5 → E5 |
| The system is hacked or there is a security risk | Extremely Improbable (E) | Hazardous (2) | Air traffic control will have to take over operations and a software developer will come in and create more defenses. | E2 → E4 |
| The transition of implementing the program | Remote (C) | Minimal (5) | Air traffic control and pilots will grow to learn the program and get used to it. The air traffic controllers will be more involved in the first implementation of the program but will slowly rely on it more to do its job and ease the work of the air traffic controllers. They will end up just doing a quick check before sending the route to the pilots. | C5 → D5 |
| There are weather or other delays | Frequent (A) | Minimal (5) | The program will account for delays or early arrivals and adjust accordingly. | A5 → C5 |

# Projected Impacts of Findings

## Cost Benefit Analysis

This section contains a holistic summary of expected cost and benefits for this machine learning implementation. This table 4 shows the early research and development costs for this project. Some significant expenses include the set-up/integration needed to be done by technicians and the intensive testing/simulating of the code. These costs account for most of the initial costs.

*Table 4: Research & Development CBA*

| Item | Rate | Quantity | Subtotal | Remarks |
|---|---|---|---|---|
| Student labor | $25 | 150 | $3,750 | Group planning, documentation, proposal development |
| Technician | $100 | 2080 | $208,000 | |
| Engineering design | $170 | 400 | $68,000 | Code development |
| Prototyping materials | $60,000 | 1 | $60,000 | Prototyping server hosting for airports to run software on (10k for a server per airport) |
| Software license | $7,500 | 1 | $7,500 | Commercial design software |
| Testing | $200 | 1000 | $200,000 | 200 dollars per hour at 1000 hours for real world testing |
| Subtotal | | | $547,250 | |

Table 5 accounts for the production, marketing, and distribution costs for airports to integrate the solution. This phase emphasizes the stage of getting airports interested in the solution along with airlines and customers (airlines being the main beneficiaries). It is also important that there is an engineering manager available to manage the system. In developing, the only material cost is the software license and testing because the project is a digital algorithm that can be implemented into an existing system.

*Table 5: Production, Marketing, & Distribution*

| Item | Rate | Quantity | Subtotal | Remarks |
|---|---|---|---|---|
| Marketing/sales labor | $80 | 500 | $40,000 | Assumes 500 hours marketing/sales labor |
| Logistics labor | $60 | 50 | $3,000 | Assumes 50 hours logistics labor per year |
| Engineering management | $175 | 500 | $87,500 | Assumes 500 hours engineering operations per year |
| Travel | $0.54 | 230 | $124 | Mileage reimbursement |
| Marketing materials | $500 | 1 | $500 | |
| Subtotal | | | $131,124 | |

Table 6 highlights operational costs. It is integral that there both be software tech support and operations & management available if there is any issue with the system. Issues with the system can lead to hazardous outcomes if there is not significant oversight on the system.

*Table 6: Operations & Management*

| Item | Rate | Quantity | Subtotal | Remarks |
|---|---|---|---|---|
| Software tech support | $170 | 2080 | $353,600 | Assumes 2 employees working 85 dollars per hour for 40 hours per week each year |
| Operations & management | $175 | 2080 | $364,000 | Assumes 175 dollars per hour working 40 hours per week each year |
| Technician travel expense | $1,000 | 50 | $50,000 | Per diem, assumes 4 site visits/year |
| Subtotal | | | $767,600 | |

This following table summarizes costs in developing and operating the solution. Where most substantially, there is a half million savings in fuel consumption per week. In the less tangible sense, there is a proposed 3.5 million savings in airline customers returning on the assumption that 1 in 10,000 customers decide to book another flight due to the time savings when they would not have otherwise.

*Table 7: Cost Summary (PIT Airport for 3 years)*

| Item | Rate | Quality | Subtotal | Remarks |
|---|---|---|---|---|
| Costs | | | | |
| Development | $678,374 | 1 | $678,374 | Table 4 and 5 |
| Operations | $767,600 | 3 | $2,302,800 | Table 6 |
| Total Cost | | | $2,981,174 | |
| Benefits | | | | |
| Reduced idle times based off of gas | $467 | 1,248 | $582,267 | Eliminate 19 gallons an hour burned idling, 1 day saved per week, 52 weeks in a year, based on Pittsburgh Airport |
| Reduced pilot and employee stress (est.) | $18 | 300 | $5,400 | Estimated value of reduced employee stress with terminal and runway |
| Increase in airline consumers based on passenger satisfaction | $380 | 9,300 | $3,534,000 | Increase due to passenger satisfaction (assuming a good experience means they return), 9.3 million passengers out of Pittsburgh, 0.01% satisfied |
| Subtotal | | | $4,121,667 | |
| Payback Time for Pittsburgh Airport = (Total cost to airport in year 0) / (annual benefit-annual cost) = .27 years | | | | |

Though the program is made for the airports to ease the job of the air traffic controllers, a tangible benefit is that airlines would be more willing to use the airports implementing the program because they will use less fuel, saving them money. It is estimated that 19 gallons an hour is burned idling, and the program saves about a day's worth of taxiing time per week. Using the average cost of Jet fuel at $6.48 and multiplying it by the amount of fuel saved per year, the airline should save about $582,267. An intangible benefit from the program is the reduced stress of air traffic controllers. The program will provide the most efficient taxi route from the runway to the gate, so the air traffic controllers only need to double-check that the path is clear and give the route numbers to the pilots. The National Institutes of Health mentioned how the cost of work-related stress is about $18 per working person. Considering the number of affected employees at Pittsburgh International Airport and the number of pilots flying into that airport, the team ended up getting that the savings would be about $5,400 per year. Another intangible benefit is the passengers' satisfaction from a reduced taxi time. Passengers will be happier with the airline when they are on the plane for a shorter amount of time. Using the average cost of a domestic flight and estimating that 0.01% of passengers going through Pittsburgh International Airport would be satisfied with their experience enough to use the airline or airport again for their travels, the team calculated that there would be a benefit of about $3,534,000.

## Future Implications

There is substantial research that shows that airplanes burn great quantities of fuel while waiting on runways or moving inefficiently. Minimizing this issue of airplanes idling would not only save airports fuel costs significantly, but also reduce fuel burn is beneficial for the environment. The most practical solution is the use of a machine learning algorithm to route taxis. This algorithm is estimated to save Pittsburgh International Airport over half a million a year from fuel costs. Looking to the future, this current prototype has been made specifically for the Pittsburgh airport. Fortunately, the code can easily be modified by changing the map and restimulating it to work at different airports. While this would take some work and power, it would be significantly easier to do future airport layouts now that there is a working model for one.

# Appendices

## Appendix A: Contact Information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**Appendix B: University Description**

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 work load 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: University Partners and Industry Experts

**University Partners:**

Charles Watson

- Penn State Computer Science 24’, Nittany AI Alliance Expert Specialist
- Tensorflow, PyTorch, React, ML Algorithm, and Developer Expert

**Industry Experts:**

Mr. John Greaud

- Sr. Project Manager
- Barge Design Solutions

Mr. Barry Bratton

- Associate
- ADK Consulting & Executive Search

Felipe Rodriguez

- Adjunct Lecturer
- University of Maryland – Eastern Shore

## Appendix E: Evaluation of the Educational Experience

Students

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?
This opportunity provided a meaningful environment where the team developed leadership and team skills. Each member of the team led the group for some time, enabling members of the team to develop leadership skills under the pressure of a large, semester-long project.

2. What challenges did you and/or your team encounter in undertaking the competition? How did you overcome them?
The team struggled particularly with task delegation and communication in the team. While these were challenges early on, they clarified their expectations with one another, and leads focused on delegating tasks with more granularity, and the work became smoother. The team also had some difficulties in reaching out to relevant industry experts. Fortunately, it just took asking many experts many times to get answers to the questions that came up.

3. Describe the process you or your team used for developing your hypothesis.
To develop the hypothesis, the team moved through several phases of research. Initially, the team found the environmental category interesting and investigated issues there, the most interesting of which was fuel consumption. They poured through data of flight fuel usage to discover that a substantial amount of fuel was burned before the plane even took off. This led them to narrow their research to reducing gate to gate emissions and after rejecting some insufficient solutions, they came to this solution of using machine learning to maximize the route efficiency.

4. Was participation by industry in the project appropriate, meaningful and useful? Why or why not?
The team found that the participation in the project by the industry was acceptable. The team received useful advice and shut down some of the less practical ideas. It was, however, unfortunate how difficult it was to hear back from these experts (although this would be expected with such busy professionals). They were also very helpful in developing in the team an understanding of what has already been tried and where this solution can be unique.

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?
In the realm of technical learning, it developed a better understanding of how airport traffic works and the use optimal path algorithms with machine learning. More importantly, it developed integral skills in leadership and management. The project's length and breadth forced the development of a strong team with important skills like task delegation.

Faculty

l. Describe the value of the educational experience for your student(s) participating in this competition submission.
Students in our leadership course are learning how to lead within the engineering context. This project provides an exceptional and organized experience for our engineering students to apply the knowledge and their personal leadership style as they lead their teams throughout the

semester. The challenges provided mimic a real-world experience giving students an opportunity to practice both technical and non-technical problem-solving skills.

2. Was the learning experience appropriate to the course level or context in which the competition was undertaken?
Yes, the learning experience was appropriate for the level of our students and fit within the context of our learning environment, per the note above.

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

4. Would you use this competition as an educational vehicle in the future? Why or why not?
We have used this competition as an educational vehicle for the past several years. The competition structure allows us to combine innovative project development via the 5-stage design process while giving student teams opportunities to learn about leadership.

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

## Appendix F: References


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