Airport Parking System Design
in the Age of Autonomous Vehicles

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Executive Summary

Ground transportation and parking systems play a significant role in airport operations. As Autonomous Vehicles (AVs) are expected to be prevalent in future, the current strategies for dealing with ground transportation and parking at airports will need to change to make up for lost parking revenue due to the lack of need for AV parking. Additionally, strategies must find ways to utilize the benefits of AVs to maximize airport efficiency. To do this, an integrated two-part design consisting of a physical redesign of terminal curbside parking and the development of an AV-based traveler information system (AV-TIS) is proposed. This design utilizes a new revenue generation model based on terminal curbside access to make up for the anticipated reduction in parking revenue.

For the physical redesign, a conceptual design was used to highlight features of the redesign, such as increased terminal curbside parking. The highlighted features are common to all airports, despite the varying terminal and parking characteristics. The proposed design of the AV-TIS provides travelers with an in-vehicle hub to prepare them for their trip to the airport while communicating critical information to the airport before arrival. Finally, a convenience-based curb access fee that combines elements from both aspects of the design is proposed as a new revenue model.

The proposed design allows airports to maximize terminal curbside parking space, increasing the amount of short-term parking for which demand is expected to increase due to AVs. Additionally, the AV-TIS connects the airport and the traveler, exchanging information via the AV, to allow for advanced airport traffic prediction and improved planning methods. This will lead to more efficient operations on the ground transportation side of the airport, while the

revenue generation model developed from combining the options of the AV-TIS and increased curbside parking will counteract any lost revenue from decreased long-term parking.

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Problem Statement

As autonomous vehicles (AVs) become more prevalent, ground transportation options for travelers will change significantly. This will have impacts on airports, as it will change the preferred ways that travelers travel to and from the airport. Additionally, it will significantly reduce the need for long-term parking, altering the parking revenues that many airports rely on. To ensure that airports are fully equipped to deal with the emergence of AVs, it is necessary to review and adapt the existing ground transportation and parking system strategies in order utilize the benefits of AVs to improve airport operations and the overall traveler experience.

Literature Review

Airport ground transportation and parking operation is a critical focus in the overall plan of an airport, as indicated in ACRP Report 24 (Jacobs Consultancy et al. 2010). In terms of space, NPIAS commercial service airports typically provide at least 1,000 parking spaces. Additionally, most of the large parking structures (over 5,000 spaces) in the United States are in airports. In terms of customer service, airport parking facilities provide the first or last impression on passengers, which represent the image of the airport and entire city. Financially, parking service generates a large amount of revenue. For example, parking revenues are usually over $10 million per year (25% of all airport revenue) at most small-hub airports, and at the largest airports, the amounts are beyond $100 million (18% of all airport revenue) (Jacobs Consultancy et al. 2010).

The FAA encourages airports to achieve a high level of customer service, improve operational efficiency and enhance net parking revenues. In order to achieve these things, Jacobs Consultancy et al. (2010) conducted a project that assessed customer needs and preferences, selected and evaluated potential strategies and supporting technologies, and made suggestions to implement the selected strategies and suggested actions. These strategies and technologies included parking space availability query via phone/radio prior to arrival, space locators, and in-vehicle parking technologies. The report provides various parking strategies and technologies to help airport operators achieve long-term goals and objectives.

While current parking strategies may have been developed with the knowledge that autonomous vehicles will emerge, they typically do not treat AVs any differently than traditional, human-driven vehicles. With the development of sensor technologies and advances in artificial intelligence, AVs are expected to replace human drivers on the road, and due to this, it has been estimated by many studies that the emergence of AVs will have a significant impact on parking strategies and parking infrastructure. Without the need for a driver, AVs will be able to drop passengers off at their desired destinations and proceed to park themselves. Because of this, Nash Islam (2016) estimates that the space needed to park AVs at airports will be reduced by two square meters per vehicle This is because without drivers or passengers, space typically provided for opening car doors will no longer be required. Additionally, space for elevators and staircases in multi-level parking structures can be reduced, or possibly even eliminated, and driving lanes within parking facilities will become narrower. Another study found that, because of this reduction in space needed for AV parking, parking facilities designed for AVs could reduce the total amount of space needed for parking by 62 to 87 percent compared to conventional parking facilities (Nourinejad et al 2017). However, these studies are based on the assumption that vehicles will still park at their destinations. With AV technology, vehicles will have the ability to drop off passengers at their destination, and then return to their origin, or in the case of shared AVs, move on to the next passenger. It has been predicted that this ability could completely eliminate the need for up to 90 percent of the parking spaces currently being utilized (Islam 2016). As a result, the airport may benefit from this new technology, by reducing the number of parking facilities and allowing for expanded land use for other areas of operation. However, it will also be necessary to make adjustments to new challenges such as reduced revenues from parking fees.

The benefits of AV technologies, like automated dispatch, were discussed in the ACRP Report 146, Commercial Ground Transportation at Airports: Best Practices (LeighFisher et al. 2015). The major benefits include better use of airport staff, reducing emissions, and faster throughput. The automated system will reduce the workload of airport parking staff (i.e., fewer parking cashiers would be needed during peak hours) and change their responsibilities to focus on customer service. The use of AV technology allows vehicles to be parked at a designated area and deployed to the terminal right before they are required to move; therefore, the engine running time of vehicles will be reduced significantly, reducing emissions. Lastly, the technology will help to maintain a reasonable number of vehicles at each terminal's curbside boarding area and mitigate the traffic congestion at the airport.

Another potential advantage of using AVs is that AVs can be utilized as a traveler information system for airport passengers. For example, AVs will be able to help travelers make the trip plan, track their flights, and save time. The communications between AVs and airport operators would also improve airport efficiency , as AVs would be able to relay information about the traveler and their trip to the airport, allowing airports to more accurately predict passenger traffic in the terminals. This would also help maintain a high level of safety by allowing airports to mitigate congestion during peak periods.

One of the primary challenges that the airport parking system may face will be adapting the existing parking system to adequately incorporate new technologies such as AVs. The adaptations to the system will include tasks like installments of new infrastructure for AVs, implementation of new traffic management rules (Lean, Lei, and Wilson 2016), and repurposing the current parking space. The current parking space could be re-used for new buildings, businesses, or other airport infrastructure. The change will also help improve the pedestrian experience (Alessandrini et al 2013). At the airport, one of the potential changes could be setting up creative passenger boarding areas, like angled boarding spaces at the curbside sidewalk, where the vehicles park at a 45-degree angle to the curbside sidewalk rather than parallel (LeighFisher et al. 2015). By doing this, the walking distances of passengers will be shorter, and travelers will know exactly where to board and find the vehicle more easily since they can see the side of their AVs. It also improves airport accessibility by allowing passengers leaving or boarding the vehicle from a raised curbside adjacent to the vehicle's door.

Another challenge is to assure airports are still financially self-sufficient in the era of AVs. With the future introduction of AVs, it is predicted that the number of travelers using airport parking lots will decrease. This means that revenues generated from these parking spaces will drop dramatically. Airports have to find creative ways to create revenue in order to replace the current revenue that parking space provides. Some current strategies to enhance parking revenues will still be practical for AVs. Examples includerelated customer services, like vehicle washing and servicing, onsite sale of food, beverages, and other products, and electric charging stations (Jacobs Consultancy et al. 2010). But the parking fee would likely be replaced by new convenience-based fees. AVs would be capable of reporting a vehicle's real-time position information. Therefore, it would be possible to allow airport operators to track all trips made by

AVs and calculate a convenience-based fee based on the volume of trips made on airport roadways, terminal curbsides, hold lots, and dedicated areas. For example, airport operators may use a dwell fee to replace a parking fee. The dwell fee assesses a time-based fee for a vehicle that is detected as it arrives and as it leaves the airport. Other revenue options include privilege fees and demand management fees, which have already been used on commercial ground vehicles (LeighFisher et al. 2015).

Design Approach

A two-part design for incorporating autonomous vehicles into airport ground transportation systems is proposed. This two-part, integrated design will include a redesign of current airport terminal curbside areas and parking systems. Additionally, the associated parking revenue models will be reconfigured. To complement the physical redesign, an in-vehicle traveler information system that will exchange information between the traveler and the airport via the autonomous vehicle is proposed. This system will consider traveler preferences, current airport operations status, and costs associated with the new parking revenue generation models, allowing for a better traveler experience and more efficient airport operation.

Physical Curbside Parking Redesign

Because autonomous vehicles will reduce the need for parking at airports, existing parking space can be reconfigured to better fit the needs of the new airport terminal and parking system. This design will focus on reconfiguring a portion of the parking area adjacent to the airport terminal to provide additional terminal drop-off space. Even though airports differ in many characteristics, the conceptual design is useful for highlighting issues common to many airports and illustrating ground transportation redesign in the age of autonomous vehicles.

As shown in Figure 1, currently many of the medium hub NPAIS airports, such as the Nashville International Airport, the Kansas City International Airport, and the St. Louis International Airport, have a similar parking layout: the curbside area is adjacent to the terminal building and a short-duration parking garage. The curbside roadways are one-way roadways located immediately in front of the terminal buildings where vehicles stop to pick up and drop off passengers and their luggage. For most airports, the common users of curbside area are pick-up and drop-off private vehicles, door-to-door vans, scheduled buses and prearranged limousines. The space of curbside area is also relatively small, compared with the nearby parking garage and free to private vehicles. Meanwhile, the adjacent parking garage is dedicated to short-duration parking and costing much more than long-duration parking. Typically, the passengers using the short-duration parking garage need to use a crosswalk to access the terminal building.

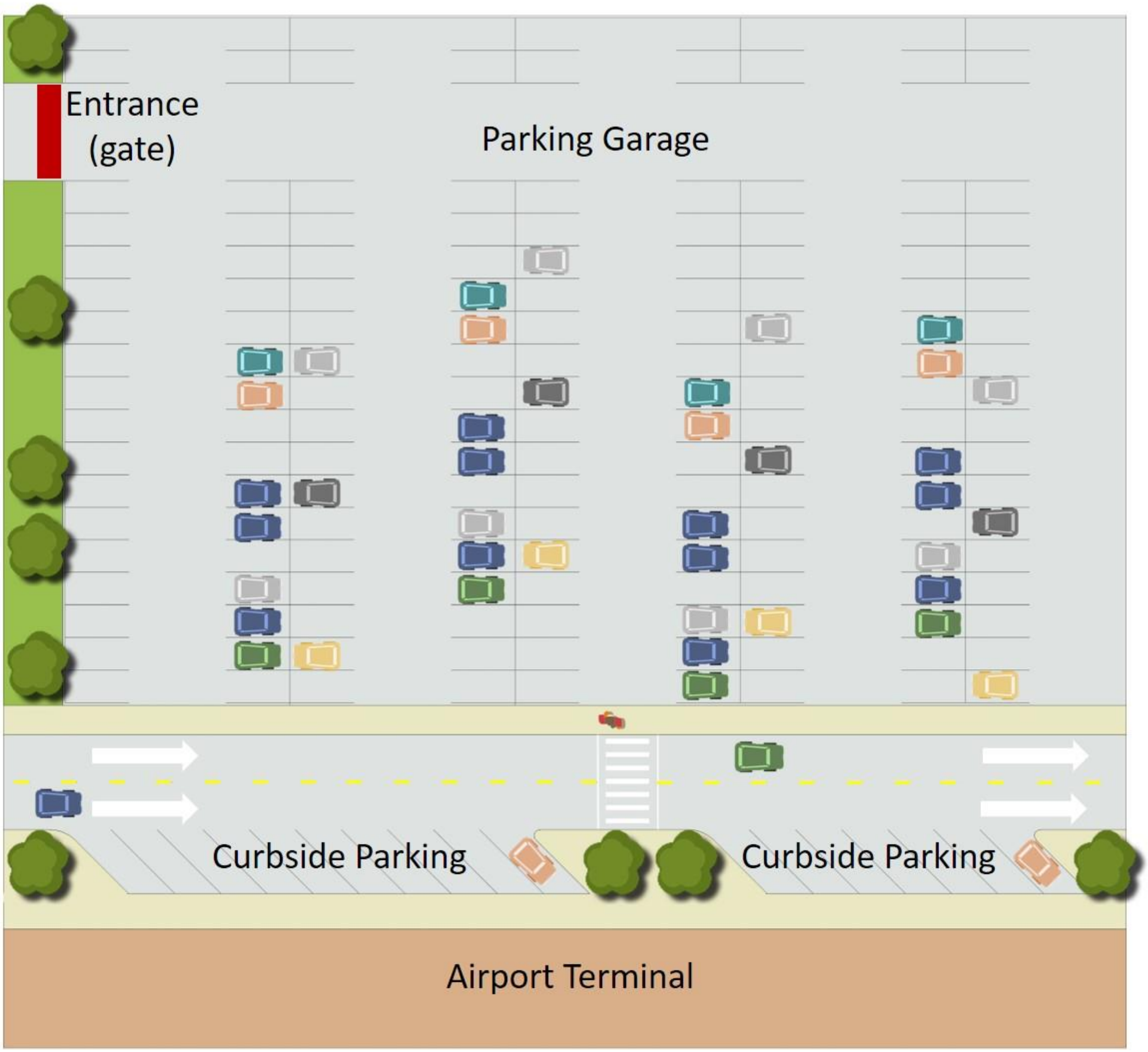

Figure 1. Example Layout of Passenger Pick-up and Drop-off Area

The new drop-off spaces will be configured as shown in Figure 2. In order to accommodate more vehicle arrivals at the terminal during peak hours of operation, a portion of the space of the parking garage is removed and replaced with additional passenger drop-off areas. The advantages of the new design are: 1) For all passengers, the walking distance between any parking space and terminal building is less than 400 ft. 2) The drop-off spaces are on the same level of terminal building. Therefore, passengers can walk into the terminal without use of an escalator or elevator. 3) As all drop-off spaces would be assigned along the terminal's side, passengers have no need to cross any traffic lane, promoting pedestrian safety.

The assignment of a vehicle's parking space and the collection of parking fees will be implemented by an intelligent transportation system (ITS) located at the entrance to the curbside parking area. The ITS system will automatically communicate with the AVs entering the area, replacing the need for gate arms or a cashier booth.

Figure 2. The Conceptual Layout of New Curbside Parking Space

The conceptual design shows the service area for private AVs only. For human-driven vehicles, drivers can still use the traditional areas of a parking garage. The designating of different pick-up and drop-off areas for AVs and human-driven vehicles helps to maximize the efficiency of the entire parking system. For the same reason, the new parking system will also dedicate special areas for large vehicles. The differing characteristics of vehicles will be taken into account in the physical and operational plans for the new curbside area.

Implementing this design will allow for more vehicles, and therefore passengers, to access the terminal at any one time. This will help the airport serve more passengers in a shorter amount of time. Additionally, having multiple terminal drop-off areas at different distances away from the terminal opens up the possibility for a new model for collecting revenue, which is another key aspect of this design.

Autonomous Vehicle Traveler Information System

The second part of the proposed design is a traveler information system for autonomous vehicles called the Autonomous Vehicle Traveler Information System (AV-TIS). The AV-TIS is a system that serves airports, airlines, and passengers alike, as it will facilitate real-time communication between travelers and the airport, using the autonomous vehicle as a medium. The system will provide an in-vehicle interface for passengers to input their travel information, such as flight number, along with other personal information and preferences. The autonomous vehicle will then communicate this information to the airport, and the airport and airline will process the information and release the most useful information to the passengers.

As shown in Figure 3, the AV-TIS will utilize the in-vehicle interface to display basic information about the user’s flight, such as flight number, departure time, takeoff and landing city, check-in counter and boarding gate. Additionally, the system will relay real-time updated travel information for the user’s flight. For example, if there is a pre-sequence flight delay, the traveler information system will provide all necessary information to the passengers before they arrive at the airport, such as delay times, gate changes, or other possible available flights.

Figure 3. The AV-TIS inside AV and Its Interfaces (Planner/Map Mode)

Because the AV-TIS will be in constant communication with the airport, it will be able to provide the passenger with the information and services that could be found at the airport before they arrive. The interface will be able to show the airport take-off and landing conditions, indicating any delays, such as weather or traffic restrictions. Additionally, the system will show the current flow of people at the airport. This includes providing passengers with updated queue times of the check-in counter, baggage check, and security checkpoints, along with other possible information such as how many passengers have already checked in for the user's flight or areas of the terminal experiencing congestion. In addition to airport operation information, the system will allow the user to access certain airport services, such as advanced check-in. This option also includes requesting a wheelchair or other disability services to be ready upon arrival at the terminal. Other possibilities include accessing the terminal's store map, dining information, and other service information to prepare in advance for the user at the airport. Based on the information the traveler gives to the airport, the system will give feedback to the traveler on a suggested arrival time to the airport in order to space out arrivals to each terminal and accommodate traveler needs and preferences.

Another important aspect of the Automated Vehicle Traveler Information System is the route prediction and selection module. Using the real-time information received from the airport along with passenger preferences, such as proximity to the terminal gate to be dropped off, the AV-TIS will automatically route the AV to the correct terminal and the correct parking spot within the redesigned airport parking facility. To do this, the system will consider the driving time to the terminal drop-off area, drop-off area queue times, check-in and security check queue times, and estimated walking time to the terminal and gate, along with estimated times of any other user-requested services. The AV-TIS will provide multiple route options to the user. One option is the fastest route. This route is suitable for passengers with more luggage, international flights, or time-critical passengers. It will utilize the drop-off area closest to the terminal and will direct the passenger to the check-in and security check lines with the shortest queue times as well as offer advanced check-in, possibly for a fee. The second route option is the cheapest route. This route uses a farther drop-off point to avoid high fees, but the disadvantage is that it takes more time. This route is suitable for passengers with less baggage, domestic flights and ample time. As an example, the fastest route may cost $20 due to close-proximity parking and additional expedited services, while the cheapest route may only cost $5 for parking. Travelers will be granted access to the cheapest or most expensive temporary parking options. Although cheaper parking will slightly increase travel time, it will be affordable for travelers of any income level. The third route is a custom route. Passengers may feel that the fastest route is too expensive, and the cheapest route is too inconvenient, thus the route planning and selection module provides the passenger with custom options such as the ability to choose an acceptable drop-off price range in advance or add a trip to a store or other stopping point to the route.

The AV-TIS will not only reduce passenger queue time and travel costs, but will also help airports and airlines operate more efficiently. Once a passenger has established their route through the in-vehicle interface, the AV-TIS will communicate this information to the airport. Based on the information the traveler gives to the airport, the system will give feedback to the AV, suggesting an optimal arrival time to the airport in order to space out arrivals at each terminal. This will allow the airport and airlines to predict traffic patterns, traveler movement within the terminal, and anticipate services that will be used, allowing airports to plan accordingly, improve efficiency, and provide the proper information to other incoming passengers. Through AV-TIS, the airport will be prompted by the system to arrange staff to help passengers in wheelchairs or others in need of assistance. This can effectively alleviate congestion during peak hours.

Design Impacts

The airport parking system is typically composed of three units: public parking, employee parking, and ground transportation. A sound parking system provides passengers with convenient and effective transportation choices to arrive at and depart from the airport. The FAA and the National Academies sponsored multiple projects (ACRP report 24 and 146) and synthesis (ACRP synthesis 36) to improve customer service, increase operation efficiency, enhance net parking revenues, and provide effective commuting options for airport employees (Jacobs Consultancy et al. 2010; LeighFisher et al. 2015; Ricard 2012). The airport parking system also generates a large amount of revenue to support airport operations. As an example, the parking system units of Denver International Airport (DEN) generated $187 million in revenue in 2016. As the airport's second largest revenue source, parking represented approximately 25 percent of the airport's total operating revenue (City and County of Denver, 2018). The proposed airport parking system design for AVs would bring two major changes at airports: a new airport parking revenue model, and enhanced customer satisfaction.

New Parking Revenue Model

Currently, at most airports in the U.S, the parking services are duration based. Under this method, the longer the vehicle stays in an airport parking space, the more the vehicle owner is charged, generating more revenue for the airport. According to Bergal (2016), U.S. airports generated a grand total of $3.5 billion in parking fees, which represented 41 percent of total airport revenue. This large amount of revenue would decrease significantly when automated vehicles become more common in society, as they can simply pick up or drop off passengers at terminal curbside areas and navigate themselves back to the owners' home or workplace, without the need for parking at the airport. As the result, the need for parking spaces will decrease dramatically, especially these long-duration parking spaces that are located far from the terminal.

With the proposed design, some of the revenue that is anticipated to be lost can be recovered through a new revenue model based on convenience-based dwell fees for autonomous vehicles (Figure 5). Currently, the main parking revenue are generated through short-duration and long-duration parking. The curbside parking is free to passengers. In the era of AVs, the major revenue will be generated from curbside parking and the long duration parking will be eliminated. To incorporate the proposed convenience-based dwell fee, the multiple drop-off areas in front of the airport terminal would be priced differently based on their proximity to the entrance. For this system to work, an AV would be tagged by an automated system when it enters the drop-off area. Once the vehicle exits the area, the vehicle would be tagged again, determining the amount of time that the vehicle spent in the drop-off area. The vehicle would then be charged on a minute-to-minute basis based on the proximity to the terminal of the drop-off area used. For example, if there were five different drop-off areas, the area closest to the terminal could charge five dollars per minute, and the fee for each consecutive drop-off area would decrease by one dollar per area the further they are from the terminal, with the furthest drop-off area fee being one dollar per minute spent in the area.

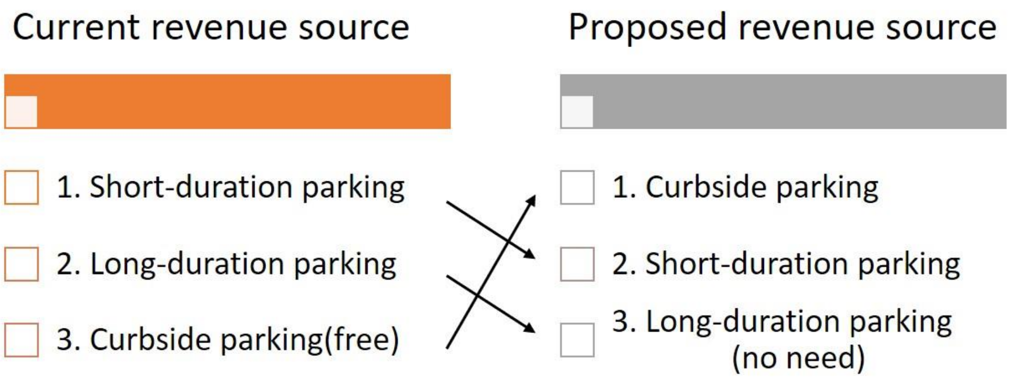

Figure 4. Proposed Revenue Source

A case study of DEN is designed to illustrate how the new revenue model works for the airport in the age of AVs. As shown in Table 1, currently the short-duration parking spaces are only 2.3% of total parking space in DEN. However, the revenue generated by each short-term parking space was three times higher than that of long-term economy parking spaces in 2011 (City and County of Denver, 2012). In a similar way, the new parking system will try to generate enough revenue by offering close-to-terminal spaces to overcome the reducing need for long-duration parking spaces.

Table 1. DEN Parking Revenue and Spaces by Areas

Parking Location	Annual Revenue in 2011	Parking Spaces	Average Revenue /Parking Space
East & West Short Term	$6,994,980	841	$8317.46
East & West Garage (medium-duration)	$71,308,161	16,686	$4,273.53
East & West Economy & Shuttle Lot (long-duration)	$43,764,616	18,195	$2405.31

The new curbside-focused parking system for AVs would adopt a convenience-based pricing strategy. This strategy charges passengers on a per-trip basis, and is typically used for commercial ground transportation providers, especially transportation network companies (TNC). TNCs are companies that use a digital platform, such as a smartphone app, to connect and facilitate transactions between prospective riders and drivers. These companies, such as Uber and Lyft, do not own, control, operate, or manage the vehicles used by the TNC drivers, as most of the vehicles are privately owned by drivers (City and County of Denver, 2018). In June 2017, DEN charged transportation network company operators $2.60 per trip. As shown in Figure 6, the annual revenue generated by the activity fees charged to TNCs has increased significantly since 2015. These results show that the activity-based pricing would be suitable for pick-up and drop-off activities of AVs as they gain popularity moving forward.

Figure 5. Annual Access Fee Revenue by TNC's, Taxis, Limousines (City and County of Denver, 2018)

Based on the conceptual design, the curbside parking spaces will increase by 250%; therefore, there will be around 2,500 curbside parking spaces at the DEN airport. For each AV using the curbside parking, the parking system charge $1.00 for each entrance, plus $1.00/min as the dwell fee for spaces within 100 ft. to the terminal building. For the spaces from 100 ft. to 200 ft., the fee will be $0.50/min; for the rest of space, it will $0.25/min. For example, if an AV enter the curbside area and park at the closest space for 5 min., the total parking cost will be $6.00 ($1.00/per entrance + $1.00/per minute * 5 min.).

As each space will on the average generate $0.58 per minute, the assumed daily usage rate is 30%. Accordingly, the curbside parking area can generate $626,400 per day, or 228 million a year. Compared with the revenue in 2016, the public parking unit of DEN generated $ 170 million in total. With the increasing of AV's popularity, the daily usage rate will be expected to grow, and the total revenue will increase correspondingly.

The new parking system would also save airports money on labor, as fewer workers, like lane supervisors and cashiers, would be needed. Using DEN as an example, in order to ensure adequate staffing coverage, the parking system hired 949 employees to cover 11 airport parking facilities in 2017, with employees working in shifts to keep parking spaces open 24 hours per day (City and County of Denver, 2018). With the reduced need for parking facilities due to the proposed design, this number will be lowered.

Enhanced Customer Satisfaction

Airport parking facilities provide the first and last impression on passengers, which represents the image of the airport and the entire city in which it is located. To ensure that the proposed design produces high levels of customer satisfaction and leaves a good impression, the effects of the new parking system will be gauged by three key passenger experience factors outlined in Airport Service Quality surveys: 1) Minimize walking distance between drop-off area and the terminal entrance, 2) Passengers should be able to navigate between drop-off areas and the terminal with minimal use of stairs, escalators, or elevators, and 3) Maximize pedestrian safety between drop-off areas and terminal buildings. The proposed design addresses these three factors in the following ways: 1) The walking distance between any terminal curbside parking space and the terminal building will be less than 400 ft., 2) The curbside parking spaces used for passenger drop-off will be located on the same level or elevation as the terminal building, allowing passengers to walk into the terminal without the use of stairs, escalators, or elevators, and 3) All parking, or drop-off spaces would be assigned along the terminal’s curb, so passengers have no need to cross any traffic, ensuring pedestrian safety. In following the three aforementioned factors, it is expected that the scores from the Airport Service Quality surveys would improve significantly after implementation of the proposed design.

Implementation Phasing

Providing a separate area for curbside, short-term parking for AVs can be accomplished through different stages, commensurate with the rising popularity of AVs and the service of TNCs. At the beginning stage of implementation, only a portion of the parking spaces located closest to the terminal building in the current parking facilities will be converted to the new AV-centered parking system design, while the rest of the existing parking area will be operated under the existing model. As the popularity of using AVs and TNCs grows over time compared to traditional vehicles, the rest of the parking spaces located in facilities closest to the terminal can be modified into the proposed design. Additionally, some of the long-duration parking facilities located further from the terminal will be closed. During the final stage of implementation, once AVs and TNCs are widely accepted and used by the public, the remainder of the entire parking system can be reorganized to incorporate the proposed design.

The costs for implementation of the proposed design will vary, based on whether a new curbside, short-duration parking area is to be constructed from the ground up, or if an existing facility is to be modified. For example, a small airport can directly transform its drop-off/pick-up area into curbside parking system for AVs. On the other hand, a large airport needs more constructions to implement the design. In addition to construction or modification of new or existing surface or structured spaces, costs would be incurred for AV-ITS communication devices and new roadway guide technologies. However, as discussed, the implementation of the proposed design catering to AVs and TNCs has the ability to increase revenue generated.

Safety Risk Assessment

In order to successfully implement the proposed parking system design, a safety risk assessment must first be completed. To complete the analysis, the Safety Risk Management (SRM) process outlined in the Safety Management System (SMS) Manual (FAA 2017) and Advisory Circular 150/5200-37 (FAA 2007) was utilized. The SRM process is divided into five phases. First the system must be described. Next, potential hazards of the system are identified, and for each hazard, the associated risks are determined and then analyzed. After risks have been assessed, mitigation or treatment strategies are proposed.

System Description

The parking system to be implemented will focus on reallocating parking spaces adjacent to airport terminals. Traditional parking spaces reserved for long-term parking adjacent to airport terminals will be removed. With the space freed up from the removal of these parking spaces, the terminal curbside drop-off area will be reorganized to provide additional drop-off space for passengers.

The proposed parking system design is based on the expected increase in the use of AVs. Therefore, in addition to reorganizing curbside drop-off areas and increasing short-term or temporary parking in these areas, wireless systems will be put in place in order to track vehicle movement throughout the terminal curbside drop-off area and implement a usage fee depending on the amount of time spent in the drop-off area in order to make up for parking revenues that are expected to be lost due to the lack of need for parking AVs.

Hazard Identification, Risk Analysis, and Risk Treatment

With the proposed design implementation, one possible hazard is the failure of the AV control system. This could result in risks such as vehicles driving into pedestrian areas like sidewalks or crosswalks, or collisions with other vehicles. This failure and associated risk would be similar to a human driver losing control of a vehicle or not paying attention, a hazard that already exists, and it is expected that the chance of this happening would be reduced with AVs. However, though there is a remote likelihood of these incidents occurring, the consequences could be major if pedestrians are struck, resulting in a medium level of risk according to the FAA's Predictive Risk Matrix (Figure 4). Due to this, some treatment would be necessary, and therefore, it is proposed that concrete bollards be installed along the terminal curb to prevent vehicles from entering the pedestrian travel areas. In order to limit vehicle collisions, the parking system's ITS system will have the ability to reroute vehicles to other parking areas at no charge to mitigate congestion. Additionally, the ITS system will be able to halt incoming vehicles when it detects other vehicles pulling out of a parking space.

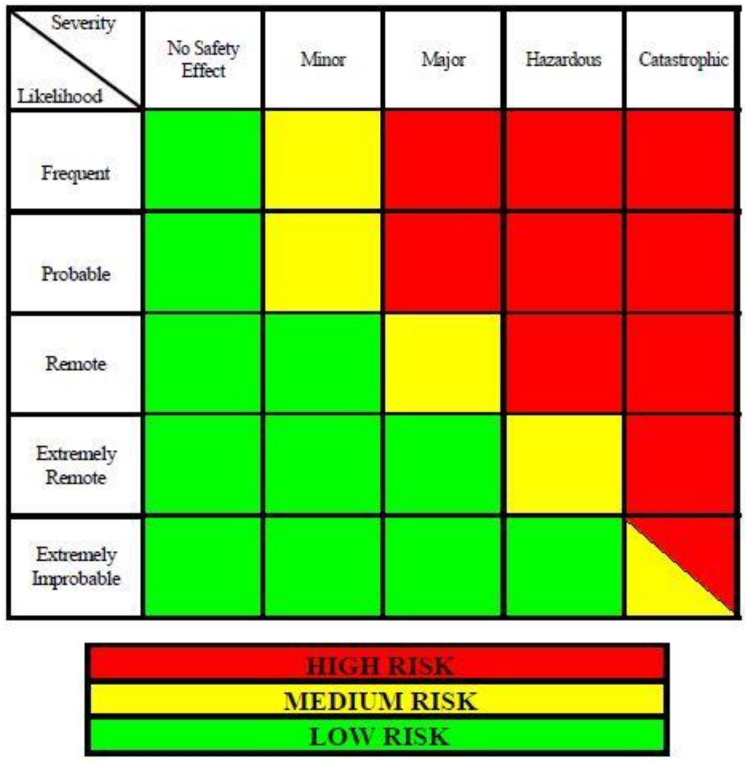

Figure 6. FAA Predictive Risk Matrix (FAA 2007)

A similar potential hazard associated with the proposed parking system redevelopment is pedestrians interacting with AVs. This creates a risk for vehicle-pedestrian collisions. Similar to the previous hazard and associated risks, the risk of pedestrians being struck by vehicles already exists, and has a remote chance of happening. However, a pedestrian being struck could have resulted in a major severity, resulting in a medium level of risk and a need for treatment. To mitigate the chances of pedestrians being struck, our design was arranged so that there is no need for pedestrians to enter driving areas. They will enter and exit vehicles along the curb with no need to cross any driving lanes. Additionally, bollards would separate the curbside area from the driving area, preventing vehicles from entering the pedestrian travel areas.

Because it is unlikely that AVs will be used exclusively, especially in the near term, there is also a hazard created by the interaction between AVs and Human-driven vehicles (HVs).

Because AVs would not be able to communicate with human drivers like they are with other AVs, there is an increased risk of collision between AVs and HVs compared to AVs only. Similar to previous hazards, the likelihood of collisions is remote. Because vehicles already have safety measures in case of collisions, consequences would likely be minor. Therefore, this would be considered low risk and treatment would not be necessary. However, the proposed design incorporates signage to limit confusion for human drivers and traffic calming devices such as speed bumps to control the driving behavior of human drivers in order to reduce the risk of human drivers causing a collision with AVs.

Expert Interaction

The design team met with several experts to collect information and arrive at the final proposed design. During the process of narrowing the problem scope, the team interviewed the Missouri Department of Transportation (MoDOT) aviation programs manager, Andrew Hanks. When asked about the revenue generated by the parking service at airports, Hanks suggested that the design should focus on hub airports, rather than GA airports, because only hub airports are able to generate enough revenue from parking to support airport operations. Besides, he confirmed the financially self-sufficient parking system is very vital, because the federal or state agencies usually don not fundparking project at airports.

Another critical party interviewed was Timothy Cope, Burns & McDonnell transportation engineer. He was working on several airport terminal transportation projects. Hearing Cope's perspective was crucial to understanding the role of curbside, where travelers and their baggage enter and exit the terminal. He shared his experience on airport curbside and terminal area roadway operations and provided suggestion on how to increase the volume of curbside parking. He also emphasized the importance of pedestrian safety at the curbside area.

The team also reached out to Angel Ramos, the Assistant Director of Planning & Engineering of the St. Louis Lambert International Airport. He mentioned the issue of employee parking in the design. The need of employee parking won't be eliminated, as the AVs will still be parked at airports during the work hours. Therefore, in the design, the short-duration parking is retained for human-driven vehicles and employee's AVs. The short walking distance will benefit not only the passenger, but also the airport employees.

Throughout the entire design process, the team consulted with its faculty advisor at the University of Missouri, Carlos Sun. The team utilized Dr. Sun's expertise in airport engineering to gain valuable insights into every step of the design process.

Appendix A

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Appendix B

Description of the University of Missouri

The University of Missouri – Columbia, located in the city of Columbia, Missouri, is both the state land grant university and the state research university. The flagship university of the University of Missouri system has a total enrollment of approximately 30,000 students and employs over 13,000 faculty. The university is a member of the American Association of Universities, an association of 63 of the leading public and private research universities in the United States and Canada. Additionally, the University of Missouri has been classified by the Carnegie Foundation at the highest level for doctorate-granting universities.

The transportation engineering program at the University of Missouri employs six faculty members and has approximately twenty graduate students at both masters and Ph.D. levels. The program also has strong ties to other programs at the university, including the Truman School of Public Policy, Agricultural Economics, Statistics, Electrical Engineering, Industrial and Manufacturing Engineering, Computer Science, Library Science, Rural Sociology, and the School of Law.

Airport activities are included within the transportation engineering program at the University of Missouri – Columbia. These activities include an ACRP research project on safety, ground transportation, and terminal accessibility, research on airport pavements for the Missouri Department of Transportation, and an airport engineering class taught by program advisor Dr. Carlos Sun, who was previously employed in the airline industry by Airshow, Inc. (now Rockwell/Collins) designing aircraft information systems.

Appendix C

No non-university partners were involved in this project.

Appendix E

<u>Evaluation of Educational Experience</u>

Students

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

   This design competition provided the team with a meaningful learning experience for multiple reasons. The competition provided the valuable benefit of challenging students to respond to a request for proposal, an experience that will be common outside of school. Additionally, students were able to apply knowledge learned in class to a real-world project.

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

   A primary challenge for the team was that none of the team members had previous experience or knowledge of airport operations. This was overcome through studying class material and conducting a thorough literature review. Additionally, as with many team projects, ensuring that all team members were on the same page was a challenge, but constant and thorough communication helped overcome this obstacle.

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

   To develop the design, the team combined interests and experience of the members. Because members had experience in transportation design and experience in intelligent transportation systems, the idea of working with ground transportation as the transportation industry experiences technological advances was developed.

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

   Industry participation was helpful, as it gave students better insight into the current state of the industry. Additionally, it gave students experience in professional communication, which will be helpful in the future.

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

   Because the team had little prior knowledge of airport operations, the team was able to gain a lot of knowledge about this area. While team members may not use this knowledge as they pursue careers, skills such as professional writing, professional communication, and responding to proposals will provide significant benefits moving forward.

Faculty

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

   The competition replicated the steps needed to put together a significant piece of professional writing such as a grant application, a bid document, or a final report. Outside of senior design, this type of deliverable is rare for classes in an engineering curriculum.

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

   Yes. As a conceptual design, the requirements are feasible. Any type of actual implementation would be infeasible for the majority of students due to time constraints, lack of resources, and access to facilities.

3. What challenges did the students face and overcome?

   One major challenge was the acquisition of the foundations and background necessary (e.g. advisory circulars) to perform design. Students had to acquire knowledge incrementally as they were developing their designs. Another challenge was the difficulty in obtaining data and expert assistance. The level of support provided by industry and FAA experts was uneven. Some were extremely helpful, while others wondered why they were listed as Expert Advisors on the ACRP Design Competition website.

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

   Possibly. I have been including this competition as part of my Airport Engineering class since 2003. Advising for such a competition is extremely time consuming from both technical and writing perspectives. However, the experience is very beneficial to students.

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

   As part of resources, add inks to FAA and related data sources, such as airport operations, runway incursions, airport improvement grants, and NOAA weather. Also provide airport master plans for as many airports as possible.

Appendix F

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