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Article

Airport Operations Delays and Possible Mitigation Through Electric Taxi Systems: A Qualitative Case Study

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Airline daily departures, not including private aircraft, increased from 25,143 in 2000 to 36,722 in 2017. More passengers necessitate more aircraft and more flights. With more aircraft at terminals, ground delays, based on current airport design, will continue to increase. Systems that allow for reduced aircraft time on the ground will improve airline economics and airport operations, in addition, will reduce airline delays both for departure and arrival at the gate. The purpose of this qualitative research study was to explore the efficacy, from ramp controllers' perspectives, of equipping airliners with an electric taxi system. Prototype electric taxi systems have shown a savings of up to 10 minutes for an aircraft to pushback and depart the ramp area. A case study methodology was employed to examine the various aspects of four representative airports regarding the potential implementation of the electric taxi system. Results showed that although ramp controllers saw economic and environmental benefits to an electric taxi system, most believed that these systems would not save time in and out of the ramp entry and exit areas due to limitations of airport design. Releasing control of more airport ground areas, to the ramp controllers, would be far more effective in reducing gate delays.

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Introduction

Airlines carried 4.3 billion passengers on scheduled services in 2018, an increase of 6.1% over 2017. The trend is expected to continue, with the latest data available showed that daily airline departures, not including private aircraft, increased from 25,143 in 2000 to 37,823 in 2018, according to the latest data from Airlines for America (2019). More passengers necessitate more aircraft and more flights. With more aircraft at terminals, ground delays, based on current airport design, will increase. These ground delays create schedule problems, missed connections, as well as increased noise and other environmental problems for airports. Systems that allow for reduced aircraft time on the ground will improve airline economics and airport operations, in addition, will reduce airline delays both for departure and arrival at the gate.

Purpose

The purpose of this qualitative research study was to explore the efficacy, from ramp controllers' perspectives, of equipping airliners with an electric taxi system. Electric taxi systems could reduce the use and cost of fuel for each airplane. "Fuel costs are a significant but highly variable expense for airlines worldwide, constituting 23.7 percent of total expenditure in 2019. This figure decreased from 32.3 percent in 2012 but is expected to rise again to 28.4 percent of expenditure in 2020" (Statista.com, 2019, Fuel Cost section). In addition to lower fuel costs, this could result in less noise and lower engine emissions.

A case study was selected as the appropriate method, since case studies are based on an in-depth investigation of a group or event to explore the causes of underlying principles (PressAcademia, n.d.). Nineteen ramp controllers from four major airports (Chicago, Denver, Houston, and Los Angeles) were selected. These airports are representative of major airports with a high number of ramp operations. Whereas small airports have fewer delays, major airports could benefit the most from improvements in efficiencies.

Background

Time for a tug (external vehicle designed to move aircraft) to push back, park, set, and disengage from an aircraft averages 5 minutes, and a sample of 6,723 aircraft pushbacks showed the time increased to 11 minutes to capture 95% of all pushbacks, based on distance to the pushback spot, assuming no problems are encountered (WheelTug, 2019). An electric system could allow an aircraft to push back on its own and taxi within as little as 45 seconds. This could allow for expedited aircraft movement, thereby reducing ground delays. Tow-in tugs are also needed in blast-sensitive areas, necessitating further delays in parking at the gate; an electric taxi system might also be used to allow quicker parking at the gates.

Normally, a pilot taxies an aircraft utilizing thrust from the engines and the brake system to reduce speed. Even when the aircraft is stopped, the engines continue burning fuel, similar to most automobile operations. This wastes fuel and results in engine operations longer than needed which also increases engine maintenance costs, fuel burn, pollution, brake wear, and noise. For this reason, electric taxi systems (i.e., traction drive systems that employ electric motors) have been developed for use with aircraft.

There are two types of electric taxi systems in development: internal and external. An internal system is mounted within the aircraft itself and use electricity from an auxiliary power unit to drive electric motors, mounted in the wheels, allowing the aircraft to move without having to start the engines. An external system is not part of the aircraft, but is a remotely-operated “mini-tug” that attaches to the aircraft nosewheel, allowing the pilot to immediately taxi the aircraft, again without having to wait for engine start. Once no longer needed, the unit detaches and returns to a holding area.

Numerous patents have been issued to a variety of companies developing electric taxi systems. These include WheelTug, a division of Borealis Technical Limited (“Patent Issued for Clutch Driven,” 2018), Goodrich Corporation (“Patent Application,” 2019), Honeywell International (Patent Issued for Aircraft Electric,” 2017; “Patent Issued for High Integrity,” 2015), and TaxiBot, a division of Israel Aerospace Industries (Globes, 2011).

The three companies currently producing electric taxi systems are Wheeltug®, Safran®, and Taxibot®. The main structural difference is that the first two, Wheeltug® and Safran®, use systems that are installed on the aircraft, whereas Taxibot® uses an external system to steer the aircraft (under complete pilot control). Once the aircraft is moved to the correct location, the system detaches and returns to a pre-determined spot on the airport, so no modification is made to the actual aircraft. Initial costs vary, depending on the number of units purchased, but Taxibot advertises a price of $3 million per unit (Globes, 2011), no information was found for Safran, and WheelTug has no initial costs, but would charge the airline an hourly rate (WheelTug, 2019).Since the Taxibot is an external system, it can be used on multiple aircraft, whereas the Safran and WheelTug systems need to be installed on individual aircraft.

Ramp Control Operations

There are a tremendous number of aircraft operations at major airports. For example, Atlanta Hartsfield conducts more than 2,700 operations and Chicago O’Hare more than 2,400 operations each day (Flightradar24, 2019). At smaller airports, the Federal Aviation Administration (FAA) ground controller handles the traffic to and from the gates, because the volume of traffic is low. At major airports, there are too many aircraft entering and exiting the gate (ramp) area for a single FAA ground controller to handle. When airlines operate such a high number of aircraft at one location, the operations in and out of their ramp areas are managed by the respective airline. Airline personnel who control movement with the ramp area are referred to as ramp controllers. A ramp controllers’ primary job is to create an orderly flow of traffic from the taxiways to and from the gates. See Figure 1.

Figure 1. Ramp controller station, including ramp controller view of the ramp area and computer displays of gate areas an aircraft arrival/departure timeline. Adapted from "EWR Ramp Controller" n.d. Reprinted with permission.

Literature Review

Nikoleris, Gupta, and Kistler (2014) carried out a study that focused on the delay and capacity factors of planning, and they revealed that taxi operations comprise some of the largest sources of emissions during a typical landing-take-off cycle at Dallas Fort Worth International Airport. Data was collected from airports to determine the emission and consumption rates; their analysis revealed that the stop-and-go activities account for around 18% of the fuel consumed, which was 35% higher when compared to contexts where aircraft are moving in an unimpeded approach at 20 knots (Nikoleris et al., 2014). The hydrocarbon and carbon dioxide emissions are also higher during departures in compassion to arrivals. This means that arrivals have a more-uninterrupted surface trajectory. The reasons behind this are that the runway could be a bottleneck within the air traffic system. Alternatively, it could arise from the on-time performance metric set by the Federal Aviation Administration that considers any arrival 15 minutes after the scheduled time to be late. Since the departure flight metric relies on gate pushback, it leads to pressure on arrival flights to reach the game quickly, and the controllers will stop fewer arrivals in comparison to departures.

Ganev, Chiang, Fizer, and Johnson (2016) focused on the installation of electric propulsion in the landing gear. The system would lead to environmental benefits and fuel savings. It will also minimize brake wear while reducing ground tag operations. Ganev et al. stated that, "the drive for energy-efficient eTaxi imposes the need for bidirectional power transfer" (2016, p. 67). This makes it possible to recycle the regenerated power arising from a dynamic braking system. The transfer module (TM) would be mounted on the landing gear is a device that converts electrical energy to mechanical energy. However, the authors suggested that the device can be switched with a bidirectional converter that actively works to transfer the regenerated power from the braking back to the bus. Despite this, installing TM can lead to several challenges, such as potential contamination, thermal stress, and mechanical stress. This necessitates the need to encapsulate electrical components and use of a cooling fan. Future implementations will also have to consider lower volume and weight to attain a higher speed TM.

Postorino, Mantecchini, and Paganelli (2019) posted that the aviation sector relies on different stakeholders, including local authorities, airport operators, travelers, and the air industry. They all have different needs, and airport operators face more opposition from community groups due to issues such as atmospheric emissions, noise, runway expansion, and other effects of the airport on the community. Improving the taxi-out operations has not always been a focus for environmentally-friendly initiatives in airports. Instead, other approaches have been considered, such as greener vehicles. However, remodeling the percentage of tug times and ground aircraft times would lead to a reduction of the emission rates in airports.

Zhang and Wang's (2017) research on management of the airport surface revealed that a renewed focus has emerged due to delays and excess emissions from planes. Unimpeded taxiing time is a measure that is used to determine taxing delay and is also used as a performance indicator. Some of the bottlenecks in airports that congestion could arise include taxiways, apron area, gates, and runways. Zhang and Wang also suggested that there is need to have an accurate definition of taxiing time and a consistent approach of establishing unimpeded taxiing times should be used during evaluation of the airline's operational performance. This will provide accurate data to determine taxing efficiency. Excess taxiing delay is also attributed to the number of aircraft on the surface.

The research on electric taxi systems has mainly concentrated on the potential economic and environmental advantages. These are certainly important factors, but previous research has failed to include perspective from the ramp controllers. Including ramp controllers' perspectives will allow a more broad-based analysis of using electric taxi operations for aircraft.

Current Study

The purpose of this qualitative research study was to explore the efficacy, from ramp controllers' perspectives, of equipping airliners with an electric taxi system. This qualitative case study was designed to utilize purposeful sampling of the participants' viewpoints and expert opinions regarding potential advantages and challenges with the implementation of a new system, the electric taxi system. Qualitative research is the traditional method for discovering a deeper understanding of a subject in a way that quantitative-only data cannot give us.

This research study was guided by three primary research questions:

RQ1: How do ramp controllers perceive potential benefits of electric taxi systems at major airports?

RQ2: How do ramp controllers perceive potential problems of electric taxi systems at major airports?

RQ3: How do ramp controllers perceive the implementation of electric taxi systems?

Method

The authors used a semi-structured interview format to understand he perceptions of the ramp controllers. The interview protocol contained a greeting, description of the purpose of the research, research questions, interview questions, follow-up questions to each key research question, and space for reflective notes. Using the research questions, we developed open-ended questions with follow up questions to probe for deeper meaning (see Appendix).

A case study methodology was employed to examine the various aspects of the four representative airport operations with regarding to the potential implementation of the electric taxi system for airplanes that are moving to the runway. This case study was designed to bring the researchers to a deeper understanding of this issue, which adds depth to what is already known about a phenomenon to be examined. As a result, multiple perspectives were obtained on this main topic with a significant tangential data collected that have been analyzed and placed into specific themes for the purpose of addressing the research questions.

Institutional Review Board permission was obtained from both the sponsoring university and the respective airline prior to any participant recruiting or data collection. To maintain the confidentiality of the participants, all identifying information was redacted from the transcripts.

Participants

Four major airports from the continental United States were selected for participation in this study. The 19 purposely-selected participants were airline representatives from Chicago (7), Denver (3), Houston (4), and Los Angeles (5), which allowed for a perspectives from a cross section of major airports that experience a significant number of ground delays on a regular frequency (Chicago, Houston, and Los Angeles) and one where a large number of ground delays does not typically occur (Denver). These airports allowed an initial evaluation of the potential differences experienced by those managing different airports with multiple air traffic flow patterns as well as ramp controllers' overall experiences and perceptions of the issue of ground delays and possible methods to mitigate this issue. In the data collection and analysis process, each participant read and signed a confidentiality consent form, was assigned a code to ensure confidentiality, and privacy was maintained at all times. Saturation of the data was met through this number of participants by ensuring that adequate quality data was collected to support the study; no new information was expected to be added to the emerging patterns that would enhance or change the findings of this study.

A high degree of validity was designed into the research process. The first step to ensure validity consisted of inter-rater reliability (IRR) training. Interviewers discussed potential biases and then met to create mock interviews, thereby ensuring consistency of questions and follow up techniques. Next, the researchers ensured that an appropriate sample was selected, by interviewing ramp controllers from four major, geographically-dispersed airports. Finally, triangulation was used to also ensure validity. Interviews were conducted by two IRR-trained researchers in different locations. Once the interviews were complete, the researchers individually analyzed the data before meeting to compare and cohobate their individual results.

Data Coding and Analysis

The researchers voice-recorded each participant's discussion throughout the interview. A written transcription was developed for each participant after de-identifying each participant's information. Each of the participants' responses offers insight into their perceptions, opinions, and personal recommendations of airport operations. The MAXQDA qualitative data analysis software was accessed to summarize these transcripts. The participants were identified as Participant 1, and so forth. Using the inductive approach to data analysis, the researchers then extracted key statements and phrases while organizing them into broad patterns that corresponded with the research questions and finally summarized what was being communicated within each statement. From this extraction, the researchers identified the primary themes. Because this analysis process was not based on a structure or predetermined framework, the approach to qualitative data analysis was more exhaustive and deliberate.

While the researchers had specific interview questions that were accessed during each of the semi-structured interview session, the interviewers allowed for the free flow of dialogue, which provided a broader set of information, yielding richer overall information that is presented in this discussion.

Limitations

Many limitations could have influenced the research study as well as the results. Limitations that could have been associated with the research study are whether the participants were available to be interviewed, the timing of the interviews, and that purposeful sampling was used. All participants met the research criteria and were ramp controllers from four major airports, Chicago, Denver, Houston, and Los Angeles. Although the participants were representative of major airports, smaller airports do not have the same ramp issues to address.

Results and Discussion

The purpose of this qualitative research study was to explore the efficacy of equipping airliners with an electric taxi system. As an initial study, this data is intended to support a foundational understanding of ramp controllers' impressions of the system and potential impacts of the airports' current functioning status. As in any research, unintended or secondary findings, which are not the primary target of the planned procedures, can greatly contribute to the results of this study and by proxy, that of the field. Further, the possibility of determining positive economic benefits to the airline industry and airport operations was envisioned as a secondary function of this study.

The following sections will include an organization of the research results. They are organized by the research questions that were addressed. Any applicable responses from the participants are also included in this section and the themes that emerged. Through the data collection process, the researchers were able to freely engage with the participants, which yielded additional unexpected findings. While not initially planned, the additional data provides a wealth of interpretive data to support the findings from the original three structured research questions.

The data reduction process was helpful in further identifying these patterns and alignment to the research questions and by proxy, the data aligned to the interview questions that support the research questions. Taken into consideration was the totality of the data set. In the review of these themes, the above connections are drawn based on their similar responses and the interpretation of this data. What is important to be mindful of is that qualitative data analysis is ongoing, fluid, and in fact, shed light on the broader study questions as indicated below.

As with all qualitative research, the concepts of credibility, transferability, dependability, and confirmability must be addressed. These concepts indicate the trustworthiness based on the methodology, the ability to transfer research findings from one context to another, the stability of data over time and over conditions, and the degree to which the results could be confirmed or corroborated by others (Creswell, 2018). As described previously, the IRR training of the researchers, sample selection, and triangulation techniques help ensure trustworthiness of the process and results.

Research Question One

When asked the first research question, *What potential benefits do electric taxi systems offer major airport operations?* LAX2 stated, *"…*But the idea I think, anything to expedite, move, get out quicker, decrease delays, who's not for that?" There were a number of themes identified including fuel savings and the environmental impact, saving money, and minimizing delays of the ground crew.

Fuel savings and the environmental impact. Fuel savings and the environmental impact was one combined theme that emerged from the line of discussion. Responses from all four locations supported the need to consider the environmental impact during the taxi phase of flights that included delays in pushback and traffic related considerations. The use of an electric taxi system received a positive response from the participants in this regard. DEN1 stated, "The environmental impact, the fuel savings that the air carrier would experience, those will be a very, very positive benefit for that." Participants were interested in ideas that supported the potential implementation of the electric taxi for the airlines for the purpose of saving time during the process of taxiing the aircraft out to the runway. As an example, IAH2 said, "But in theory this would save a lot of time. And every time you save time and fuel at the airport, you're going to save money" and ORD4 expressed, "I could see a possibility in it. I really could, as far as, I think it would be a time saver and a cost saver. Yeah. I don't see why you couldn't do that. You know, at one time, the SPs here [*an older model of the B-747 that is no longer used*], they used to tow them all the way out to the runways."

Participants provided their personal experience with the issues of delays and how the implementation of the electric taxi system could have a positive impact. ORD3 shared the following recent personal experience.

> One of the other thoughts on the electric taxi system was not necessarily on the ramp considerations, but environmental noise, fuel. And like when I came in last night, we ended up sitting in the penalty box [*a holding area when you cannot get into the gate*] for about 20 minutes. They could have shut down the engines during the electric taxi.

LAX3 subsequently began asking questions regarding the topic of saving money as a way of simultaneously having an environmental impact of reducing emissions by shutting down the engines during this portion of the interview as indicated above. Examining what "could be" or methods of improvement was evident in the responses received as indicated by ORD1:

> And again, they're always looking for ways to try and make it a little more efficient. This is one of the proposed ways that was out there. And the other thought on this was, especially if they're holding coming in, if they're going out to the penalty box, theoretically they could shut down the engines for their five, ten, fifteen, twenty minutes and then taxi back in on electric. But again, it's just a proposed thing out there. And so kind of the last part on here, with the electric taxi system on potential benefits or negligible on there.

Fuel savings was a topic that was discussed in multiple interview sessions where the data is consistent with the theme of the overall benefit of saving money, which is akin to saving time. The theme of cost savings is evident in multiple responses and throughout the various research questions. "Every time you save time and fuel at the airport, you're going to save money" (ORD7). While not specifically requested as a direct prompt of the researchers, this appears to be a common topic.

Minimizing delays. Minimizing delays of the ground crew was also a pattern identified in the responses of the interview sessions along with other related elements that contribute to delays at airports. To distinguish the responses, there were multiple contributions made by the participants regarding overall ground delays including the actions of ground crew and the various types of equipment and regulatory aspects required of their jobs. The emphasis was on the benefits of the electric taxi system and how adding this as a feature to the ground crew procedures could increase the efficiency of the ramps and taxiways. Here, DEN3 stated the following supporting comments:

> I think it'd be significant benefit because, as I mentioned earlier, one of the delays is waiting on the ground crew factor. Now, if you're pushing the aircraft back, you're still going to have some of that, but once they're disengaged, in theory, you can proceed. But I think the concept of being able to put an aircraft in reverse and as long as they can do it safely and efficiently, it's an incredible concept.

Additionally, weather-related delays were frequently discussed during the interviews. More specifically, it was presented in the ways the weather impacted connections, overall airport functions, and how these weather-related delays cause multiple challenges including the recency effect (ORD4). Further contributing to the delays is the sheer volume of the traffic (ORD3). The combination of the aforementioned factors can greatly impact the terminal and ramp delays, specifically.

LAX1 reported the following,

> …taxiing aircraft out of our alley to their area of control, then now here come our ground delays, where those aircraft can't get out of the alley. We just had it happen five minutes ago. It's not a terrible weather day here, we do obviously have en route issues."

ORD3 went on to explain that in this situation, it was not weather-related issue although "weather can greatly impact how quickly they can exit traffic from our area, so it impacted those 8 aircraft that were in the alley." The stacked delays continue to occur as a result of the delays and the weather, volume, and ground crew.

As a result of these delays, there were significant comments in support of the electric taxi system and what benefits it might provide given these types of complications. One specific suggestion was for the tower to monitor the taxi times of each aircraft in order to obtain averages of wait time, and how much time they're using to taxi out to the runway" (ORD2).

An example of a proscribed benefit was offered by ORD3 as a resolution to his personal experienced offered during this interview. He was in support of the great benefits of the electric taxi system given what obstacle may be in front of the airplane. He shared,

> Boy again, if we had that ability even just now, think about two eight hour flights to Hawaii, Bravo 16 and Bravo 17, they could have both pushed on time and conceivably taxied out on time, but same thing with Charlie 29 and 27, now we're jammed up in the ramp area, how far we could have gotten, how far they could go, could we taxi them halfway to the runway to the departure and whatever. But those four aircraft that were delayed could have pushed.

Further, ORD2 continued with this similar topic of support for the electric taxi system, indicating that it could be helpful to get the airplanes “right out of the alley” (ORD2). If the planes could move straight back and they just pushed back, turned and then taxi, this process could work well for reducing the congestion. The delays occur “mostly on the taxi out” (ORD2).

> For example, today we had a request from the ramp tower to hold our traffic exiting the north port because they had an issue with an aircraft with a steering issue. So we did, and we thought they'd bring him in right away. Well, they held them out there for a 10, 15 minutes almost. So it put us in a little bit of a bind here, a little bit, trying to move this traffic out, but again, we've got weather restrictions today, eastbound in southbound so that creating more of a backlog of traffic onto the taxi ways. So I can see where ground cannot move a lot of this traffic out because we're lending on real estate (ORD2).

Pilots find that they are in a bind due to these various types of delays but having a way to quickly move airplanes out of the way of others can be a potential benefit of the electric taxi system.

Research Question 2

When asked the second research question, *What potential problems do electric taxi systems offer major airport operations?* There were a number of themes identified in the data. These included the pilots not having control of the plane, the cost factor of implementing this option, and human factors contributing to concerns in the use of the electric taxi system.

Control of the plane. The theme of always having control of the plane was a pattern that appeared in the data through the process of interviewing the participants. Essentially, a fear of the unknown with the potential use of the electric taxi system was implied through the following response “…And having the ability to disengage the electric motor when you’re coming in to land and not have them engage accidentally when you’re coming in to land” (DEN2).

Relatedly, having control of the aircraft when not having sufficient room to maneuver was expressed as a potential concern as well giving rise to safety matters. The term “concept” was a term that was given to the electronic taxi device by the participants in multiple occasions giving rise to the idea that because this is a newer notion in current airport design, mechanisms, and procedures, the concept of how the pilot would maneuver the plane was ambiguous as best. To illustrate was the response of DEN1

> My only other concern… is that because of different airport designs, is how much room do you have to work with, with that aircraft? With those kind of concepts of an electronic push or whatever, you’ve got to make sure you have plenty of room to maneuver that aircraft in a safe manner. Some airports are so tight, that’s why they have a tug driver doing it so they can have positive control.

Implementing strict aircraft parking and pushback procedures to maintain safe operations around the taxi areas continues to be a priority in all airports.

Cost of implementation of the electric taxi system. One important point that was discussed is the impending costs involved in the application of the electric taxi device. Not knowing the related factors of the use, participants expressed some reservation over the benefit to the airlines given the current processes in place at airports in the United States. At this time, the data shows that participants responded that the next steps would be to “convince some people to look at it” (IAH1) and to “put the funding in place to create a team to look at it" as an option to reducing overall problems at the airports despite the costs involved. Getting a "prototype to test would be a good first step" (ORD2). ORD2 also expressed the following,

> And the company has these other ideas about getting really into other things like that. I won't say what it is, but I've seen the prototypes for things like this, and they are cool and it looks like they will work, but have they ever been tested with an arrival rate of 96 and 114 gates? No. So maybe it could help during periods where we have lower volumes.

ORD2 also used the example of Tesla and that the electrical taxi system is a mechanical device and will take some time to use, refine, and train crews to use.

DEN2 theorized,

> I think the trend has already started with super-tugs and utilizing them to reposition aircraft from the hangar, saving that fuel cost and I've heard of that concept of taking them actually up to the runway and letting them spool up there. That saves the airlines, and all the stakeholders, a significant amount of money when it comes to the cost of the operations.

Human factors. Unpredictable factors in the gates and taxiways are a common consideration due to the unpredictable environment and the degree of possible human error. Human factors causing errors in the gates can cause inefficiencies leading to delays and other significant issues. For example, the concern was expressed of "accidentally engaging the electric motor when landing" (DEN1) was mentioned as a concern.

Similarly, DEN2 expressed concern with "having the ability to disengage the electric motor when you're coming in to land and not have them engage accidentally when you're coming in to land." Having increased situational awareness of the potential for human error while learning the benefits of the electric taxi system could serve more beneficial overall when accessing the electric motor. (ORD7) expressed that "The application is far more difficult than the concept." Envisioning the value of this new, more autonomous system appears to be challenging because participants view the electric taxi system as a new tool, system, and related procedures that while increasing efficiency, could also be a challenge to learn.

Research Question Three

When asked the third research question, *What are ramp controllers' opinions and concerns about the implementation of electric taxi systems?* There were several themes that emerges through this data collection process, namely, making ramps more efficient, saving time, and sampling the system.

Make ramps more efficient. Because ramps are often busy areas with heavy airplane traffic and other vehicles and objects contained throughout a given airport, there is great concern for increasing the efficiency of this environment while also fostering safety. Safety within the taxiway areas was identified as the most important objective for the participants. Some mentioned the electric taxi system would be beneficial because it would be an "instant push back" (ORD2) given other factors including consideration to what the other obstacle that are in front of the aircraft. Certainly, these matters depend on the specific airport, time of day, and level of congestion at the time.

> I think in like Denver if it's more spread out and they're straight back and they just push back and turn and taxi, that might work well for them. For O'Hare, we're in a congested area, and it's ... you gotta watch what you're doing (ORD2).

ORD2 continued with the responses on this theme of safety, this time more specifically on the experience of the employees working outside of the aircraft posting a potential safety issues, stating “Yeah, and depending on the ramp guys, how much experience they have, some guys can take a little bit longer than others, so it's not exactly three minutes every time or four minutes. Asa result, “ramp needs to be more efficient on pushing back on their mark….That electro tractor is a factor, and then the FAA is a factor” (ORD2).

Saving time. Participants shared their varied experience with the possibility of the electric taxi saving time during the taxi out. There was significant data that pointed to the importance of factors limiting the potential use of the taxi system including steering issues, weather (as mentioned earlier), and the ramp tower requesting traffic to be held.

The participants explained that there are “always looking for way to try and make it a little more efficient…” (ORD1). In this case the participant was offering an option to potentially shut down the engines for 5 to 20 minutes and use the taxi device relying upon the electric. Because this is a proposed idea, it appeared challenging for the participants to rely upon experience mainly because there was none in the use of the electric taxi system. Ultimately, as IAH2 stated, “…every time you save time and fuel at the airport, you're going to save money.

As a result of the data, the theme of sampling the electric taxi device was popular during the interviews. Most of the participants were supportive of the idea given the aforementioned themes. In order to learn more about this system, it was mentioned that trying out the system in the airport would be important in order to make a more informed decision of the benefits and potential challenges of its use. IAH1 stated, “So now it’s just convincing some people to look at it. Someone was to look at it, or put the funding in place to create a team to look at it.” Similarly, LAX4 replied,

> I could see a possibility in it. I really could, as far as, I think it would be a time saver and a cost saver. Yeah. I don't see why you couldn't do that. You know, at one time, the SPs here, they used to tow them out to the runways.

IAH3 agreed with the sentiment indicating, “But the idea I think, anything to expedite, move, get out quicker, decrease delays, who's not for that.”

Unanticipated Findings

As in any research, often the data collected yields information, ideas, or additional themes that were not anticipated. When this occurs, a rich and detailed set of findings can support the gap in the literature and further support the research questions. In this case, there was one major unintended finding that was not only common throughout the interviews, but is significantly related to the data. While this later theme may not be directly aligned to the original research questions, it is related to the perceptions and opinions of the participants.

- While the participants appear interested in the electric taxi option, seeing potential economic and environmental benefits, they were far more concerned with the problems of airport layout and control of movement areas.
- Although they understood the potential economic and environmental impact of an electric taxi system, they felt it would be of minimal impact to aircraft movement and delays in the ramp area.
- For the most part, the controllers couldn't seem to really imagine how this technology would of benefit for getting aircraft pushed back and onto the

taxiways or into the gates from the taxiways, because of the ramp entry/exit problems.

Airport Design and Control of Real Estate

Airport design was mentioned as the major problem at 3 of the airports (Chicago, Houston, and Los Angeles). In general, ramp controllers felt that the biggest impediment to operations in and out of the ramp area was the volume of traffic and the limited options to arrive into or depart from the ramp area. As ORD 4 stated, “we are often running far in excess of capacity. There are times when we should have 40 movement (*pushback from and entry into a gate*) in an hour and we are scheduled to move 55 aircraft.” ORD 3 reiterated this by stating “once an aircraft pushes onto the Bravo or Charlie line, it taxies to the exit point (*known as Northport or Southport*) and then can wait for up to 10 minutes before ground lets it taxi out. That entire time it sits there, more aircraft line up behind it, blocking gates, which prevents us from allowing aircraft into the ramp area. You want to increase efficiency far better than an electric taxi system? Give us a place to go! Have the ground controller give us (*the ramp controller*) the ability to move the aircraft somewhere out of the ramp area while waiting for ground to accept it. I saw once case where they could not accept an aircraft going north, because of weather, but the southbound aircraft were launching. Unfortunately, the north-bound aircraft was the first aircraft to exit, so all the other aircraft were delayed for 20 minutes because ground would not let the north-bound aircraft taxi out of the ramp area.” See Figure 2.

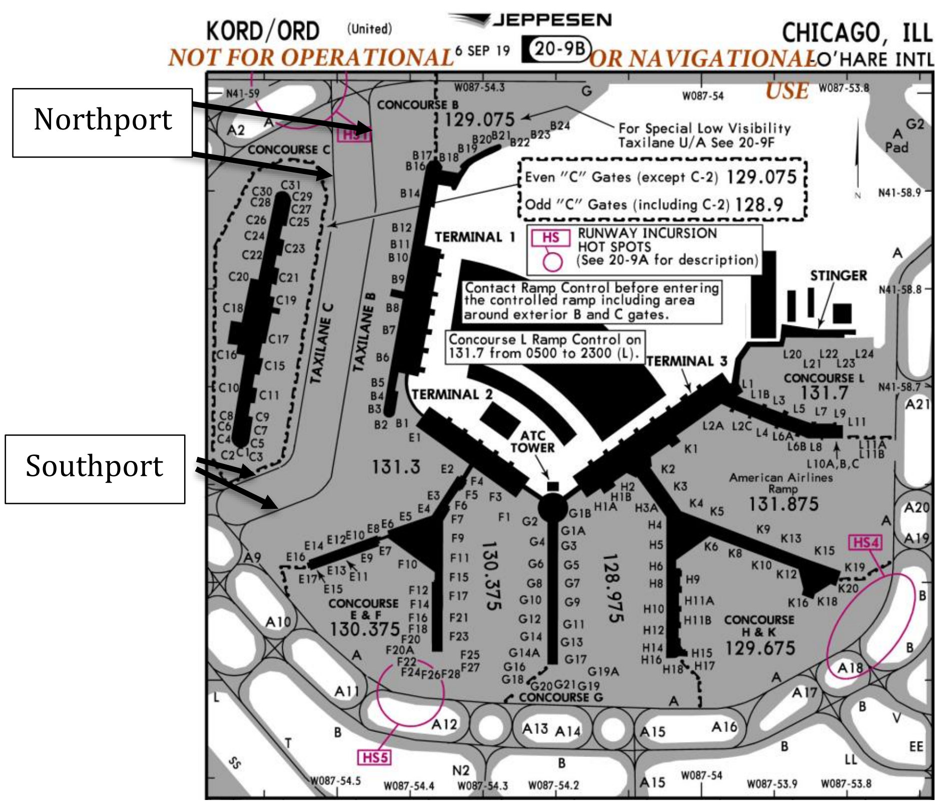

Figure 2. Chicago ramp area. The entrance and exit areas shown are on the left side of the figure, annotated by “northport” and “southport.” Adapted from “Chicago-O’Hare International Airport Ramp Area” by Jeppesen, n.d.a. Reprinted with permission.

LAX1 echoed a similar statement. “They towed the aircraft to the starting point on Charlie-8, just short of Charlie. The aircraft had a mechanical issue, and since ground would not let it go anywhere (*to resolve the issue*), they blocked the only entrance into 14 gates for more than 20 minutes. If we could control part of the Charlie ramp, we could have the aircraft move (under its own power of by a tug) to keep it from blocking the entrance/to the ramp.” See Figure 3.

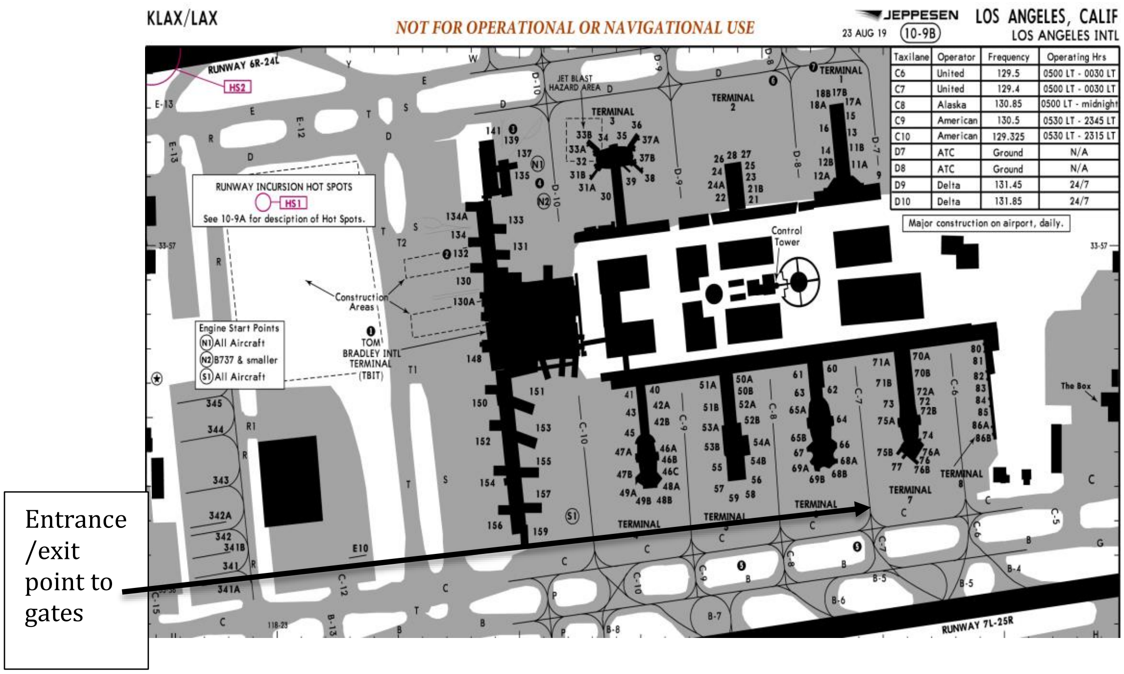

Figure 3. Los Angeles ramp area. The entrance/exit area is shown on the right side of the figure (intersection of Charlie 7 and Charlie), annotated by the arrow. Adapted from “Los Angeles International Airport Ramp Area” by Jeppesen, n.d.d. Reprinted with permission.

A number if IAH ramp controllers made similar observations about the design and control of their ramp area. Most every controller from Chicago, Houston, and Los Angeles stated that if there were areas for aircraft to wait go to, away from the ramp area, the efficiency of ramp operations would improve tremendously. See Figure 4.

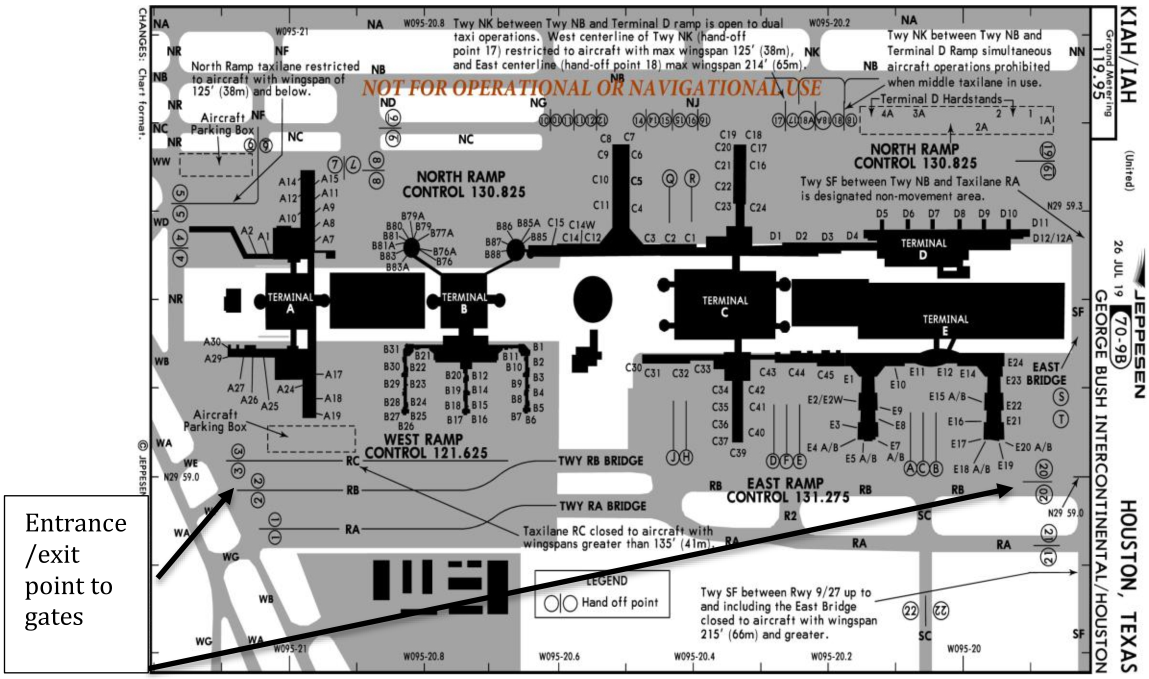

Figure 4. Houston intercontinental airport ramp area. The entrance and exit areas are shown on both the right and left sides of the figure, annotated by the arrows. Adapted from "Houston Intercontinental Airport Ramp Area" by Jeppesen, n.d.c. Reprinted with permission.

This agrees with the findings of Zhang and Wang (2016), who found that at major airports with both a ramp control tower and an air traffic control tower, airport personnel designate which spots to appropriately take over the control of aircraft from each other. As an example, only three out of 14 available spots on the surface of Philadelphia International Airport are allowed to be used between two towers to take over the control of flight movements.

The one exception to this recommendation was Denver. Because Denver is a much newer airport, the design is very different. The Denver design is not nearly entrance/exit restricted as older airports. As DEN1 stated, "At Denver, multiple aircraft can push back without infringing on other aircraft movement. Even with aircraft pushed back from the gates, there is enough room for all types of aircraft to taxi along the AN, BS, BN, and CS lines. Any aircraft can taxi along the taxi line without getting too close to another aircraft." DEN 2 added, "For every gate, we have two entry and exit points on each side. That gives us tremendous flexibility. Say an aircraft was coming in from the west, into gate B36. There are two entrances. One is always open-I have never seen both occupied at the same time. But, if for some strange reason both BS and AN were occupied, we would just have then go in BN, taxi across the ramp, and enter at BS on the east side. Worst case, they added 4 minutes to their taxi, but still go right into the gate. If something ever did happen, we would just have them taxi through the ramp area, on the other side and then taxi to the gate. See Figure 5.

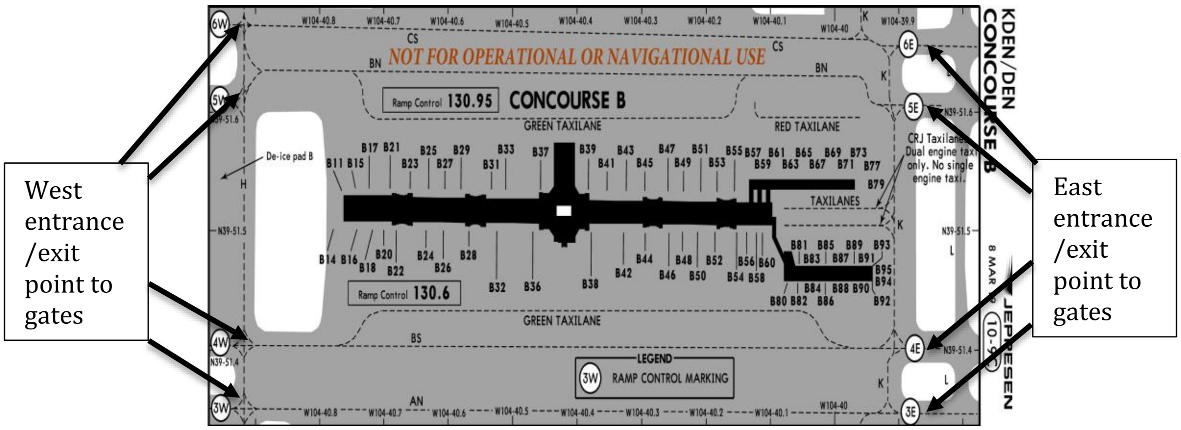

Figure 5. Denver international airport ramp area. The entrance and exit areas discussed are on both the right and left sides of the figure, annotated by the arrows. Denver's unique layout gives tremendous advantages for movement within the ramp area, thereby virtually eliminating delays due to the position of any other aircraft. Adapted from "Denver International Airport Ramp Area" by Jeppesen, n.d.b. Reprinted with permission.

Recommendations for Further Review

All ramp controllers saw the potential economic and environmental value of electric taxi systems, however, most felt that an electric taxi system would have little effect on more efficient ramp operations. The first recommendation is to maximize efficiency and reduce delays in and out of the ramp areas, airport officials must work with ramp controllers to find specific holding areas, outside of the ramp areas, where aircraft can park, to keep the entry and exit paths to the ramp area clear. Creating these designated areas for both arriving and departing aircraft would increase the ramp efficiency by allowing unencumbered movement to and from the gates. The second recommendation is to create a quantitative analysis of potential costs and costs savings of implementing electric taxi systems, without consideration of the ramp delays.

Summary and Conclusion

This study sets the foundation for numerous academic follow-up studies, including the analysis of a larger cross-section of airports, both domestically and international, environmental effects, and fuel savings for the airlines. For participants, the airport design and lack of ability to quickly allow entrance and exit from the ramp areas were the greatest concern. However, the benefits of accessing the electric taxi system, at least initially, were positive. Initially employing the electric taxi system can enhance the safety, capabilities, and efficiency of the airport environment, while reducing the overall costs and environmental impact of the taxiway and related area operations.

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Appendix

Interview Questions:

What do you see as the major causes of airport ground delays?

Where do the delays occur? (ramp exit, taxi out, taxi in, ramp entrance)?

What effect do you think airport configuration has on ground delays?

How do you think you can minimize the causes of these delays?

What options have you explored for minimizing the effects of ground delays?

How do you track delays? What database(s) or systems do you use?

One potential advantage of an electric taxi system is the ability to electrically push back, without a tug, and taxi without delay. What effect do you think an electric taxi system may have on mitigating airport delays?

Where might you expect to realize positive benefits of electric taxi systems at your airport? Taxi out, taxi in, or another venue?

Similarly, what about negative effects/consequences with implementation of an electric taxi system? What are these and how might they be managed to leverage otherwise positive benefits you've described?

Do you think there is a future for the electric taxi system in the airport industry? Why or why not?