Tower ASDE-X Improvement (TAXI)

A Proposal for

Increasing Runway Safety and Ground Traffic Control Efficiency

2016 – 2017 Airport Cooperative Research Program

University Design Competition for Addressing Airport Needs

Runway Safety/Runway Incursions/Runway Excursions

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Executive Summary

This report provides a design for improvements intended to reduce runway incursions by creating an understandable, visual technological solution to be used by pilots and air traffic controllers. Current solutions are lacking in three main ways: there is no way for a controller to create a route visually to share with the pilot, there is not enough alerting should a safety issue arise, and there is too much reliance on human interactions. Tower ASDE-X Improvement (TAXI) addresses all three of the above problems and resolves them by building upon the existing Airport Surface Detection Equipment, Model X (ASDE-X) and Controller-Pilot Data Link Communications (CPDLC) systems and enhancing them.

With TAXI, a controller is able to create a path on a touch-enabled tablet device that is in the tower. With this device, he or she is able to graphically see the airport in real time, able to select a flight that has just landed or is about to take off, and give the flight a route to/from their gate. Along with this, TAXI is designed to remember frequent paths and be able to give suggestions. A pilot in the cockpit will also have a device that is able to receive the path from the controller, he or she will then be able to directly follow this route. Should a pilot misread or misunderstand the route and make an incorrect turn, the system would alert both users in order to have the action corrected as quickly as possible. By having the route displayed graphically, it minimizes possible language barriers or miscommunications between the tower and the cockpit, thus limiting possible human error.

The improvements outlined will result in fewer pilot deviations and fewer runway incursions overall. By building on the current system, it is possible to utilize existing tools and improve them for the betterment of everyone's safety.

Table of Contents

1. Problem Statement and Background on Design Challenge

Los Angeles International Airport (LAX) is an airport that has daily heavy traffic and suffers occasional setbacks because of it. Mark Benner—a veteran ground controller and our primary LAX contact—mentioned that it is difficult to scale any useful process there because it is known to be the busiest international airport per square inch in the *country*. Located in a densely populated area of Los Angeles, the airport is designed in such a way that prevents it from large-scale expansion, so we focused our efforts to create an improved system that handles critical existing problems in an effective way. Our team spoke with other ground controllers at LAX and questioned them about the difficulties they faced while performing their responsibilities. This helped us gather information regarding the current processes used by major airports, and how effective they are at performing efficiently and mitigating risk.

Current tools used by the Federal Aviation Administration (FAA) to provide a state-of-the-art plane navigation system—complete with safety precautions and timely system alerts—are largely flawed. In 2001 the FAA commissioned Airport Surface Detection Equipment, Model X (ASDE-X), the first updated system of its kind, with the hopes of solving fundamental issues at some of the country's busiest and most complex airports [1].

While the plan was to have fully functioning ASDE-X implemented in 35 airports by 2007, budget constraints and strategic changes caused restructuring delays, and new planning estimates announced completion by 2011. However, this new plan was disappointing—although ASDE-X would be installed at all expected airports, it would not include all of the expected functionality of the original plan. Mainly, the system would be missing core safety enhancements that are vital to reducing the risks of pilot and vehicle operator errors, such as monitoring intersecting runways and converging taxiways for ground collisions as well as prompt alerts to both controllers and pilots when collision risks are triggered. Even in airports where these safety enhancements were implemented, like Louisville International Airport in Kentucky (SDF), frequent failures cropped up during testing. Operational performance problems like system outages and untimely alerts at collision hotspots were discovered in testing stages, and would have proven fatal if the system responded similarly during normal runtime [1]. As a key component of the software, and a main selling point as a critical safety feature, not including a properly working version of this functionality at *all* airports made the expectations placed on ASDE-X difficult to fulfill.

ASDE-X had other promises that went unfulfilled. There existed plans to provide pilots with real-time alerts in the cockpit, which were discarded [2]. The suggestion to include pilot alerts in a newly developed system was handed down directly from the National Transportation Safety Board (NTSB), and when the FAA proposed ASDE-X without this requested feature, the NTSB rated the system as unacceptable. Although this rating might seem drastic, the statistics prove otherwise. Airport safety research shows that about 70% of runway incursions from 2004-2007 were a direct result of pilot or vehicle operator errors, with 54% of runway incursions caused by pilots [1]. Without any real-time way to alert a pilot of an impending collision, it falls on the controllers to quickly follow up and address the situation when they receive an alert. If there is a system outage, or the alert gets to the controller late, it might be impossible to notify a pilot in time. If ASDE-X followed the NTSB's direction, sending alerts to *both* the controller and the pilot, there would be additional safety overhead, with twice the opportunity for averting a crisis.

Along with the faults of the current ASDE-X system—features that were both promised and not implemented or failures that appeared during testing—there are other problems that crop up in various airports that no system addresses. We spoke to our ground control contacts and gathered both their concerns about the current tools at their disposal and their suggestions for future improvements. Looking specifically at LAX, we can make note of some of these problems and ideas in the quest to build a better system that can finally attend to these flaws.

There is a strangely heavy reliance on old technology, even though LAX claims to be a state of the art facility. The control tower itself does not support technology such as touch-screens and large visual displays. Bringing these advancements to the tower would improve a controller's ability, as they could rely less on their memory and use more modern, reliable methods to keep track of the planes within their jurisdiction. Additionally, they currently use slips of paper that are passed around the room to model a plane's movement throughout the airport. This is a risky maneuver, with the possibility of damage or loss to a paper slip leading to delays and significant runway safety risk. Additionally, controllers rely on the gates they can see from the tower to determine whether or not those gates are available or occupied. They also have to pay attention to the direction a plane is traveling and whether it is on the correct route. It's the controllers' job to monitor all of these events happening around the airport, and notice if there are any mistakes—in the pilot's driving, plane scheduling at gates, and more. All of these events could lead to accidents and cause delays if not properly managed. There is no room for error in the control tower and as such they require more effective tools to manage their workload.

A visual display for the control tower and also for individual pilots would be a prime addition to a new system. Without this visual display, controllers must rely on their memory and knowledge of where a plane should be, and have no other means to determine if a pilot is following the route they were given. Pilots would benefit from a visual navigation display at an unfamiliar airport or even in reduced visibility situations. Additionally a visual display could point out blocked runways and unusable routes, or broadcast an alert when a plane has gone off-route or is heading towards a possible collision point. The lack of a visual display within the tower means that none of these benefits are available, and instead pilots and controllers must communicate only through audio, which has many flaws. Miscommunication—with language barriers and unintelligible accents—can easily lead to routing mistakes. This could be avoided with additional communication mediums—it is much more effective to *show* the right path than to *tell* it.

2. Literature Review

Throughout the design, we conducted research on existing tools in order to not duplicate what was already done, and in order to have an appropriate level of understanding.

2.1 ASDE-X Benefits

We researched the history and future of ASDE-X in benefitting Total Airport Management (TAM) initiatives across the current 35 US airports which have ASDE-X systems implemented [3]. TAM is a considerably challenging procedure, since airports are "operational and economic eco-systems with multiple stakeholders each trying to independently optimize their operations" [4]. Fundamental ASDE-X system capabilities include 1) 2D Airport Surface Situation Display (CWP), 2) Controller Conflict Alerts, 3) Surveillance and System Data Recording, and 4) Surveillance Data Distribution [4]. What makes ASDE-X so essential are many-fold: it enables collaborative decision making National Airspace System (NAS) wide; it provides analysis of real-time and recorded data to assist in understanding operations, to capture significant and useful airport metrics, and to assess and monitor airport efficiency; it allows for operational recording / playback and external surveillance data sharing via the Data Distribution (DD) cabinet; and most importantly, it makes possible active surface management, 4D surface trajectory conformance monitoring and prediction, and ultimately reduction of total runway incursions [4]. ASDE-X has already proven nearly a $250,000 return on investment (ROI) at current airport sites, and incremental effectiveness of 7% to 17% in accident avoidance [5]. In the future, ASDE-X will prove a pivotal tool, one which can be leveraged as a "surface management tool [that] would assist the ground controller by generating conflict free taxi paths and identifying surface movement conflicts before these impede the flow of surface aircraft and vehicles" [4], an application which our proposed TAXI solution aims to bring to reality.

2.2 System Wide Information Management (SWIM)

In our design for TAXI, many elements are included as a part of System Wide Information Management (SWIM), which is focused on "Delivering NextGen Major Investments." [6] Specifically, we focused on SWIM since it showed that through the SWIM Terminal Data Distribution System (STDDS), ASDE-X data is being streamed with, "runway visibility data"[6]. Through finding this SWIM resource, we were able to interact with their team and even receive sample messages that we used to structure our designed data stream.

2.3 Controller-Pilot Data Link Communications (CPDLC)

Since pilots already receive data in the form of CPDLC messages, we are proposing to use this link to send our own data. Besides the original purpose of the link, which provides delivery of departure clearances to the pilot, we wanted to utilize the free text capability to consistently send data to the cockpit [7]. That data would then be parsed by an onboard computer that will create and display a route for the pilot to follow. Adding to the original purpose of CPDLC, this will eliminate the need for radio transmission of route instructions by supplying a visual aid as a supplement to the text messages. This allows radio to be used only for emergency communication purposes between the ATC and pilot.

3. Team's Problem Solving Approach

3.1 The Research Process

Our research stemmed from an initial online meeting that Michael Crowley, our faculty advisor, had with Mark Benner, an air traffic control trainer at the time, in the fall of 2016. At this meeting, we learned of the human errors that air traffic controllers face every day and how they might be avoided. Benner's concerns included the need for controllers to remember every route they assigned to pilots, not knowing whether a pilot has left a gate, and radio miscommunication with pilots. We researched existing aviation technologies, and more specifically, realized we could improve on ASDE-X to solve these problems. The FAA has deployed visual and audio alarms, known as Safety Logic, as an upgrade for ASDE-X to alert controllers of possible runway incursions, but we found that the extent of these alarms were lacking [8].

Our proposed system, TAXI, involves having a laptop/tablet computer in the cockpit. Many pilots already use such a computer to use in lieu of paper charts. Our team met with two commercial airline pilots to discuss the problems we are proposing to solve. Their input provided us with a better idea of how TAXI can be as effective as possible.

To keep each team member's work focused, we split into frontend and backend teams of five students each and held weekly design meetings on Mondays and Thursdays. On Mondays, the two teams met separately so that we could work more efficiently. On Thursdays, we had everyone review the design together. Our frontend team focused on creating an effective user experience for the interface of the TAXI system while our backend team devised a logical manner to generate taxi routes and process the ASDE-X stream. When working as an entire group, we went over design decisions made during the separate meetings to make sure our design was still valid in all possible scenarios. For example, the frontend team found that some planes may be too large for some runway segments, so it was communicated to backend to keep track of plane size within the system. The backend team also realized that planes may deviate from assigned routes so it was communicated to the frontend team added alerts to both pilots and controllers if that occurs. We also showed parking areas on the map of LAX to give controllers the option to direct planes to parking areas when the assigned gate is not available.

After having a comprehensive understanding of the project, we moved on to the second phase, designing a prototype for the TAXI system. In this phase, we focused on designing the TAXI user interface, functionality for pilots, controllers and control managers, and data flow of our system. We followed the FAA Requirements Engineering Management Handbook closely to ensure our process followed recommended industry practices on how to organize system requirements. Using the Handbook, we were able to transition from a high-level design to detailed descriptions of behavioral and performance requirements of our system [9]. Our overarching design policies going into TAXI were based on the following criteria:

- Minimize human errors in the process of controller and pilot communication
- Be user friendly to pilots, controllers and control managers

To minimize human error, we added a few layers of redundancy. Currently, LAX controllers read the route directions to pilots over radio. This approach is error-prone, with statistics showing that 40% of runway collision accidents are caused by such communication errors [10]. To reduce the possibility of communication errors, we decided to also send visual route instructions. Since pilots already receive data in the form of CPDLC messages, we are proposing to use this link to send our own data, which will be parsed by an onboard computer that will then display a route for the pilot to follow. This will eliminate the need for radio transmission of route instructions but still be available for emergency communication between the ATC and pilot.

We also designed our system to be as user friendly as possible. In our color-coding system, red means bad, yellow means warning, and green means good. When designing the color system, we referred to FAA Air Traffic Control Display Standard and made sure to be consistent with its rules, such as “color use shall always be consistent with its standard meaning (HF-STD-002, 3.3.5) ” [11]. In TAXI, planes with routes assigned are green, planes without routes assigned are yellow and planes off route or on blocked routes are red. This lets the ATC easily multitask giving pilots routes and keeping an eye on pilots’ current situations. With the special choice in programming language (JavaFX), we also have the ability to internationalize the pilot’s interface. Languages besides English can be displayed and instruct the pilot in their native language on a certain path lowering the possible error rate. This would be extremely helpful for international flights.

Because we have a large team of ten students, we used a few different tools to synchronize our workflow. With Google Drive and Google Sheets, we were able to share documents and links. Having a main location to save our progress made it very simple for us to combine everything in the final report. For our system prototype, we used a GitHub repository to maintain an environment that every team member can contribute to in parallel. By allowing team members to push new features without interfering with the progress of other members, we were able to reach optimal efficiency. We also used GroupMe to communicate on a day-to-day basis.

3.2 Timeline

- On November 18th, 2016, our faculty advisor exchanged email messages with Mark Benner discussing initial thoughts on the possibility of USC students working on a project that could improve LAX ATC workflow.
- On January 25th, 2017, three students and our advisor took a tour of the LAX control tower led by Mark Benner. During this trip, we learned how air traffic controllers conduct their day-to-day job and observed the shortcomings of ASDE-X in the busy environment.
- On January 26th, we had our weekly group design meeting. Based on the feedback that a tool for controllers to keep track of assigned routes would be of immense help, our design of the TAXI system would be based on the ability to assign and edit routes for planes.
- On January 30th, the backend team did research on how ASDE-X data is updated every second and could be used as an input for TAXI.
- On February 6th, the backend team learned about Surface Movement Event Service (SMES), which automatically publishes Surface Movement Event Messages (SMEMs) based on ASDE-X data.
- On February 13th, the frontend team discussed about the features we were going to implement for our prototype and worked on designing the architecture of the prototype.
- On February 16th, the frontend team wrote some pseudo code for the prototype and did a code review during the design meeting. We also broke the project into a set of tasks and assigned work for each group member.

- On February 27th, the backend team finished parsing the SMES for data needed as input
- On March 6th, the frontend team designed the user interface for pilots, controllers and control managers and started to implement front-end features.
- On March 20th, a shared code repository was created for the whole team.
- On March 22nd, the backend team completed a set of pre-generated data to replicate the ASDE-X stream. This allowed us to test multiple critical scenarios with our system.
- On April 15th, the whole team spent the day at our faculty advisor's house and finished implementing the prototype. The frontend team was able to display routes for planes, using data provided by the backend team.
- On April 22nd, the whole team spent the day at our faculty advisor's house and wrote a majority of the final report.
- On April 25th, the whole team met to complete final edits on the report.

4. Safety Risk Assessment

Risk management and mitigation is key to designing a reliable Safety Management System (SMS) monitoring aircraft navigation risks on airport grounds so this was an important component when designing TAXI. Of the four essential SMS components—Safety Policy, Safety Risk Management, Safety Assurance, Safety Promotion—we have created a detailed Safety Risk Management (SRM) plan to reduce aircraft navigation risks. In describing the system, identifying the possible hazards, analyzing the risks (in terms of likelihood and severity), assessing the risks, and controlling the risks, we lay out a thorough SRM plan aimed at reducing on-ground aircraft navigation risks such as runway incursions and miscommunication between ATC and pilots navigating between terminals and runways [12].

Since ASDE-X data allows ATC to track all on-ground moving vehicles, smaller airports without ASDE-X data sensor technology run a higher risk of runway incursions. TAXI can help smaller airports heavily reduce existing risks and larger airports more effectively manage congested aircraft traffic and maintain clearer communication with pilots.

TAXI is designed to reduce the chances of detecting false positive risks and triggering false positive alerts on the graphical user interface, something that may irritate ATC. TAXI notifies ATC of any suspicious or dangerous aircraft movement, including when an aircraft goes off route or navigates off paved runways. False positive alerts would involve irrelevant alerts pinging ATC, not only unnecessarily disrupting their workflow but also losing their confidence in the system's risk detection capabilities. It is imperative that we effectively identify all plausible risks in the system, ensure that they are detected accurately, and promptly notify ATC of any such risk arising.

We identified the risks by speaking with Mark Benner, a recently retired Air Traffic Controller at LAX. To evaluate the likelihood and severity of these risks, we spoke with Steve Debban, P.E., who works as a National Resource Expert for Airport Design at the FAA.

4.1 SRM for Aircraft Navigation

System: On-ground aircraft navigation, routed between terminals and runways.			
Hazard	Risk Analysis: **Likelihood**	Risk Analysis: **Severity**	**Risk Mitigation**
Miscommunication, unclear instructions?	There is a low risk of a plane going on the runway in the wrong direction, planes crashing into each	This can cause severe issues, including fatal accidents, if not discovered early on.	Print out instructions that need to be read aloud between air traffic controllers and pilots and ensure that it's read back. Try to

	other, planes crashing into cargo trucks and such.		keep this brief since pilots already get bombarded with a lot of information when they're departing and landing. Keep a digital record of where all the planes are at once, and notify air traffic control if a plane goes off track.
Not being able to keep track of plane movement / wrong movement	Currently, air traffic controllers have to constantly check ASDE-X monitor for plane movement, highly likely they don't check frequently enough to notice wrong movement amongst all planes.	This can also cause severe issues, especially when planes cross runways out of turn.	Create an interactive visual map for air traffic controllers to view plane movement and to schedule new routes for planes to aide ASDE-X. Also feature push notifications alerting ATC's of possible runway / ground aircraft incidents.
Server goes down	The risk of this happening is relatively low.	Low to moderate severity. This can cause loss of communication method with pilots and ground vehicles but there are already contingency plans in place so this won't be a high risk.	Keep servers up and running well, constantly check them, have copies of all the information that air traffic controllers need so that nothing gets deleted.
ASDE-X radar sensors malfunctioning	There is probably a low risk of this, but this is also an opportunity for future research.	The severity of this depends on how the radar sensors malfunction. If they just stop working, this is better than if they start emitting the wrong signals.	This risk can be mitigated if the radar sensors are inspected as required and all the hardware equipment is routinely inspected for malfunctioning parts. Additionally, ensure system redundancies to make sure the

			system can still run even if one section of it is malfunctioning.
Lose radio communication between pilot and air traffic controller	There is low risk of this, and would probably be paralleled with some loss of power or server outage.	This could cause major confusion for pilot and delay flights as travel slows down, and can be very severe. However, there are contingency plans in place for if radio communication goes down so the severity of this in practice is relatively moderate.	This risk can be mitigated by routinely inspecting hardware components involved in direct communication between the pilot and air traffic controller.
Lose data stream from the FAA	There is a relatively low risk of this happening.	This could cause confusion for the pilots and other personnel, but ultimately will not be a severe risk due to the fact that there are contingency plans in place that the pilots are familiar with.	Regularly inspecting hardware components and running routine tests of the data stream system can mitigate this risk.

5. Description of Technology

TAXI seeks to holistically address the aforementioned safety and ground navigation problems by relying on existing technologies, such as ASDE-X and CPDLC, and integrating them with a newly developed software and algorithms. The software, which provides a visual user interface for controllers, significantly reduces their workload by simplifying and partially automating ground navigation on the airport surface. It also enhances the presentation of information, which also increases safety and efficiency by reducing human error.

TAXI achieves this increase in safety and efficiency by providing the following nine features:

1. Simple visual presentation of information and ground traffic on the airport surface - similar to the ASDE-X screen.
2. User-friendly and simple user interface.
3. Generating and assigning taxi routes.
4. Taxi route management.
5. Incursion detection to avoid collisions and accidents.
6. Visual and audible warning system.
7. Different access levels for manager, ground controller, approach controller, etc.
8. Quickly disabling taxiways and surfaces on the airport due to emergencies, construction, etc.
9. Digital communication to the cockpit for assigning taxi routes using CPDLC.

In the following subsections, the aforementioned features are described in detail with screenshots. Please note that the screenshots are from the current prototype we have made, and therefore, some features, such as taxiway and runway labels, still need to be visually implemented.

5.1 Simple Visual Data Presentation

Feeding on the data provided by ASDE-X, TAXI shows the live state of traffic at the airport. All planes are labeled with their corresponding flight numbers. Controllers can access more detailed information about each flight by just touching a plane on the display. Planes are also color-coded based on their current status. For example, planes that are assigned a taxi route and are following the assigned route are colored green. Planes that do not have an assigned taxi route are colored as yellow. Planes that go off their assigned route or are on an active runway that could potentially cause incursions turn red, and subsequently both an audible and a visual warning are generated so the controller can quickly resolve the issue. Finally, the plane currently selected by the controller (to access more information about the flight or to assign a taxi route) is displayed in white with a slightly larger icon.

Our color-coding follows FAA color requirements to meet human factors guidelines for attention, identification, segmentation, and text legibility [9]. Furthermore, contrasting colors from opposite sides of the color wheel are chosen for the items that are most frequently used. Figure 1 shows the CIE 1931 XYZ color space, which is approved by the FAA for use.

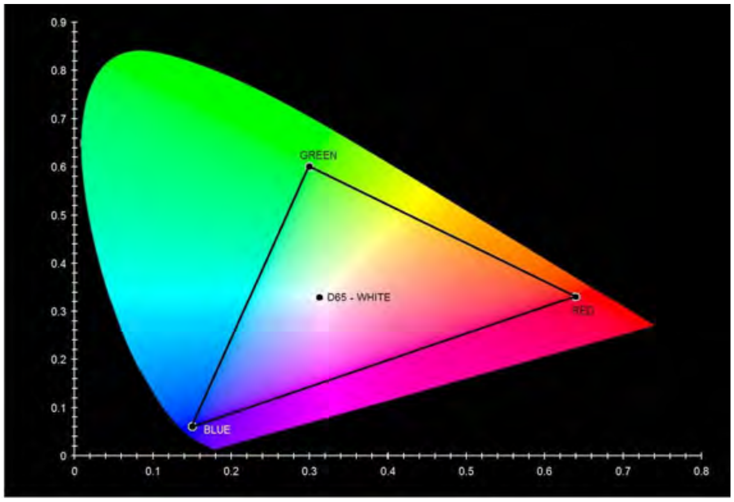


Figure 1: The CIE 1931 XYZ color space, which provided colors used in TAXI.

5.2 Simple User Interface

TAXI features very simple data organization and an interface to maximize controllers' absorption of information. This allows them to act as quickly as possible when needed. Figure 2 shows an outline of the interface design. By selecting a plane, detailed information of the flight, such as flight number, departure time, gate number, and more are displayed in the Output Panel. The Button Panel includes buttons designed for the controller to create, edit, or confirm a path, and for the system to create suggested routes . The Input Panel is where controllers can enter a gate number or a runway for a flight, if that data is not already present. The Input Panel also lists all suggested routes, as well as the interface for updating flight information or system and airport settings–this panel changes based on the controller's current selection. Lastly, the Warning Panel displays any active warning messages related to incursions or system errors.

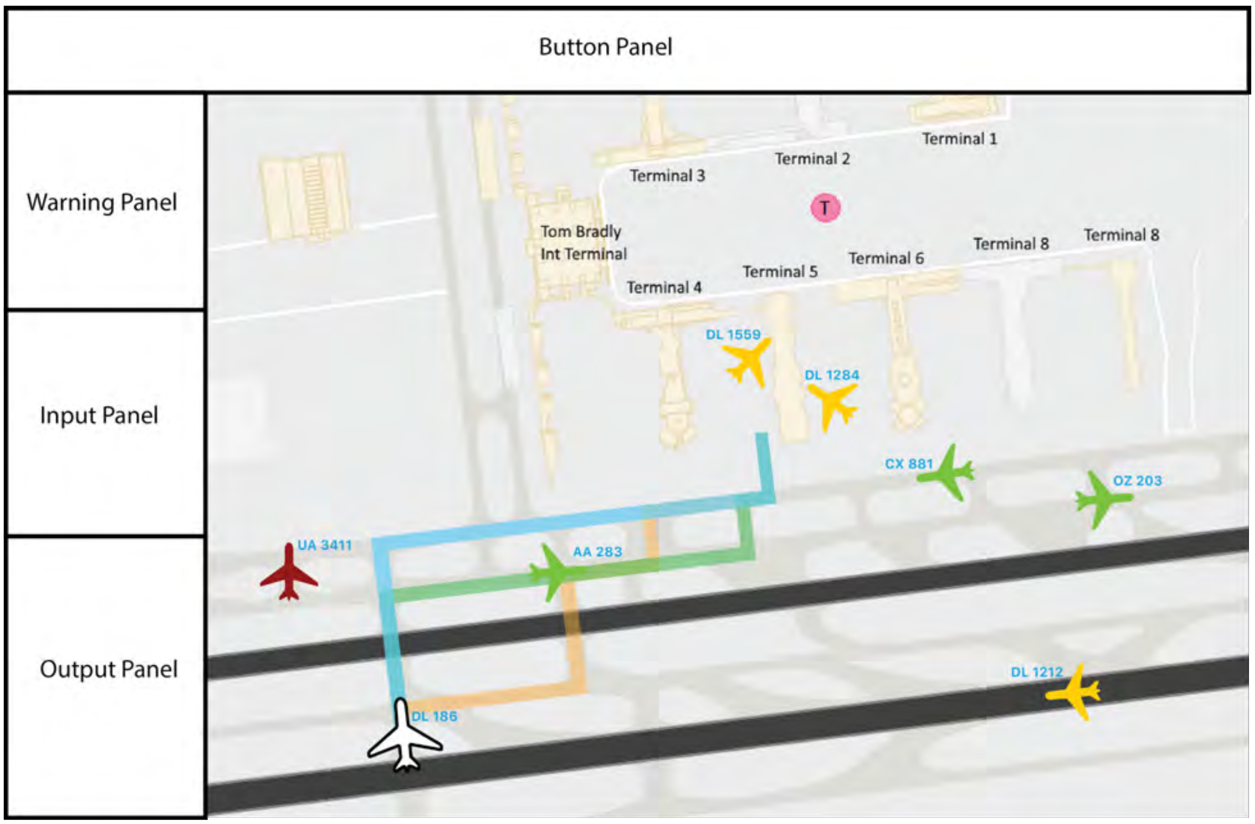


Figure 2: Summary of the controller view of TAXI

5.3 Generating Taxi Routes and Taxi Route Management

Another feature which significantly reduces controllers' workloads and increases aircraft on-ground navigational safety and efficiency is TAXI's ability to assign a taxi route to the airplanes. Upon choosing a plane, the controller can assign aircraft taxi routes to and from runways and gates from the current plane's position by clicking on the "Assign Route" button. The system automatically generates up to three suggested routes based on the size of the plane, availability of the taxiways, simplicity of the assigned route as well as distance. The suggested routes are displayed in following colors based on highest to lowest priority: blue, light green, and light orange, which can be seen in Figure 3 below. By touching the specific route desired and clicking the "Confirm" button, the system will assign the chosen route for the plane, and the chosen route will be displayed in blue.

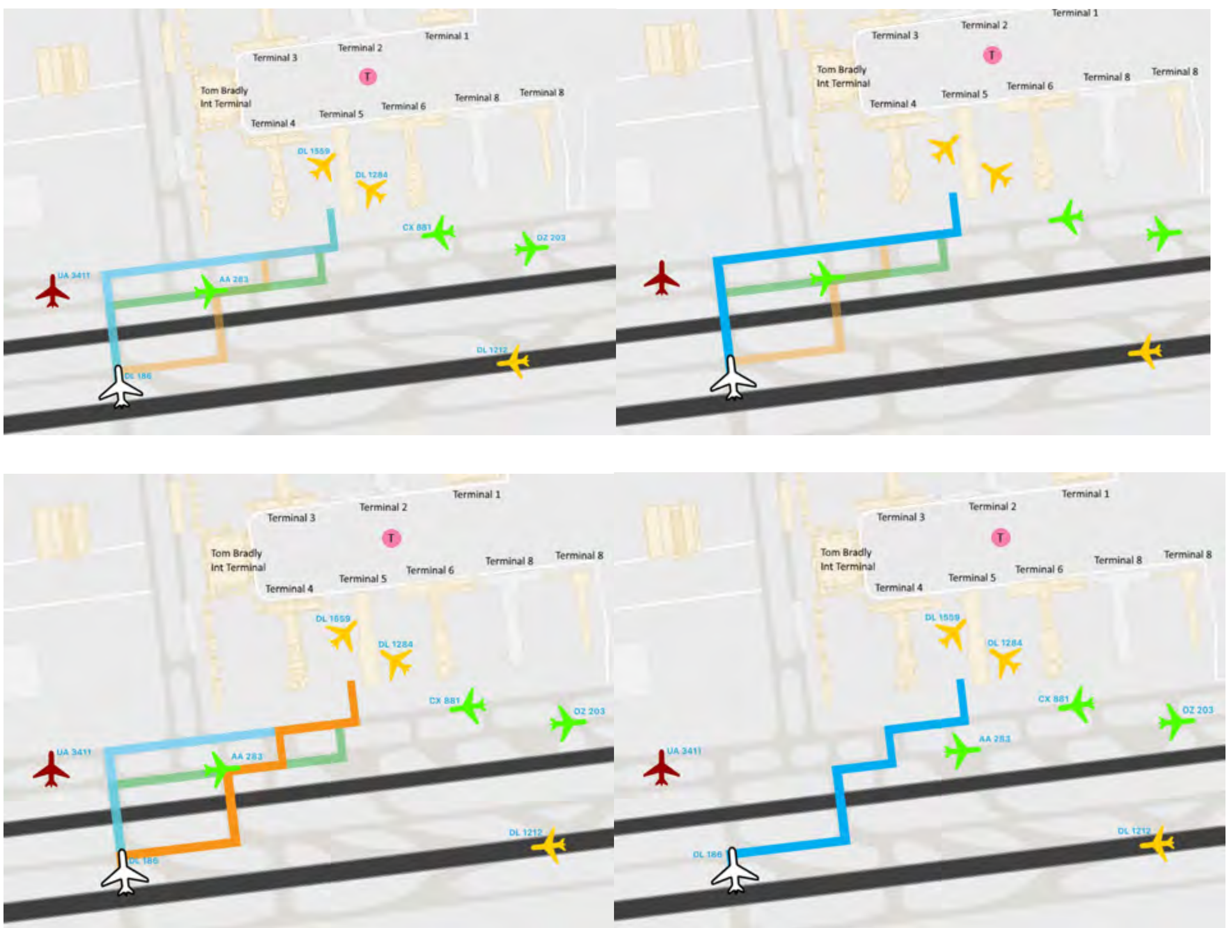
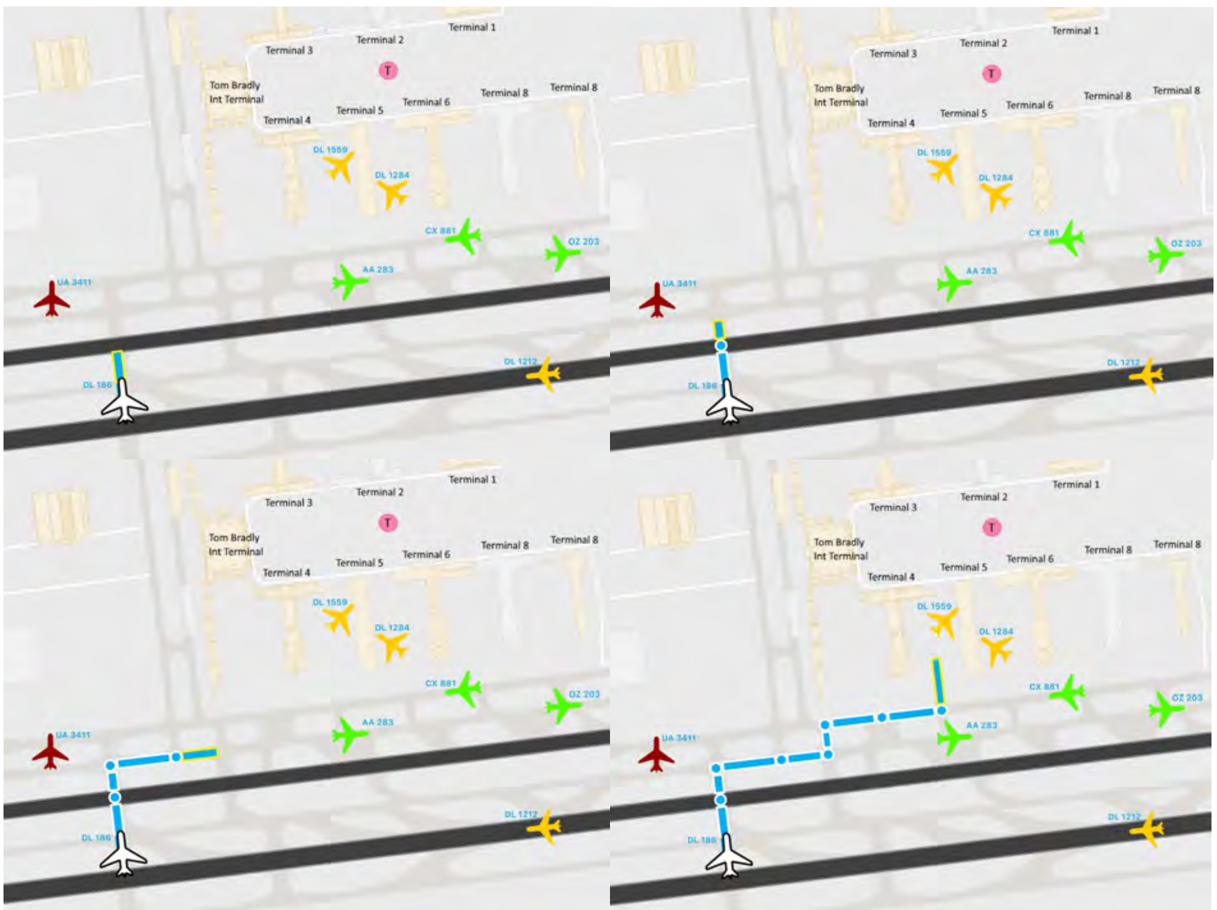


Figure 3: The controller can see three suggested paths upon selecting a recently landed plane, and select one for the pilot to take.

If the controller wishes to manually create a taxi route for the plane, he or she can do so by selecting “Edit Taxi Route” and manually selecting the taxiways. Figure 4 shows a piece-by-piece creation done by selecting intersections along the desired route. After assigning the taxi route, the selected plane turns green and controller can see the assigned taxi route as a blue highlighted path on the surface of the airports. The controller would not be permitted to create a route through an area that has been previously marked as blocked, an example of this would be a construction zone.



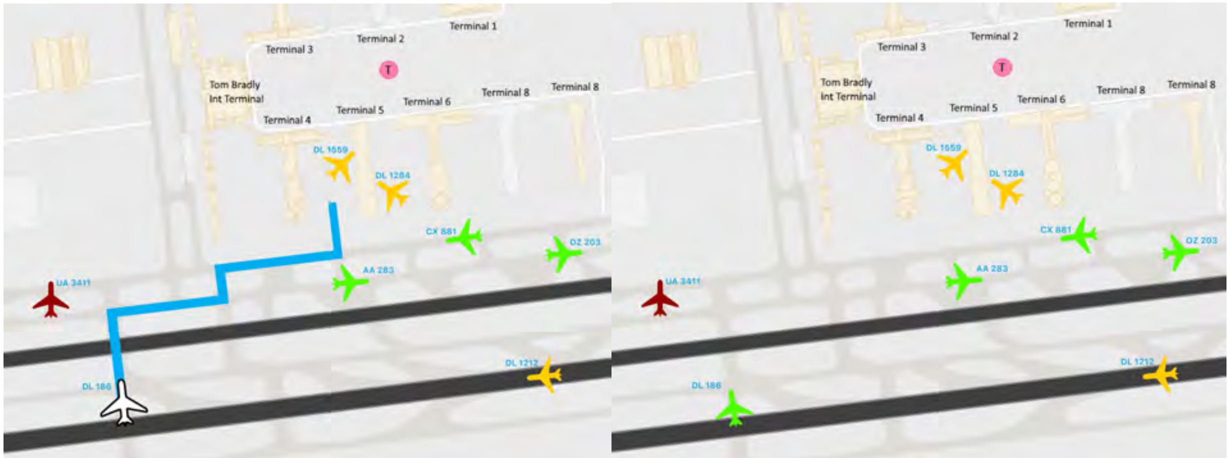


Figure 4: A controller can create a path by selecting intersections from the plane's current location to the gate. It will then turn green once the path is completed.

To keep the display clear and avoid complexity, the assigned taxi routes are not displayed unless the controller selects a specific plane. Then he or she can see the assigned taxi route. In addition to the visual representation of the taxi route, a text version of it in the traditional radio communication fashion containing the taxiway labels and steps needed to follow the path is also provided in the lower left side of the display to minimize miscommunication with the pilot. Lastly, this text version of the taxi route is sent to the cockpit of the corresponding plane via CPDLC, which is converted into a visual taxi route in the cockpit so that pilots can easily follow the assigned route. More detail about this feature is discussed in section 3.3.7.

The controller can edit the assigned taxi route at any given time by selecting the plane and selecting Edit Taxi Route button. Controllers can edit the route by selecting and deselecting the segments of the assigned route. By clicking the Confirm button, the edited route will be reassigned. Figure 5 shows a controller re-assigning a plane to a shorter route to their gate.

Figure 5: Once selected, the white plane is assigned a new route

5.4 Visual and audible warning system

To further reduce the workload on the controller, the software automatically keeps track of the planes with assigned taxi routes and continuously verifies that they are following their assigned route. Should a plane go off the assigned route, the controller will receive both a visual and an audible alert. In addition, the system will highlight the plane as flashing red so that the controller can easily identify the plane and the issue and to quickly intervene and resolve the situation. All warnings and caution alerts are displayed on the top left of the display and contain the information such as the flight number of the plane.

5.5 Incursion detection to avoid collisions and accidents

Another feature that increases runway safety is that the software automatically detects potential incursions and conflicts of path on the runway and taxiways. For example, if a plane is approaching a runway to take off and is within a certain distance of the runway, the runway status changes to unavailable, like the red runway in Figure 6. Therefore if another plane becomes too close to the runway on an intersecting taxiway or is crossing the runway at that time, the controller will immediately receive a warning to prevent any possible accidents.

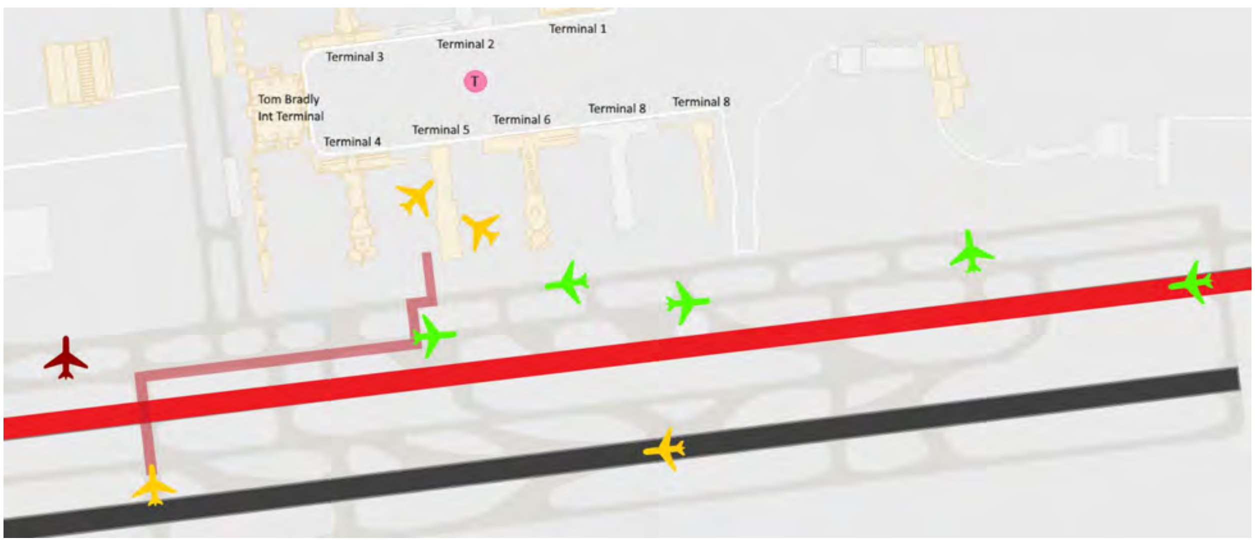


Figure 6: The controller is able to see where an incursion may occur based upon red pathways.

5.6 Different Access Levels and Blocking off Surfaces

The system is designed to have different access levels to different users. Accordingly, certain features are disabled or some additional features are provided depending on the access level of each user. For example, all the ground controllers, approach controllers, and ground crew will be able to use TAXI; however, approach controllers cannot assign taxi routes, and ground crew will mostly be able to use TAXI as a visual guide and a source of information.

Another example is that the supervisor at the tower will have the ability to disable parts of the airport, such as runways and taxiways. The disabled surface of airport will be marked with . This feature is particularly useful if there is an emergency or construction happening that require planes to avoid a certain area on the airport. Once a taxiway is disabled, the system will automatically avoid taxi routes that go through the blocked off section and will reroute the taxi route for the planes that have been already assigned a taxi route that goes through the disabled taxiway.

5.7 Digital Communication to the Cockpit for Assigning Taxi Routes Using CPDLC

As mentioned in the problem statement, one of the biggest causes of traffic mistakes is the use of the radio for controllers to transmit verbal taxi instructions to pilots. Our system will use the existing CPDLC system to send a text version of the assigned taxi route to the cockpit. The taxi route message will be parsed and converted to a visual representation of the taxi route on a flight deck computer so that pilots can easily follow the taxi route without any errors, even in the worst weather and visual conditions. Many of the next generation commercial planes have the feature to display taxi routes embedded in their flight deck. Therefore, converting the message from CPDLC to a visual representation on the displays can be implemented at a negligible cost. For the older planes that do not have this functionality, it can be achieved by using existing technologies such as tablets.

5.8 Current Prototype

We have built a prototype has been implemented using JavaFX language and includes features such as assigning and managing taxi routes, blocking off sections of taxiways and runways, visual warnings, and collision detection. Figure 7 is a screenshot of some of the code completed during the design. It shows some of the requirements for the Airport class, which contains various parts of the airports, such as runway segments, the airport visual, and routes.

```
public class Airport{

        private static GUIAirport guiairport;
    private static HashMap<String, Segment> segments;
    //private static HashMap<String, Segment> disabledSegments;
    private static HashMap<String, String>managerAccounts;//holds the username
    private static HashMap<String, Intersection> intersections;
    private static HashMap<String, Route> routes;
    private static HashMap<String, ArrayList<String>> routesWithSegment;
    //private static ArrayList<Employee> employees;

    public static Intersection getIntersection(String name) {
        return intersections.get(name);
    }

    public static Segment getSegment(String name) {
        return segments.get(name);
    }

    public static Route getRoute(String name) {
        return routes.get(name);
    }

    public static ArrayList&lt;Segment&gt; getSegments() {
        ArrayList&lt;Segment&gt; segs = new ArrayList&lt;Segment&gt;(segments.values());
        //System.out.println(segs.get(0));
        return segs;
    }

```

Figure 7: A short sample of the code written during TAXI’s design.

5.8.1 Coordinates’ Generation

To generate a segmented map of LAX, we visually split all of the runways and taxiways into Segments (blue) and Intersections (orange). Therefore, each segment stores its own specific data such as: coordinates, speed limit, size of segment/intersection, and maximum size of plane. These can be viewed in the annotated map in Figure 8.

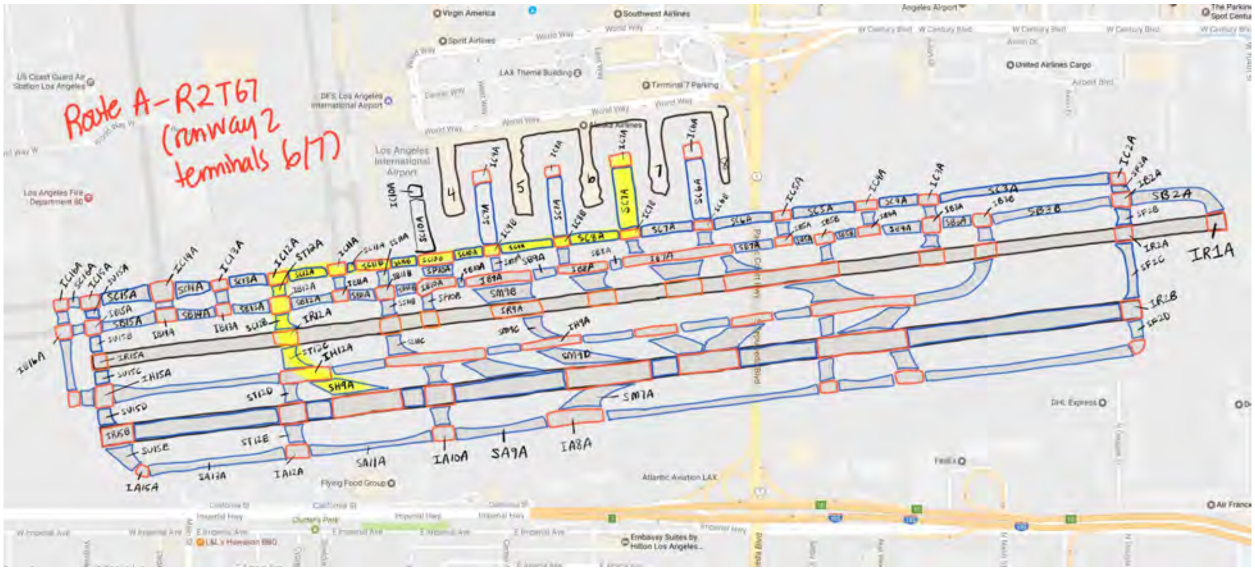


Figure 8: Annotated image that shows the segments and intersections of LAX

To visually display these segments on our map, we manually found and recorded all 4+ coordinates (latitude and longitude) per segment via point placement on Google Maps, and stored these in separate text files to be parsed and converted into map pixels using the mathematical calculation in Figure 9.

```
double yPixels = (this.latitude - 33.936061) * 76 / 0.003618 * (-1) + 370;

double xPixels = (this.longitude  + 118.419370) * 691 / 0.039609   + 300;
```

Figure 9: Calculation to go from latitude and longitude to map pixels.

The pixel coordinates of the map enable the system to generate the location of the segments of the route, and the current position of planes as well, as well as track whether planes are on route or not. We calculated these coordinate-to-pixel conversion equations by selecting two coordinates far apart on our annotated map in Figure 8, and then selecting their equivalent pixel in our GUI. With these two inputs and outputs, we calculated the scale difference in maps and axis spacing, and thus were able to replicate this translation with any latitude and longitude values to equivalent X and Y pixel coordinates.

5.8.2 Choice of Data Source

Instead of using real ASDE-X data provided by SWIM to test our prototype, we decided to use mock data instead. This gave us the freedom to test the system in different scenarios that otherwise would not have been possible had we used real life data. It also allowed us to replicate the human interaction of pilot and controller. We still implemented the function to parse the ASDE-X data.

5.8.3 Control of Plane Movement for Testing

To better test the plane movement on the map, we simply made it possible to move the plane by keyboard to simplify the testing process. This way, we could move the plane the way a pilot would do to check different taxi route assignments, off-route detections, and warnings.

5.8.4 Off-route Detection

The prototype continuously checks the location of planes with assigned taxi route and compares them with their taxi route. Accordingly, if a plane fails to follow the assigned taxi route, it generates a warning and changes the color of the plane to red. The color of plane will change back to green when the plane comes back to the assigned route.

5.9 Create Route Module

Before the TAXI aircraft route visualization system is launched into routine ATC workflows, we plan for an ATC employee(s) to interact with a Create Route Module in order to load their specific airport’s TAXI system with generated route presets from various start and end points (runways, terminals, parking spots). This interface will serve as the route creation prestep, and will allow ATC employee(s) to specify commonly used routes, their priorities, and as many route variations they are accustomed to giving to pilots normally. To make this step more efficient, the TAXI system will utilize path-finding algorithms to intelligently suggest the quickest routes from an inputted start and end destination. This will accelerate the ATC supervisor's route pre-generation step and additionally allow them to manually input their own route preferences, which will be visually available as route options once ATC begin interacting with TAXI and routing aircrafts to and from gates and runways.

5.10 Future Plans

For future iterations of TAXI, we plan on designing a Data Analytics Module, which can help ATC employees analyze all of the historical ASDE-X data compiled since first integration in the airport. This will provide key insights to ATC employees and opportunities for an airport to expand telemetry tracking efforts to better understand route usage, aircraft traffic trends, congestion frequency, and more. Many of ASDE-X's beneficial metrics are outlined in [4], allowing 4D surface trajectory conformance monitoring and prediction, and ultimately reduction of total runway incursions. The Future of TAXI aims to automate as many of ATC decision-making processes as possible while also generating as many useful analytics for better ATC decision-making in the future.

6. Communication with References Description

6.1 Interaction with Industry and Academia

Many parts of the design required calling on more experienced individuals in the field. We are very happy to have been able to use their knowledge in TAXI.

6.1.1 Air Traffic Control Personnel

Our research stemmed from an initial online meeting with Mark Benner, a now retired air traffic controller. Mr. Benner, having worked in the LAX control tower for more than 35 years as a controller manager and lead ATC trainer, was our primary contact on information regarding ATC operations. Michael Crowley, our faculty advisor, was the main point of contact for this meeting. Mr. Benner expressed an interest in having a system that could remember the routes that controllers relayed to pilots via radio. This gave our team a lot of focus on the first design of TAXI.

Our second and final meeting with Mr. Benner was at the LAX control tower. Three students, along with our advisor, were led on a tour through the LAX control tower by Mr. Benner, and were able to observe ATC operations. We focused on having our set of design questions answered, which largely contributed to our research. He also presented a lot of insight on the human errors that air traffic controllers face every day and how they could be avoided. Mr. Benner’s concerns highlighted the radio being the main factor behind miscommunication with pilots. We noticed the ASDE-X display was just a standalone screen among several that controllers need to utilize. We felt that we could improve the quality of the ASDE-X feed to provide us with an interface that could be used to solve this problem.

6.1.2 Aviators

In addition to completing the requirements requested for ATCs, we wanted to see if the knowledge of the assigned route would be useful for pilots. We spoke with two pilots, both who have been flying commercial airplanes for the past several years.

Bob Conover, a pilot with Delta Airlines, found it cumbersome with the pilot being required to look down at a screen while taxiing. He also noted that certain airports have implemented green taxiway lights in the taxiway to indicate their approval for movement. With our system displaying not only route information but also acting as an ASDE-X feed, we felt Mr. Conover's concern would not be an issue because they would even be aware of anything underneath their airplane, should that situation ever occur.

David Forsyth, a pilot with Hawaiian Airlines, noted that airlines have been converting to a paperless approach with Electronic Flight Bags (EFB) allowing pilots to receive information independent from the control tower [13]. With airlines adopting new technologies to give pilots, it is very feasible for us to expect TAXI to be used by pilots, giving them access to clear information from the ATC.

6.1.3 Other FAA Contacts

System Wide Information Management (SWIM) is a FAA technology program that facilitates the sharing of air traffic data. We tried to connect to SDDS data stream of LAX and use that data to build our prototype, so that our prototype could use real time data. Professor Crowley had a conversation with SWIM team and tried to set up VPN connection to get access to the data remotely. However, we were not able to build up the connection to the data stream by following SWIM-supporting documents. Professor Crowley sent several emails to FAA engineering team for troubleshooting but still could not make it work. Eventually, we decided to generate data by ourselves instead of using SWIM data. We believe that using data generated by ourselves is actually better for building our prototype, because we could test edge cases that are almost impossible to test with real time data, such as planes going off route.

7. Projected Impact of Design

7.1 How This Project Meets ACRP Goals

TAXI directly addresses LAX's critical modern-day needs of plane navigation in LAX terminals, as well as advanced route tracking and generation for ATCs. Formulated alongside industry guidance—including senior FAA and LAX officials, commercial aviation pilots, and thorough research—TAXI is designed and prototyped to make planes taxiing at airports safer, more efficient, and more predictable. TAXI was designed to address LAX infrastructure needs by ten University of Southern California computer science students alongside Professor Michael Crowley. USC students were directly engaged by writing a prototype program for implementing TAXI. Furthermore, conceptualization of the route tracking system required stringent attention to detail, use cases, and consideration of the critical nature of the system, as well as how TAXI would fit alongside other ATC systems, and the best methods with which ATCs would interact with TAXI.

As a framework for high-quality educational experiences, this project was ideal. By addressing the multiple parts of the report, and providing a comprehensive and well-researched design document including feedback from major airline pilots and LAX officials, we gained exposure and insight into a well-rounded educational experience that involved in-person visits to the LAX control tower, as well as primary and secondary research. These visits and research gave us profound insight into the fascinating world of aviation and airports, especially how technology and engineering have critical value in their daily operation. Furthermore, we were able to spend 5 hours/week with our advisor, Professor Crowley, which heightened the educational experience and incentive for success. This class is the initial interdisciplinary endeavor for USC's capstone class for computer science majors, and will serve as the launch point for more interdisciplinary capstone classes in the future which will also provide quality educational experiences.

In future years, TAXI allows for further student and other academic involvement in ACRP as there is design and implementation work remaining. The process to implement it mirrors similar FAA projects that involve ATC updates with no new hardware for pilots. We see TAXI as a natural fit in FAA’s NextGen suite of improvements and updates. For example, the DataComm program would fit hand in hand with TAXI—ensuring on both the pilot and ATC ends that the planes receive and follow the correct route to and from the gate. A projected timeline of TAXI is available below.

Program Milestones	Date
NextGen Validation and Demonstrations Completed	December 2017
Preliminary Design Review Completed	June 2018
Achieve TAXI Final Investment Decision (FID) for Qualification Phase	August 2018
Critical Design Review completed	March 2019
Achieve TAXI FID for Deployment Approval of Operational Systems	April 2019
Functional and Physical Configuration Audits completed	June 2019
Contractor Acceptance Inspection of Equipment at key sites	July 2020
Operational Test and Evaluation completed	September 2020
Key sites Initial Operating Capability	January 2021
In-Service Decision	May 2021
Production and Deployment of TAXI Operational Systems	2021-2026

7.2 Benefits of TAXI

The improvements that can be made by the implementation of TAXI are beneficial to ground controllers, pilots, and passengers. These improvements will lead to increased flight efficiency, enhanced productivity, and improved general safety. TAXI’s specific benefits include many benefits that are found in the most current ASDE-X tool used by the ATC and the NextGen programs that are focused on surface improvements. Some of those include:

- ❖ Permit taxi operations to occur that support low visibility operations for takeoff, improving access during those times.
- ❖ Enabling more effective scheduling that includes runway, departure fix, and Traffic Flow Management (TFM) ground-management constraints.
- ❖ Reducing fuel burn and operating costs related to long departure queues.
- ❖ Beyond what has been done by ASDE-X and NextGen, TAXI would have benefits focused on:
- ❖ Advancing effective scheduling with virtually no delay between when the controller decides a route and when the pilot receives path information.
- ❖ Utilizing existing technology where possible in order to keep costs low.
- ❖ Eliminating communication errors between the controller and pilot for taxi instructions.

An important aspect of the TAXI system is that it has two components, one for the tower and one for the pilots in the cockpit. With his or her view, the pilot is able to see the path it must take in order to get to the gate. In 2016, the FAA estimated 943 runway incursions were caused by pilot deviation [14], and this was the highest category of the total 1,560 throughout the year. With TAXI, most, if not all, of these deviations would be avoided since their path would be clearly visible. In an extreme case, a runway incursion may cause injury to passengers or pilots, according to the FAA; even a minor injury could cost $28,800 per injury. With TAXI, this cost would be avoided and more people would be safe [15]. If only 10% of the incursions from 2016 involved minor injuries, this would be nearly $4.5 million worth of savings. Taking into account that runway incursions also affect runways as well as the aircraft themselves, we expect this number to be even higher, however it is difficult to assess since many costs are not publically available.

In terms of fuel burn, a Boeing 747 should burn approximately 3,000 pounds of fuel during taxi [16]. This would be approximately 445 gallons reserved just for taxiing, and most American carriers can expect to spend about $1.75 per gallon [17]. If the average taxi time at LAX is 11 minutes—according to LA Times, LAX's taxi time was busy during the 2016 summer months—that would be around 40 gallons per minute, or approximately $70 of fuel burn per minute [18]. If TAXI is able to save a minute off the 1,578 reported flights into and out of LAX [19], that would be saving about $110,460 just in fuel burn per day.

7.3 Costs Associated with Implementation

By using the existing technology in the cockpits and on the ground, TAXI is able to reduce costs since there's no extra installation. Unavoidable costs would include research and development costs, actual production costs, and operational cost.

Costs already incurred are outlined below in Table 1. This includes the costs from efforts thus far. We expect there would need to be further research done in order to fully implement a few of the aspects such as airport digitization in order to have an accurate, meaningful digital view of an airport map. Potential future R&D would require speaking with other experts and doing an in-depth look at how ATC information is currently handled.

Item	Rate	Quantity	Subtotal	Remarks
Labor— R&D already incurred				
Student efforts	$30/hr.	750	$22,500.00	10 students total quantity
Professor effort	$60/hr	90	$5,400.00	1 professor
LAX advising	$58.59/ hr.	2	$117.18	Rate taken from [21]
Labor — R&D Expected				
Research team	$30	160 hours	$4,800	
Subtotal			$32,817.18	

Table 1- Incurred Costs by the team

Production costs would be the most expensive aspect of the product in order to maintain a high quality. The development team would be key, as there would need to be two members who designed and implemented the front end, visual design, and two members working with the data of the planes. One of the two backend developers would need to have experience working with ASDE-X data in order to be able to parse it and create meaningful images on the screen.

This same development team would be required to conduct safety testing in order to ensure that no issues would occur during the operation of the product. We recommend two different types of testing to be done— first unit testing where each aspect of the software would need to be tested on it’s own using data that has been pre-generated, and second, testing with real ASDE-X data that the program is able to parse in real time. During this second testing phase, there would need to be developers and FAA employees involved.

Equally important for production would be the sales team. Sales costs would be incurred since airlines would need to approve the application for pilot use.

Item	Rate	Quantity	Subtotal	Remarks
Development team	$50/hr	640 hours	$32,000	2 front end developers + 2 backend developers
Safety testing — automated tests	$50/hr	320 hours	$16,000	
Safety testing— real ASDE-X data	$55/hr	640 hours	$35,200	
Sales team			$30,000	Sales rep commission
Total			$113,200	

Table 2 - Development and Testing costs for production system

Operational costs would include upkeep of the service as well as training as new airports bring TAXI into use. Operational costs below would be incurred per airport that has TAXI. We expect training to take approximately two months. We believe there should be one trainer throughout the deployment of the product, should more airlines be brought on at one time, there would need to be more trainers. As a part of the installation, we believe there to be little cost for airlines to add the hardware to cockpits, since our research found that many already have tablet devices with the pilots. We are pleased to be able to avoid the cost of adding a device to the airline. However, given that TAXI would be touch-enabled for ease of use for controllers, we do feel it necessary to add a touch enabled device to the tower. The most appropriate device would vary based on the space available and the appropriate size required by the size of the airport itself. Prices for a large, touch-sensitive screen can range from $1,000-$1,500. For the sake of comparison, we'll consider the more expensive option.

Ideally, since TAXI runs "on top" of ASDE-X, installation costs would not be incurred to load airport data, since ASDE-X should be able to seamlessly pass it to the application. The final version of TAXI will run as a service and not require any installation costs since it should be as simple as installing a computer application. Upkeep would only be required as different parts of an airport are remodeled or changed. These types of changes would be on a per case basis, and are difficult to include as part of a recurring cost each time TAXI is deployed at a new airport.

Item	**Rate**	**Quantity**	**Subtotal**	**Notes**
Trainers	$70/hr	320 hours	$22,400	
Touch-sensitive screen	$1,500	1 device	$1,500	
Total			$23,900	

Table 3 - Deployment costs per airport

Appendix A

Team Contact Information

Name	Role	Email
Michael Crowley	Advisor	crowley@vsoe.usc.edu
Megan Joseph	Team Lead	meganjos@usc.edu
Justine Foote	Undergraduate Student	jfoote@usc.edu
Laura Gouillon	Undergraduate Student	gouillon@usc.edu
Jiahui Wei	Undergraduate Student	jiahuiwe@usc.edu
Alexander Leung	Undergraduate Student	leungale@usc.edu
Joyce Yan	Undergraduate Student	joyceyan@usc.edu
Sina Karachiani	Undergraduate student	karachia@usc.edu
Haohan Tang	Undergraduate Student	haohanta@usc.edu

Utsav Ahuja	Undergraduate Student	utsavahu@usc.edu
Shiyao Wu	Undergraduate Student	shiyaowu@usc.edu

Appendix B

University of Southern California

The University of Southern California is one of the world's leading private research universities. An anchor institution in Los Angeles, a global center for arts, technology and international business, USC's diverse curricular offerings provide extensive opportunities for interdisciplinary study and collaboration with leading researchers in highly advanced learning environments.

USC's distinguished faculty of 4,000 innovative scholars, researchers, teachers and mentors includes five Nobel laureates, and dozens of recipients of prestigious national honors including the MacArthur "Genius" Award, Guggenheim Award, the National Medal of the Arts, the National Humanities Medal, the National Medal of Science, the National Medal of Technology and Innovation, and Pulitzer Prize.

The USC Viterbi School of Engineering faculty and students extend the frontiers of engineering knowledge through their research, they also apply engineering and technology to address societal challenges. The school stimulates and encourages qualities of scholarship, leadership, ambition and character that mark the true academic and professional engineer — to serve California, the nation and the world. At USC Viterbi, we call this the enabling power of Engineering+ [20].

Appendix C

Non-University Partnerships

Steven Debban

One person we spoke to was Steven Debban, P.E., a National Resource Expert for Airport Design at the FAA. He provided clarifications on runway safety. He provided feedback on our Safety & Risk Assessment and helped us better identify runway risks. He also discussed the flow that the air traffic controllers and pilots typically go through during takeoff and landing.

Bob Conover

Bob Conover is a pilot with Delta Airlines who has flown Boeing 767-ER and the 757. Bob provided feedback on initial ideation behind TAXI and gave insight into the cockpit.

David Forsyth

David Forsyth flies with Hawaiian Airlines who has flown Airbus A330 now, and previously the Boeing 737. David answered questions we had at the beginning of the project. He gave feedback on what the pilot sees happening upon entering and leaving an airport.

Mark Benner

Mark worked for the FAA as an air traffic controller for more than 30 years. He was the ATC trainer for LAX up until March 2017, when he retired from the FAA.

Appendix E

Impact on Educational Experience

Megan Joseph:

1) I enjoyed my experience this semester of working with an outside organization to design a navigation system from scratch. It allowed me to use prior experiences in classes and internships to put together a final project that really helped me understand the computer science design process from start to finish.
2) I think that we defined a good strategy to tackle all of the important parts of this project (the initial research, speaking to contacts, and design). The main challenges were found in implementing our basic prototype of the design. However, building that prototype helped us flush out small problems and structural flow of the design itself, which helped us in the end to develop a much more thoroughly planned design for the competition report.
3) We looked at a lot of previous research into industry standards, and that helped us structure our own design. Having a base (ASDE-X) gave us a good starting point to launch from, and we were able to design a great system that made up for previous systems' weaknesses.
4) Initially our contacts at LAX were very useful and answered all of our questions. We even got to take a tour of the control tower, which was really cool and beneficial to our report. After that it fell on us to take all our ideas and their assistance to build something useful.
5) Yes, this competition and the work I did really gave me a better idea of applying design to everyday computer science problems in the workforce. When I start my full-time job

I'll be ready to handle a large-scale project where the minutiae of design is very important.

Ellen Jiahui Wei:

1) The design competition definitely provides a meaningful learning experience for me. It allows me to incorporate what I learnt in school into application in real world.
2) Understanding the whole system of LAX and finding related and useful information regarding this project takes longer time than actually designing/ programming. To settle down the final design also involved lots of communication and re-design over time.
3) We talked with Mark Benner to get the information we couldn't access via internet
4) Yes it is. Some of the information we needed is hard to find online. Meanwhile, talking with people in the industry gives us a better understanding of airport routine, which helps us a lot while developing our thoughts.
5) This project allows me to take an insider look at airport, pilot, and the ground control. As an engineering student, it also enhances my system design skill as well.

Justine Foote:

1) The design competition provided a meaningful learning experience because it was certainly out of the scope of any other class I'd taken in university. This project allowed me to give a real application to computer science where it wasn't just going towards the building of something specifically tech related.
2) I think one of the largest challenges was coordinating with not only ten other students and a faculty advisor, but also all of the experts that we spoke with. It was also challenging to get a full understanding of the scale of what LAX sees everyday and how we could help.

3) We worked a lot with Mark Benner at LAX to develop a way to sufficiently solve the problem of runway incursions. We also did a fair amount of research into FAA documents, scholarly articles, and discussions with other industry professionals.
4) Yes! Their help was incredibly useful and served to make the project even more real. It helped to guide us to what is applicable in industry.
5) I learned a lot about the daily operations of the LAX and airports all over the country. I had no experience with the FAA aside from flying as a passenger. It was incredibly interesting to become involved in something that affects so many people. I think there's always value in finding new and interesting industries regardless of if I'll be going into that field.

Laura Gouillon:

1) Working on this design project has been a meaningful experience in researching a real world problem and applying my computer science and product management skills in designing a solution.
2) Due to time conflicts throughout the week, we split our team in half, each receiving front-end and back-end design responsibilities. It was difficult designing the overall system with two groups often remote from one another.
3) Diving in and doing the initial research on SWIM, ASDE-X, and LAX aircraft navigation risks was difficult to digest but in the end led to a more relevant and comprehensive design solution proposal. We then worked in teams on specific features to implement and document.

4) In researching risk management principles and accurate aircraft navigation hazards, speaking to actual industry representatives was key since our initial conclusions may have overestimated or underestimated airport risks.
5) Prototyping a user interface and full-stack route loading with simulation were some of the highlights of my experience. I enjoyed being able to design a solution from scratch with my team members, something which mimics agile rapid prototyping.

Joyce Yan:

1) The design competition was definitely a meaningful learning experience because I was able to learn about the more practical implications of my field.
2) One of the challenges I had was synchronizing between the work other students were doing and my own research. And sometimes it was difficult to figure out how to answer a question I had, having to search through online resources as well as some industry contacts we had.
3) We talked with Mark to help identify the problems air traffic controllers had, and then designed a solution around our research.
4) Yes, absolutely. Being able to talk with industry professionals was extremely helpful.
5) In the past I've built user applications but I had never done any significant user research or worked with a client, I had only built applications that I wanted to build. This project helped teach me how to work with a stakeholder when developing applications.

Utsav Ahuja:

1) The ACRP University Design Competition for Addressing Airport Needs was a really unique and meaningful learning experience for me. It allowed me to immerse myself in a new industry (aviation), which was a fascinating endeavor into the critical challenges and

infrastructure of airports and the tens of thousands of airplanes that fly in the United States each day.

2) Our greatest challenge was balancing the unique needs of LAX with the custom solution that we designed to solve one of LAX's greatest challenge. Through thorough research, including interviews with commercial aviation pilots, an on-site visit of the air traffic control tower, and secondary research conducted primarily online, we were able to formulate a design that was both functional and efficient and suited LAX's unique needs.

3) We spoke a senior LAX official regarding LAX's needs, and then used our research—as described above—to develop a well-informed, detailed hypothesis that addresses LAX's critical issue. We ensured that our hypothesis was multi-faceted, well thought-out, and would provide a meaningful solution to the runway navigation issues that LAX is experiencing.

4) Participation by industry was one of my favorite parts of the project. While I personally did not visit the air traffic control tower, my teammates were able to and that was definitely a very meaningful experience. This project differentiated from other traditional educational projects in that we were working on a tangible need by an industry that every person is familiar with—aviation.

5) I learned how complex and critical the systems that keep our airports running are, which was both surprising and fascinating. The ability to conduct research through industry interviews and professional documents was a unique and meaningful learning experience that I know will pay dividends later on in my professional career. Furthermore, the experience of designing a system to address a critical need, and integrate it into existing

systems, APIs (such as ASDE-X) was invigorating and consequential. This project definitely helped me develop skills for a successful future.

Sina Karachiani:

1) The Airport Cooperative Research Program (ACRP) University Design Competition for Addressing Airports Needs was a meaningful learning experience for me because it was an opportunity to integrate two of my favorite disciplines, aviation and computer science, and to learn about air traffic control and its nuances.
2) Of the most notable challenges were figuring out the current problems associated with runway safety at LAX and to come up with a generalized solution for them that applies to all airports.
3) We approached the problem from a controller's’ perspective and how we could make changes in the flight control process to reduce human error and increase efficiency.
4) Yes, through participation in the industry, we were able to gain insight on how the ground control works and we learned about shortcomings and difficulties of the job. Thus, we were able to search for a solution with a more focused perspective.
5) This project helped me learn more about designing a software in a team setting by brainstorming and gradually developing on our ideas. In addition, this was an opportunity to learn more about computer science, such as JavaFX, frontend and backend development.

Shiyao Wu:

1) It has been a meaningful experience working on this project. I learned a lot about how plane routing works at airports and the technical issues in the process. I also had the

opportunity to work closely with my professor and teammates and apply the software design skills I have learned at school.

2) In the architecture we have designed, there are many different components such as controller, plane, route, etc., and they are all related to each other. Also, some of the components have both a front-end and back-end part, so it's a complex structure. To design the whole architecture, we discussed a lot at several meetings and then assigned the detailed tasks to all the team members to complete.
3) We talked to some professionals in the industry and read online documents to get the information we needed and figure out what we were going to do. Then we designed the software together, and wrote the code and report based on our research and design.
4) Definitely. As students outside of the aviation industry, we didn't have enough knowledge we needed to complete the project. By talking to people in the industry, we got to know about the problems they had and the technologies they used so that we could keep ourselves on the right track.
5) I enhanced my software design skills by working with my professor and teammates. Also, in the process, I became a better team worker and enjoyed getting involved in the team meetings and working in groups.

Alexander Leung:

1) The competition was a meaningful experience for me. Throughout my teenage years, I had attended aerospace summer camps at the Museum of Flight in Seattle and my interest in aviation only grew. In high school, I had the chance to volunteer at the same summer camp and loved every second of it. When I entered college, there was not much of a chance for me to have the same experiences as when I was at home. Given this chance to

participate in a team project to use my knowledge in computer science to improve aviation technology was a great decision.

2) The main challenge our team encountered was not being able to fully utilize a live data feed for ASDE-X data. With a constraint on time, we were not able to constantly monitor and parse every single message that came through to fit our edge cases. The only way to completely test our system was to create our own data stream to show its capabilities.
3) Our process consisted of taking the initial idea and generating a set of design questions and constantly doing research to answer those. Any new questions were added to the queue. The research we undertook consisted of reading online documents and speaking with industry professionals. This loop was very effective and led us to our final design.
4) Participation by industry was most definitely meaningful and useful. Had we not considered their opinions, our final design would be of no use. Air traffic control personnel and pilots will ultimately use the system we built, so it makes sense to include them in the conversation.
5) I learned that working as a team can be very effective but requires a lot of delegation for it to work. This project helped prepare me to work on a real software engineering team in the workforce. We spent a lot of time as a group going over design decisions before implementing them in software, which made it feel very professional.

Haohan Tang:

1) ACRP was a great learning experience for me. I learned more about how to design a real-world software system. Besides that, it was interesting to learn how pilots and controllers communicate.

2) One notable challenge we had was showing the map of LAX on our prototype. We had to use a screenshot of a Google map and wrote an algorithm to convert longitude and latitude location to pixel location.
3) We did a lot of background research. Also, we talked to Mark Benner from FAA and a pilot to get a better understanding of the operations in airports.
4) Yes, a highlight of this project is to learn more about the industry.
5) Doing this project definitely prepares me for working in the software industry. I learned how to work in a team of ten and how to work on a project collaboratively. Having the experience of designing a complicated real-world application also helps.

Appendix F

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