COVER PAGE

Title of Design: High Occupancy Vehicle (HOV) Traffic Management Concept on Airfields: Increasing Airport Capacity and Reducing Passenger Delay

Design Challenge Addressed: Airport Management and Planning

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Executive Summary

In present airfield operations across the United States, departing aircraft are queued in a first-in, first-out method regardless of their scheduled departure time, size, or passenger capacity. Inspired by High-Occupancy Vehicle (HOV) lanes on highways, this study answers the question of whether separating and prioritizing high-occupancy aircraft from lower occupancy aircraft in a departure queue has any effect on the passenger delay or throughput of airports at peak hours.

Using queueing models, fleet mix projections, the FAA high-fidelity databases, and airport design & operation circulars, both the aircraft flows on airfields as well as their taxiway layout were analyzed to determine how this queue separation would work. The study showed that implementing a HOV-style priority model during takeoffs can reduce the passenger-delay by up to 12 minutes in current fleet mix conditions and increase airport capacity by up to 13% under a viable augmentation to airline peak period fleet mixes. This augmentation would reflect the consolidation of smaller aircraft into heavy aircraft with priority on a queued taxiway. Upon a rigorous method of airport selection, consisting of choosing airports with the highest delay but also a diverse fleet mix, this study ultimately focused on three airports to formulate case studies: Denver International (ORD), Chicago O'Hare (ORD), and Hartsfield-Jackson Atlanta (ATL). Our study also demonstrates that these operations are not only subject to design and construction feasibility of implementing parallel takeoff queues on taxiways, but also subject to potential stakeholder impacts on airport-airline relations, network flows, and the passenger experience.

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1. Problem Statement and Background

Before the COVID-19 pandemic disrupted the aviation industry, airfield congestion and delays across the United States (US) airports were becoming increasingly common problems. The most profound part of the airfield delay is taxi-out delay, defined as the additional wait time an aircraft experiences while in queue for takeoff. These observations are in accordance with the industry patterns of airline mergers, increased number of direct flights, and increase in the popularity of narrow-body aircraft orders over wide-bodies for both full-service and budget airlines. The augmented use of narrow-body aircraft is more prevalent for domestic flights in the US than in European and Asian markets, which compounds congestion and creates an "inefficient throughput" problem.

The occurrence of significant apron-gate and taxi-delays, despite comprehensive demand management measures (i.e., slot controlling at some US airports), raises the question of whether different types of demand management programs are needed to combat airfield congestion. In surface transportation, the "inefficient throughput" problem can be linked to the overuse of single-occupancy vehicles on highways, which transportation engineers solve by prioritizing high-occupancy vehicles (HOV) on "HOV Lanes". We postulate that such a method could enable higher passenger capacity aircraft to be prioritized for takeoff during peak departure hours instead of competing with lower passenger capacity aircraft for the same takeoff slots, similar to how high-occupancy vehicles are prioritized over low-occupancy vehicles in surface transportation.

Therefore, the primary goal of this research is to develop a new method for routing aircraft over the taxiway system at large and congested airports. Some of the questions we ask are:

(i) Would implementing a priority regime increase peak airport passenger capacity over the taxiway system, given conditions and characteristics of each airport and its fleet mix, (ii) Would such a regime decrease average passenger delay, and (iii) Would High Occupancy Aircraft (HOA) priority regime influence airlines to change their fleet scheduling practices.

The objectives of this research are to:

- Review the existing literature and methods of analysis that airport planners use for airport capacity studies, and the different perspectives that our research applies.
- Develop and detail the methods and data sources used to perform an initial feasibility analysis, a detailed airport capacity and passenger delay analysis, as well as the analysis of design and construction feasibility.
- Communicate with airport, airline and air traffic control representatives to understand how taxiway design and aircraft taxiway routing work in practice.
- Verify usage of the proposed method.
- Apply the proposed method of analysis on three large airports (ATL, DEN, and ORD)

2. Summary of Literature Review

2.1. The Airline Perspective

US airlines typically increase the frequency of low-passenger-capacity flights (instead of increasing the frequency of high-passenger-capacity flights) in order to expand domestic capacity, especially over short-haul routes (Hansen et al., 2003). This is driven by a desire to minimize the schedule delay of passengers, defined as the time between when a passenger wishes to depart and when a departure is available, as well as the endogenous cost of pilots which are paid in correlation to aircraft size. By introducing higher frequency of flights, airlines are able to gain a greater proportional market share, compounding the airline's disincentive to instead expand capacity on existing flights (Button et al., 2005). Moreover, the difference in fuel consumption per passenger between narrow-body and wide-body aircraft operations are minimal. The tendency of airlines to favor the extensive use of narrow-body aircraft for expanding their domestic network is reflected in their fleet mix, with the largest 3 full-service airlines in the US (American, Delta, and United) operating 87%, 85%, and 74% narrow-body aircraft respectively. In contrast, large international carriers Lufthansa Group, KLM Group, and ANA operate at 66%, 47%, and 34% narrow body aircraft of their respective fleets. As a result, airports in the US have a lower passenger average number per Air Traffic Movement (ATM) in comparison to Europe and Asia: 77 vs. 110 vs. 180 passengers correspondingly (Givoni et al., 2006). This shows that the cost minimizing behavior of airlines has resulted in a reduced efficiency of the aviation system for US compared to Europe and Asia, specifically in the cases where narrow-body aircraft are used to fly high-demand routes capable of wide-body aircraft (e.g., SFO-LAX, DEN-PHX, and New York to Chicago).

2.2. The Airport Perspective

Amidst projected future growth in air traffic demand (Mott MacDonald 2016) in conditions before and after COVID-19, airports typically have a longer lead time for capacity expansion than airlines (PWC 2017). Many heuristic methods have been established to calculate the maximum throughput capacity (MTC) of an airport, a metric used for both strategic airport planning and air traffic management (Idris et al., 1998; Simaiakis, 2013). When the demand for an airport runway system exceeds its capacity, a queue consisting of the aircraft beyond the capacity will form; aircraft in this queue will endure subsequent delays (ACRP 104, 2014).

Airports with the longest time for taxi-out delays are usually large, high-capacity airports (Goldberg & Chesser, 2006), and Demand Management Programs have long been used to regulate both congestion and delays at airports where non-regulated demand would exceed capacity (Madas & Zografos, 2008). Other methods include departure queue management, ramp tower operations and utilization, and design of Performance Based Navigation (ACRP 190, 2018). This is completed on a macro-level through means of administrative, economic, hybrid, and/or tactical measures to adjust the scheduled arrivals and departures of aircraft. The most common measures include the implementation of a slot regulating and exchange system at all IATA "Level 3" Airports (Le, 2006; IATA, 2019), congestion pricing or surcharges on landing fees (Czerny et al., 2008), and Ground Delay Programs (Kuhn, 2013). The US version of this implementation, where a first-come-first-served method is used to maximize efficiency, is found to be more beneficial than the European system, where slots are limited by declared runway capacity to minimize delay (Cavosoglu et. al., 2021).

Historical methods, which attempted to deviate from a purely first-come-first-serve model, include constrained position shifting (CPS), a mechanism of reorganizing arrival or departure sequences by a constrained number of position changes optimized relative to FIFO in order to preserve fairness (Dear, 1978; Balakrishnan et al., 2010). In 1969, a High Density Rule (HDR) was also introduced at JFK, EWR, LGA, ORD, and DCA airports, which limited the movements of Instrument Flight Rules (IFR) arrivals and departures during congested hours (Le, 2006). These restrictions were eventually removed in 2000-2001, spurring re-implementation after increased congestion. There have also been efforts to optimize traffic flow on taxiway systems and optimize them as a network instead of prioritizing route preference of airlines, such as in Lee & Balakrishnan (2012) and Yu et al. (2017).

The biggest limitation with each of these systems is that they only regulate scheduled movements in an airfield by the flow of aircraft instead of the flow of passengers, which results in the lack of a penalty mechanism for the overuse of narrow-body aircraft by airlines at peak hour, resulting in inefficient throughput. Without differential treatment by airports prioritizing more efficient aircraft targeted to peak hour departures, airlines do not have an incentive to use wide-body aircraft for an effective adept *passenger* throughput.

2.3. HOV Operations on Highways and their Commonality with Airfield Conditions

The precedent for prioritizing based on passenger movements comes from HOV lanes found on numerous US highways. These surface transportation operations allow vehicles with more than one person to utilize the HOV exclusive lane, which is separated from general purpose (GP) lanes which have no restrictions on usage. Utilized properly and assuming unchanged demand conditions, HOV lanes can transfer delays experienced by both HOVs and Low Occupancy Vehicles (LOVs) to LOVs only. Although the vehicle-hour delay does not change, the people-hour delay is reduced and delay is transferred to vehicles with less passengers (Menendez and Daganzo, 2006).

In an application to our scenario of a departure queue at an airport, the proposed demand management model requires successful transfer of the people-hour delay from wide-body aircraft to those in narrow-body aircraft. This is achieved by allowing wide-body aircraft to bypass the queue of narrow-body aircraft and experience virtually no delay. Instead of the actual road capacity on highways, the constraint on an airfield is availability of takeoff slots (previously auctioned).

Kwon & Varaiya (2006) and May, Leiman & Billheimer (2007) caution that some HOV lane implementations on highways have had limited successes, with most unsuccessful projects correlated to areas without the correct conditions for them, as with the case of I-287 and I-80 in

New Jersey. The failure of such projects was blamed on an insufficient analysis of the actual HOV demand on such systems and the willingness or ability of commuters to carpool. This cautions that conditions of airfields must be carefully analyzed to distinguish sufficient demands and potential fleet mix modifications in order to observe a meaningful increase in passenger throughput or average passenger delay.

3. Problem Solving Approach

The proposed method uses data from the FAA Aviation System Performance Metrics (ASPM) and System Wide Information Management (SWIM) databases in order to perform analyses. ASPM data were used to gather the characteristics of flights, such as destination, aircraft type, and scheduled departure times, while SWIM data were used to perform spatial analysis on the routing of flights on taxiways, and the headways between successive runway departures.

The analysis starts with an initial feasibility to determine whether an airport suffers from the “inefficient throughput problem” caused by congestion of Low-Occupancy Aircraft. If this returns positive, the data points from ASPM are collected over a month-long period and analyzed to examine the improvements in average passenger delay and potential passenger throughput increases through augmenting the current conditions of flow. This determines the “capacity feasibility” of the airport. The analysis then continues to determine the design and construction feasibility of reallocating traffic or constructing new taxiways in order to accommodate multiple takeoff queues accommodating both Low-Occupancy Aircraft (LOA) and High-Occupancy Aircraft (HOA). These metrics combined provide the metrics to determine the overall feasibility and cost-benefit analysis of implementing an HOA Priority Regime at a particular airport. This process is described in the flowchart shown in Figure 1.

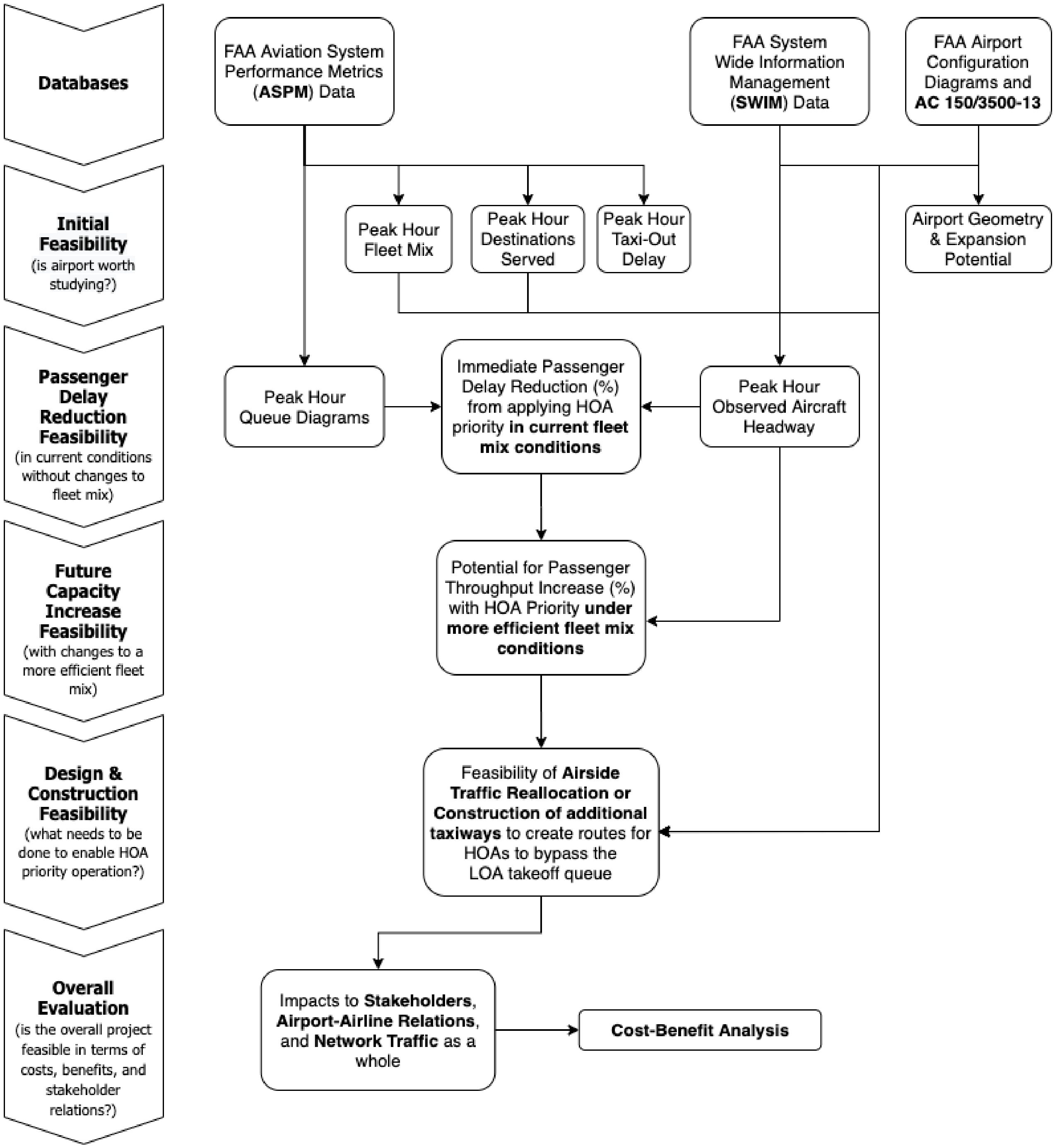

Fig. 1. Proposed Method for Evaluating Passenger Throughput Under HOA Conditions

3.1. Method for Initial Feasibility

The Initial Feasibility refers to a set of five metrics to determine whether an airport warrants further study for the use of HOA taxiways. Of the five metrics listed in Table 1, a lower on-time performance, longer peak period taxi-out delay, large land area, high constructability score, and higher percentage of heavy-type aircraft are the preferred factors which indicate the feasibility of HOA priority operations. Within these categories, some factors are immediate disqualifiers, such as the absence of regularly scheduled heavy aircraft operations. This indicates insufficient regional consumer demand or inadequate runway and terminal handling capacity.

Table 1 Metrics for Determining Feasibility Studies for HOA Taxiways

Metric	Preferred Outcome of Candidate Airport	Unworkable Outcome
On-Time Performance	Lower on-time performance indicates higher delays.	100% on-time performance could indicate no delays, making HOA priority redundant.
Peak Taxi-Out Delay	Higher taxi-out delays indicate longer queues for takeoffs.	No taxi-out delay indicates no queue for takeoffs, making HOA priority redundant.
Land Area	A larger area indicates more flexibility in additional taxiway construction to accommodate HOA lane operations.	N/A
Constructability	Visual inspection indicates that construction of Standard Plans in Section 4.3 is feasible	Visual inspection indicates that two parallel approach taxiways to departure runways is not possible (e.g. SFO).
Percentage of Heavy Aircraft Movements	Higher percentage, but not too high a percentage of Heavy Aircraft indicates that the airport is capable of handling Heavy aircraft and serves an area with adequate passenger demand for a Heavy aircraft.	0% fleet mix of Heavy Aircraft could indicate that the airport runway or terminal building is incapable of accepting Heavy aircraft, or that the airport serves an area without adequate passenger demand for regular service by a Heavy aircraft.

3.2. Method for Immediate Passenger Delay Improvements (Scenario 1)

The method to analyze average passenger delay improvement is based on literature from highway HOV lanes, except that High-Occupancy Aircraft (HOA) are defined as wide-body aircraft, while Low-Occupancy Aircraft (LOA) are defined as narrow-body aircraft. The desired outcome is the transferring of all delays experienced to LOAs only, by allowing HOAs to be served immediately when they enter the queue for takeoff. Based on queueing theory, even though the total *aircraft* delay is theoretically invariant, the total *passenger* delay is lowered because the *aircraft* delay is transferred from HOAs to LOAs.

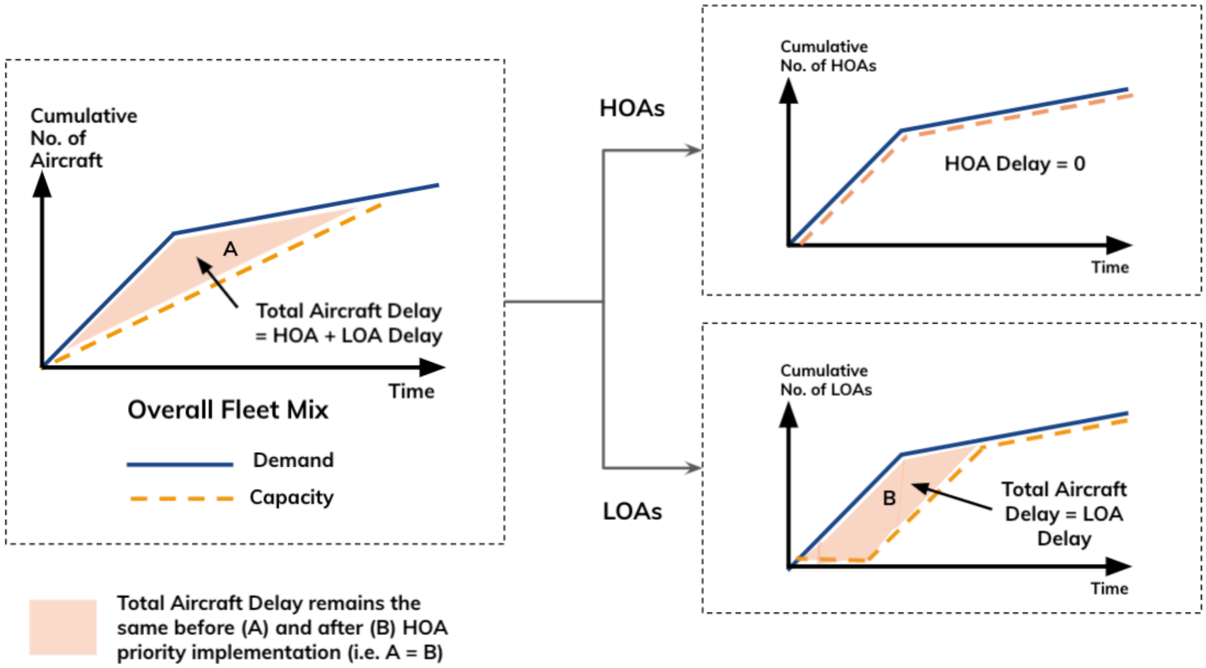

Fig. 2. Total Aircraft Delay is Transferred to LOAs under HOA Priority Regime

ASPM data on gate out time and runway departure time can be used to create queueing diagrams for each runway at any airport. These can be further analyzed to determine current delay, throughput, and demand conditions. However, for hypothetical projections of the HOA priority regime, the probabilistic separation of aircraft during takeoff is used to construct the projected capacity curve, while the demand curve is assumed to remain constant. This model relies on average separations for each leading and trailing aircraft combination observed over a month through geofencing the SWIM data.

To narrow the scope of analysis, FAA's nine categories from the Consolidated Wake Turbulence Separation Standards in Order JO 7210.126A (FAA, 2019) were consolidated into four aircraft weight categories. These were defined with the following classifications based on their Maximum Certified Gross Takeoff Weight (MCGTOW): (1) MCGTOW greater than 250,000 lbs. as heavy, (2) between 80,000 and 250,000 lbs as large, (3) between 41,000 and 80,000 lbs as medium, and (4) below 41,000 lbs as small. This means that within RECAT Phase II, aircraft classes “A,” “B,” “C,” “D,” “E” were classified as the heavy-weight class; “F” and “G” as large and medium-weight classes; and “H” and “I” as the small-weight class.

The expected mean headway, $< T >$, between each pair of leading and trailing aircraft are calculated by weighting each scenario, where the respective type of aircraft trails any other aircraft. Inter-departure headways, T_{ij}, for each leading i – trailing j case was calculated from the SWIM data in the 3-hour peak period and organized into a matrix, $[T_{ij}]$, in Table 2. The probability P_{ij} of occurrence for each case was also calculated and organized as a matrix, $[P_{ij}]$.

Table 2 Headway T_{ij} and Probability Matrices P_{ij}

T_{ij}

T_{ij}	Trailing *j*			
Leading *i*	T_{HH}	T_{HL}	T_{HM}	T_{HS}
	T_{LH}	T_{LL}	T_{LM}	T_{LS}
	T_{MH}	T_{ML}	T_{MM}	T_{MS}
	T_{SH}	T_{SL}	T_{SM}	T_{SS}

P_{ij}

P_{ij}	Trailing *j*			
Leading *i*	P_{HH}	P_{HL}	P_{HM}	P_{HS}
	P_{LH}	P_{LL}	P_{LM}	P_{LS}
	P_{MH}	P_{ML}	P_{MM}	P_{MS}
	P_{SH}	P_{SL}	P_{SM}	P_{SS}

These matrices are used in the following equations:

$$< T_{HOA,LOA} > = \sum_{j=2}^{4} T_{1,j}\ P_{1,j} \tag{1}$$

$$< T_{LOA,HOA} > = \sum_{i=2}^{4} T_{i,1}\ P_{i,1} \tag{2}$$

$$< T_{LOA\ ,LOA} > = \sum_{i=2}^{4} \sum_{j=2}^{4} T_{ij} \times P_{ij} \tag{3}$$

$$< T_{leading,i} > = \sum_{j=1}^{4} T_{ij} \times P_{ij} \tag{4}$$

where: $< T_{HOA,LOA} >$ = The expected mean headway between a HOA leading and a LOA following

$< T_{LOA,HOA} >$ = The expected mean headway between a LOA leading and HOA following

$< T_{LOA,LOA} >$ = The expected mean headway between a LOA leading and LOA following

$< T_{leading,i} >$ = General expected mean headway for a single leading aircraft type

A consequence of prioritizing a newly arriving HOA in the departure queue is an increase in the delay of existing LOAs in the queue. This additional delay for a single LOA, Δ_{LOA} , is calculated using Eq. 5.

$$\Delta_{LOA} = < T_{HOA,LOA} > + < T_{LOA,HOA} > - < T_{LOA,LOA} > \quad (5)$$

This model assumes that a "displaced" LOA in the queue would create a ripple effect to all other LOAs in the queue. The length of this queue at the time each HOA i was prioritized, Q_i , was determined analytically by using the number of departures (Wheels-off time) and the number of aircraft requesting departure slots (Gate-out time) from ASPM data. The decrease in delay for a single HOA i, $\Delta_{HOA,i}$, is calculated using Eq. 6.

$$\Delta_{HOA,i} = Q_i \times < T_{LOA,LOA} > \quad (6)$$

The passenger delay impact to HOAs and LOAs due to this affected queue is scaled to the seating capacity of the aircraft. To reduce complexity, standard seat capacities are assumed to be $C_{HOA} = 320$ for HOAs, $C_{LOA} = 160$ for LOAs. For the purpose of our analysis, all aircraft were assumed to have full utilization. The resultant decrease in the average passenger delay can be obtained by estimating the queue length of both HOAs and LOAs before and after the implementation of the HOA priority regime and using Equations. 7 to 10.

$$\Theta_{CC} = \sum_{i=all\ aircraft} (C_i \times number\ of\ minutes\ aircraft\ i\ is\ in\ queue) \quad (7)$$

$$\delta\Theta_{HOA\ Priority} = \sum_{i=all\ HOA\ Bypasses} \left(Q_i \times \Delta_{LOA} \times \frac{160}{60}\right) - \sum_{i=all\ HOA} (\Delta_{HOA,i} \times \frac{320}{60}) \quad (8)$$

$$\Theta_{HOA\ Priority} = \Theta_{CC} - |\delta\Theta_{HOA\ Priority}| \tag{9}$$

where:

Θ_{CC}	= total passenger delay in queue under current conditions
$\delta\Theta_{HOA\ Priority}$	= decrease in total passenger delay due to HOA priority regime
$\Theta_{HOA\ Priority}$	= total passenger delay under HOA priority regime
C_i	= passenger capacity of each aircraft where *i* = H, L, M, S weight classes
Q_i	= length of LOA queue during instance *i* of HOA prioritization
Δ_{LOA}	= increase in singular LOA delay caused by HOA prioritization
$\Delta_{HOA,i}$	= decrease in singular HOA delay as a result of HOA prioritization

The metric $\frac{\delta\Theta_{HOA\ Priority}}{\Theta_{CC}}$ hence represents the ratio in the reduction of overall passenger delay due to the imposition of the HOA priority regime to the total delay under current demand conditions. The next section will focus on potential passenger throughput increases and further delay reductions if this regime incentivizes airlines to make changes to their scheduled fleet mix during peak periods in order to achieve a more efficient passenger throughput.

3.3. Method for Future Passenger Capacity Increases (Scenario 2)

While the HOA priority regime in Scenario 1 may reduce passenger delay in the short term, the primary goal is to use these benefits to influence airlines' behavior by rescheduling flights or changing their fleet mixes to comprise more HOAs during the most congested periods, in order to take advantage of HOA priority benefits. This altering of future operations will be addressed as Scenario 2, which will evaluate the influence of fleet mix alterations on passenger throughput. Based on queueing theory, a fleet with a higher percentage of HOAs improves airport passenger capacity, because the processing rate of passengers using HOAs is higher than that of LOAs.

To determine the potential for future capacity increases, a "utopia" alternative was developed as an idealized fleet mix of Scenario 2. This refers to the hypothetical conditions where no two

LOAs depart to the same destination within the three most congested hours at each airport, and instead HOAs service these routes. It is postulated that if the destination airport is capable of landing HOAs, this demand could hypothetically be fulfilled by consolidating two narrow-body aircraft into a single wide-body aircraft.

As an example, from real data, 8 large aircraft operate between Denver International Airport (DEN) and Phoenix Sky Harbor International Airport (PHX), one of the busiest domestic routes in the US, during morning peak hours from 7-10 AM. Replacing these 8 large aircraft with 4 heavy aircraft would reduce the total departure processing time without reducing passenger capacity on this route. Figure 3 illustrates how current conditions can be modified using different replacement scenarios between heavy and large aircraft, where 2 large aircraft are substituted with 1 heavy aircraft. Utopia conditions reflect this substitution on routes served by 2 or more large aircraft, while Realistic conditions reflect this substitution on routes served by 4 or more large aircraft.

Current Conditions on a chosen date during a peak time interval

Arrival Airport	H	L	M	S
XXX	0	5	1	1
YYY	1	3	0	0
ZZZ	0	2	2	1
Total	**1**	**10**	**3**	**2**

Realistic Condition between current conditions and utopia

Arrival Airport	H	L	M	S
XXX	2	1	1	1
YYY	1	3	0	0
ZZZ	0	2	2	1
Total	**3**	**6**	**3**	**1**

Utopia Conditions based on consolidation of all eligible flights

Arrival Airport	H	L	M	S
XXX	2	1	1	1
YYY	2	1	0	0
ZZZ	1	0	2	1
Total	**5**	**2**	**3**	**2**

Fig. 3. Sensitivity Analysis Method for Departures to 3 Hypothetical Arrival Airports

Because the ability or willingness of airlines to substitute every inefficient aircraft operation is variable, a sensitivity analysis is conducted to find the effect of three intermediate fleet mix alternatives in addition to the current condition and utopia alternative. These analyses were performed for the busiest 3 hours of the day. The additional passenger capacity created as a result of the reduced processing time of more ideal fleet mixes was then calculated using the proportion of the old processing time to the new processing time.

The passenger throughput, Φ , of aircraft operations can be calculated using Equation 10 below:

$$\Phi = \sum_{i=H,L,M,S} C_i \, n_i \tag{10}$$

where n_i is the number of aircraft i observed during a peak period.

In order to calculate the potential increase in passenger throughput of a peak period of 3 hours, the time taken to process all aircraft in more ideal conditions is compared to the time taken to process all aircraft in current conditions. This is expressed by the ratio γ of current conditions processing time (peak period of 3 hours) to more ideal conditions processing time in equation 11 below:

$$\gamma = \frac{60 \text{ sec} \times 60 \text{ min} \times 3hrs}{n_H < T_H > + n_L < T_L > + n_M < T_M > + n_S < T_S >} \tag{11}$$

where: $< T_i >$ = The expected mean headway after a type *i* aircraft departure, where $i = H, L, M, S$ aircraft

n_i = The number of aircraft type *i* in more ideal fleet mix conditions, where $i = H, L, M, S$ aircraft

Therefore, the projected passenger throughput in more ideal conditions, Φ_{New} , is calculated by scaling the passenger throughput in current conditions, Φ_{CC} , by the ratio γ as shown in equation 12 below:

$$\Phi_{\text{New}} = \gamma \times \Phi_{\text{CC}} \tag{12}$$

3.4. Method for Design & Construction Feasibility

According to the FAA Advisory Circular 150/3500-13, as an airport expands, the stages of its taxiway system eventually evolve into a geometric configuration that includes multiple parallel taxiways. This is shown in Figure 4.

Fig. 4. Two Parallel Departure Queues Through Natural Taxiway Evolution (Standard Implementation 1)

In such an occurrence, the airport is already positioned to handle parallel departure approach taxiways which feed onto a runway, indicated by the green and pink routes in the figure above. In this case, the implementation of the HOA priority regime depends on internal traffic reconfiguration to allow exclusive use of one of these taxiways by HOAs.

However, many airfields have not evolved in the same geometric manner, due to site or operational constraints. In such conditions, airports must retrofit their airfields to create a "bypass taxiway" for HOAs to overtake LOAs in order to implement the HOA priority regime. Table 3 shows the constraints which must be satisfied in order for the design or retrofit of a parallel taxiway to be feasible. Figure 5 illustrates these constraints.

Table 3 Constraints for Designing and Retrofitting a Parallel Taxiway as an HOA Bypass Lane

Constraint	Application
Maximum Peak LOA Queue Length (X)	When constructing or reallocating a bypass taxiway, the designer must ensure that the entrance to the bypass taxiway is behind the maximum peak queue length to allow for effective use by HOAs.
Minimum Separation between Parallel Taxiways (Y)	FAA Advisory Circular 150/3500-13 provides the design criteria for minimum separation between parallel taxiways, depending on the elevation of the airfield. For example, centerlines of parallel taxiways should be 400 feet apart at sea level, while centerlines of a parallel taxiway and runway should be 500 feet apart at 1 mile elevation.
Minimum Takeoff Distance on Runway (Z)	When new bypass taxiways are constructed or reallocated from other uses (such as landing exits), the minimum takeoff distance on runways must remain satisfied.

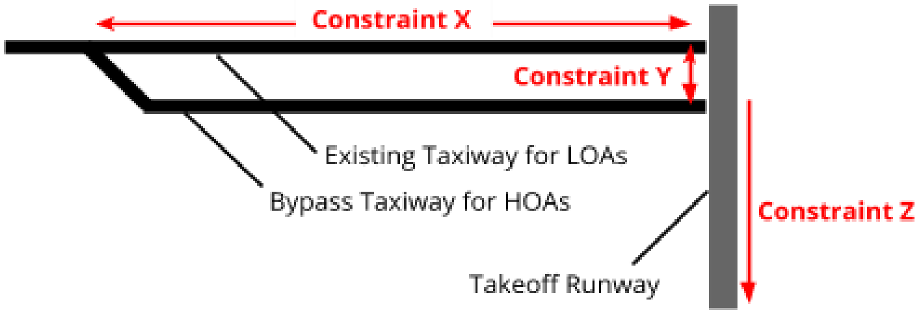

Fig. 5. Design and Constructability Constraints for HOA-Priority Taxiway Retrofits

Figures 6 and 7 indicate two possible retrofit patterns to existing airfield constraints: constructing a parallel approach taxiway (Fig. 6) and splitting an existing approach taxiway (Fig. 7).

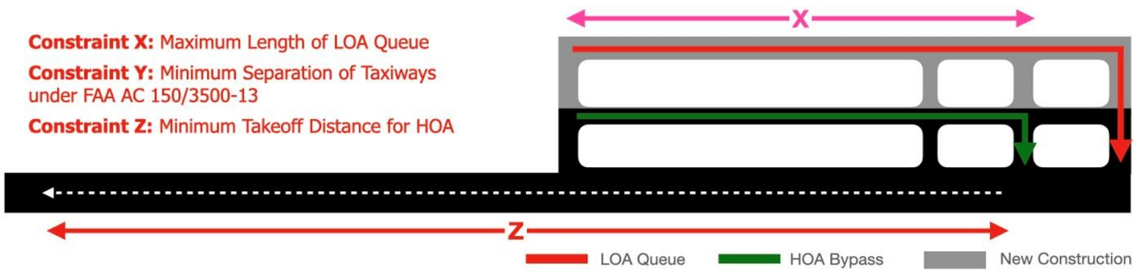

Fig. 6. Construction of a Parallel Approach Taxiway (Standard Implementation 2)

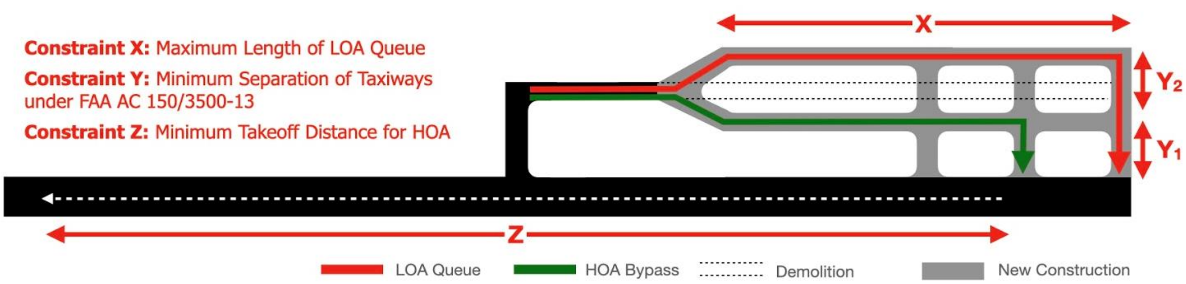

Fig.7. Splitting of Existing Approach Taxiway (Standard Implementation 3)

If neither of these standard retrofits are viable, then a "wild card" solution, such as allocating a specific runway for HOA use, or building other taxiways to redirect conflicting traffic flows, may be required to create an HOA bypass. Figure 8 shows a decision flow diagram for taxiway system retrofitting.

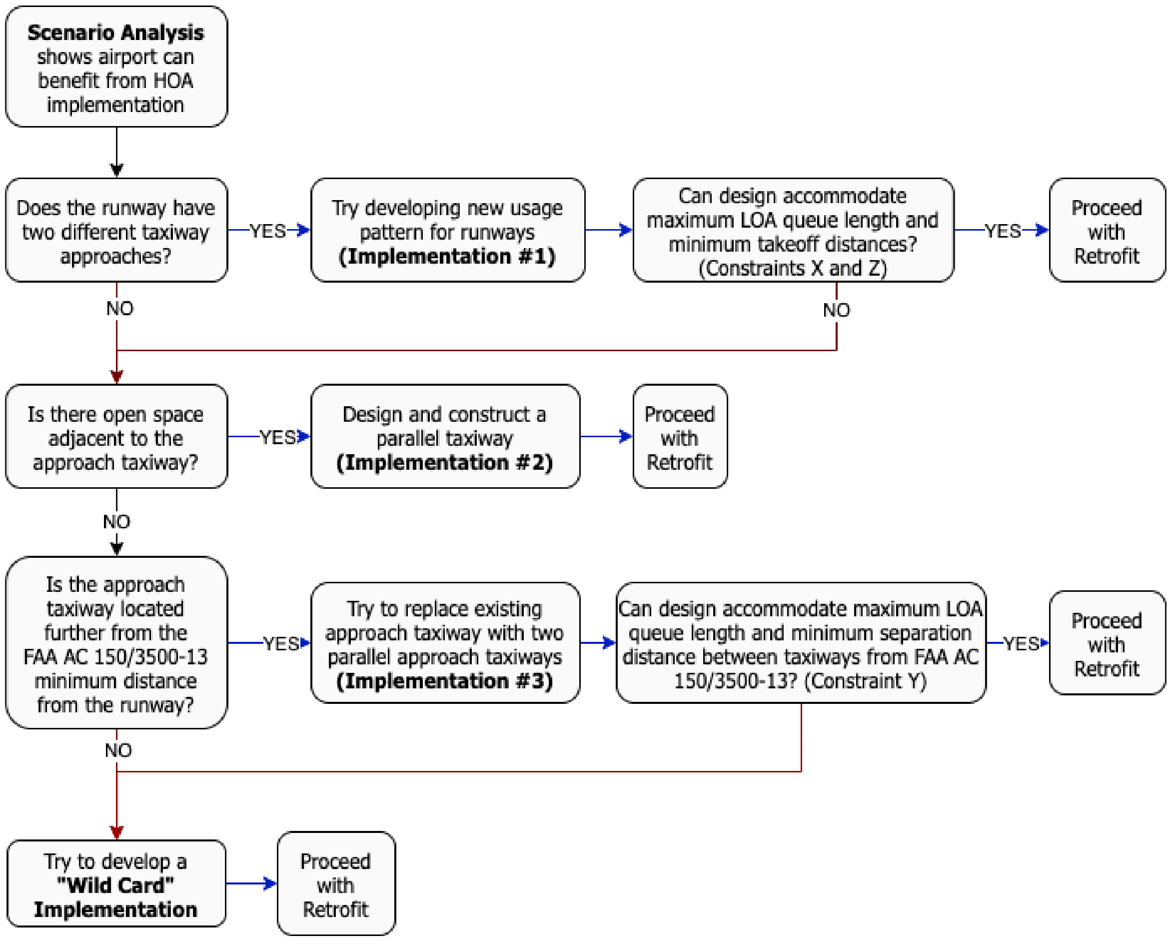

Fig. 8. Design and Construction Feasibility Workflow

While exact cost estimates are difficult to determine without further site investigations or be standardized across many US markets, Standard Implementations 1, 2, and 3 present an ascending relative order of magnitude for implementation costs. This method, described in Figure 8, serves as a generalized evaluation workflow which can be used to study any airport.

In summary, the metric of initial feasibility is used to eliminate unsuitable airports on a cursory analysis, while the metrics of instantaneous reduction in passenger delay and potential for future increased capacity are the true measures of how much an airport could benefit from the implementation of the HOA priority regime. The design and construction feasibility evaluates the associated practicality and costs of physically implementing such a system, which along with the considerations of other stakeholders, determines the overall feasibility of implementation.

4. Practicality and Feasibility of the Proposed Design

This section applies our methods to the busiest month of operations for three of the busiest airports in the US: Denver International Airport (DEN), Chicago O'Hare International Airport (ORD), and Hartsfield-Jackson Atlanta International Airport (ATL). It selects the airports using the initial feasibility analysis detailed in Section 3.1 and shows that current and hypothetical scenarios of implementing the HOA priority regime results in reduced average passenger delay and potential increased capacity at all airports, validating our analysis methods in Sections 3.2 and 3.3. It also documents the potential ways by which the airfields can be reconfigured in section 3.4, as well as their relative costs of implementation.

4.1. Selection of Study Airports, Dates, and Times

To determine the final three airports of study, nine US airports with the worst on-time performance in 2019 were examined: ATL, CLT, DEN, DFW, EWR, JFK, LAX, ORD, SFO (Slotnick, 2019). The Choosing by Advantages (CBA) decision making method (Do, 2019), was used to select the 3 most pertinent for this application of study. The CBA process relies on the importance of advantages alone as a fundamental rule - advantages and their assigned importance are measured exclusively, since a disadvantage of one alternative is an advantage of another alternative. All nine airports were scored with respect to the five factors of initial feasibility, with fleet mix advantages most central to the selection as a Paramount Advantage. Through this process, ATL, DEN and ORD airports were chosen for our analysis.

As shown in Figure 9, July was the busiest month of operations in 2019 for each airport. Of all departures in the month of July, the morning peak hour of 7am to 10am local time was found to be the busiest three-hour window for all airports based on ASPM data, as shown in Figure 10. This analysis framed our study airports as DEN, ORD, and ATL, our study month as July 2019, and our study hours 7am to 10am local time at each airport.

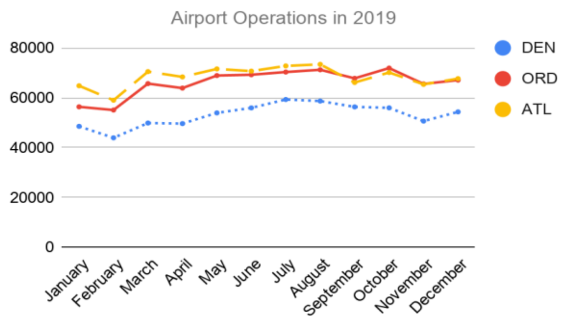

Fig. 9. Airport Operations at DEN, ORD and ATL in 2019

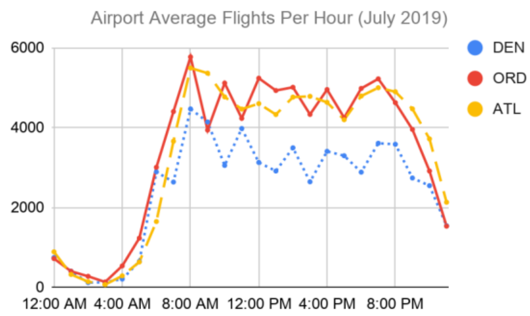

Fig. 10. Airport Average Flights Per Hour at DEN, ORD and ATL in July 2019

4.2. Analysis of Immediate Passenger Delay Improvements (Scenario 1)

The expected mean headway influencing queue delay in the HOA taxiway case for each airport was obtained using the proposed method explained in Section 3.2. This method resulted in the headway separations shown in Table 4.

Table 4 Expected Mean Headway Using SWIM Data

	ATL	**DEN**	**ORD**
Expected Mean Headway	78.3 seconds	92.2 seconds	100.89 seconds

SWIM departure data for the month of July 2019 were also used to calculate the average headway for each leading aircraft type and are represented in Table 5. As explained in Section 3.2, these headways were used in the scenario analysis to investigate the influence of increasing heavy aircraft in commercial fleets on passenger throughput.

Table 5 Average Headway of Leading Aircraft Scenarios by Airport Using SWIM Data

Headway After Leading Aircraft	ATL (sec)	DEN (sec)	ORD (sec)
T_H	81.50	88.46	91.14
T_L	76.30	83.11	74.11
T_M	75.08	80.72	73.15
T_S	76.38	104.31	60.0

Using the ASPM parameters *Actual Gate Out* time as the aircraft queue entry time and *Actual Wheels Off* as the aircraft queue exit time, the total delay under current conditions and under the HOA priority regime were calculated. For each runway with at least 60 departures, utilizing the effective headways from Table 4 and the method of Section 3.3, passenger delay reduction was computed as the percent difference from current conditions and HOA priority total passenger delay. Table 6 provides a sample of these delay changes.

Table 6 Sample of Percent Delay Reduction Under HOA Priority Model by Airport

Date	ATL		DEN		ORD	
	Runway	ΔΘ	Runway	ΔΘ	Runway	ΔΘ
7/7/2019	27R	-7.18%	25	-8.95%	10L	-3.07%
	26L	-6.93%	34L	-5.33%	9R	-3.23%
7/8/2019	27R	-8.11%	25	-14.10%	10L	-4.07%
	26L	-6.78%			9R	-4.06%
7/9/2019	9L	-7.84%	8	-7.19%	10L	-6.96%
	8R	-7.82%	17L	-16.76%	9R	-0.93%
7/10/2019	9L	-6.06%	25	-3.57%	22L	-2.59%
	8R	-8.87%			28R	-5.09%
7/11/2019	9L	-10.81%	17L	-21.95%	28R	-7.64%
	8R	-7.10%			22L	-10.51%

Averaging the percent change in passenger delay for each three-hour peak period of the month, the resulting reduction in passenger delay by airport was found to be 7.49% at ATL, 11.79% at DEN, and 4.01% at ORD. The metric of passenger delay reduction is only a measure of immediate passenger throughput increase of the airport but does not account for meaningful additions to overall capacity since the overall fleet mix of the airport is assumed to remain unchanged.

4.3. Results of Case Study for Future Capacity Increase (Scenario 2)

The "utopia" condition involved the consolidation of flights to all destinations served by 2 or more large aircraft within the 3-hour peak period, such as DEN to Boston (BOS) or DEN to Tulsa (TUL). However, these are less likely scenarios due to lower passenger demand between these destinations, as well as the likelihood that these are operated by two separate airlines, unless codeshare agreements are formed. The "realistic" condition reflects a state where flights with 4 or more large aircraft were consolidated into 2 or more heavy aircraft, likely by the same airline. Figure 11 demonstrates this process with departures from DEN on July 12, 2019.

Current Conditions on July 12, 2019 from 0700-1000 MDT

Arrival Airport	H	L	M	S
ATL	0	5	1	0
DFW	0	6	0	0
ASE	0	0	2	1
BOS	0	2	0	0
EWR	2	1	0	0
LGA	0	4	0	0
LAX	0	3	0	0
ORD	1	2	0	0
SFO	1	4	0	0
PHX	0	8	0	0
SAN	0	5	0	0
TUL	0	2	2	0
AUS	0	3	1	0
Total	**4**	**45**	**6**	**1**

Realistic Condition between Current and Utopia Conditions

Arrival Airport	H	L	M	S
ATL	2	1	1	0
DFW	3	0	0	0
ASE	0	0	2	1
BOS	0	2	0	0
EWR	2	1	0	0
LGA	0	4	0	0
LAX	0	3	0	0
ORD	1	2	0	0
SFO	3	0	0	0
PHX	4	0	0	0
SAN	2	1	0	0
TUL	0	2	2	0
AUS	0	3	1	0
Total	**17**	**19**	**6**	**1**

Utopia Conditions based on consolidation of all eligible flights

Arrival Airport	H	L	M	S
ATL	2	1	1	0
DFW	3	0	0	0
ASE	0	0	2	1
BOS	1	0	0	0
EWR	2	1	0	0
LGA	0	4	0	0
LAX	1	1	0	0
ORD	2	0	0	0
SFO	3	0	0	0
PHX	4	0	0	0
SAN	2	1	0	0
TUL	1	0	2	0
AUS	1	1	1	0
Total	**22**	**9**	**6**	**1**

Fig. 11. Sensitivity Analysis Example at DEN

Most notably, three airports which did not change their fleet mix proportions were Newark Airport (EWR), LaGuardia Airport (LGA), and Aspen County Airport (ASE). In the case of EWR, the fleet mix could not be altered due to existing operations of an optimal fleet load where only one Large aircraft operated between the two airports, and two Heavy aircraft in current conditions. In the case of LGA or ASE, these airports do not currently serve regular heavy aircraft operations and were deemed unsuitable for fleet mix augmentation, due to the runway length at LGA and the low population catchment of ASE.

To understand hypothetical capacity increases under future HOA priority airline scheduling, a scenario analysis with five levels of efficiency was performed in accordance with the methodology in Section 3.2. The five fleet mix scenarios demonstrate the variation in percentage increases of capacity dependent on the extent to which airlines change their scheduling practices. Results are presented in Figure 12.

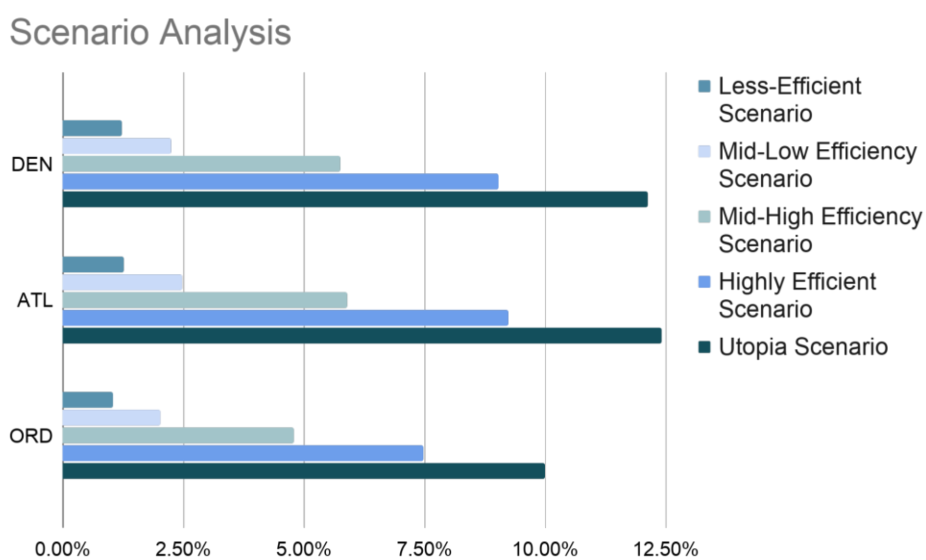

Fig. 12. Passenger Throughput Percent Increase from Current Conditions

At ATL, the maximum potential capacity is increased by 12.49%, while the intermediate scenarios range between 2.47% and 9.23% of capacity increases. Similarly, DEN's maximum potential capacity increase is 12.12%, but its intermediate scenarios receive 2.24% to 7.47% capacity increases. The data also discerns that there are significantly less potential capacity increases at ORD compared to its counterparts between 1% and 10%, with a 9.99% increase in its “utopia” conditions. This suggests that the current mix of fleet, destinations, and separation conditions have less synergies with the HOA priority regime to deliver increased capacity.

4.4. Results of Design and Construction Feasibility Analysis

This section explores results of technical standards and implementation alternatives by which HOA taxiways can be applied in the three selected airports: ATL, DEN, and ORD. Three standard implementations are: (1) traffic reallocation, (2) building a new parallel taxiway, and (3) branching an existing taxiway (as discussed in Section 3.3). Table 7 shows the options for design and construction and relative cost comparisons at ATL, DEN, and ORD:

Table 7 Options for Taxiway Design and Construction, and Relative Cost Comparisons

Runway	Possible Implementation(s)	Cost/Complexity
ATL 9L/27R	Standard 1 (Traffic Reallocation using Taxiways L and M)	Low
ATL 8R/28L	Standard 3 (Branch Existing Taxiway E)	Medium-High
DEN 17L/35R	Standard 1 (Traffic Reallocation using Taxiways ED and P7) Standard 2 (New Taxiway Parallel to ED)	Low Medium
DEN 7/25	Standard 1 (Traffic Reallocation using Taxiways G and P4) Standard 2 (New Taxiway Parallel to G)	Low Medium
ORD 4R/22L	Standard 2 (New Taxiway Parallel to V, Brown-Field)	Medium
ORD 10L/28R	Wild Card	High

DEN runway 17L/35R illustrates opportunities for two standard implementations: (1) reallocation of traffic flows and (2) construction of parallel taxiways (Fig. 13). First, reallocation of traffic flows is achievable by adjusting usage patterns of existing Taxiways ED and P7 for HOAs and LOAs respectively. This is constrained by the LOA queue length and remaining runway takeoff distance available. Second, construction of a parallel taxiway, in the green field north of Taxiway ED, is also achievable. The new taxiway becomes an LOA approach while existing Taxiway ED becomes the HOA approach. This is constrained by minimum taxiway separation under FAA AC 150/3500-13, and new LOA must maintain a 298 feet separation from Taxiway ED.

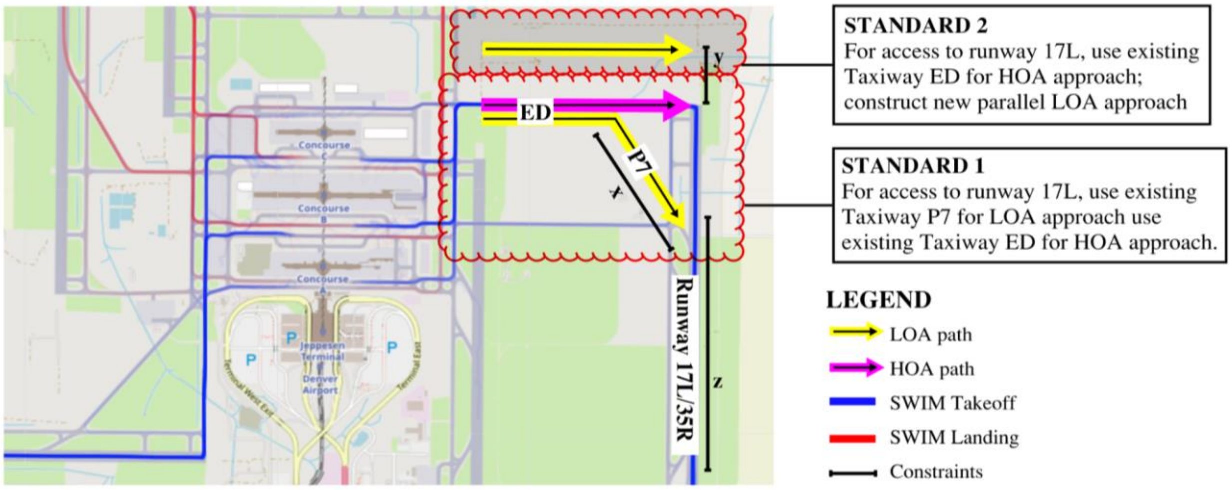

Fig. 13. DEN Constructability

ATL's runways exemplify potential for two standard implementations: (1) reallocation of traffic flows and (2) demolition and replacement with parallel taxiways (Fig. 14). On runway 9L/27R, reallocation of traffic flows is feasible because existing parallel departure Taxiways L and M can be modified for LOAs and HOAs respectively. This operation is constrained by the LOA queue length. On runway 8R/26L, partial demolition of taxiway E and branch replacement of 2 parallel taxiways for HOA and LOA approaches are viable. Taxiways E11 and E13 are designed to be removed. This implementation must accommodate maximum LOA queue length and minimum taxiway separations: 500 ft between the runway and the parallel taxiway, and 298 feet between two parallel taxiways.

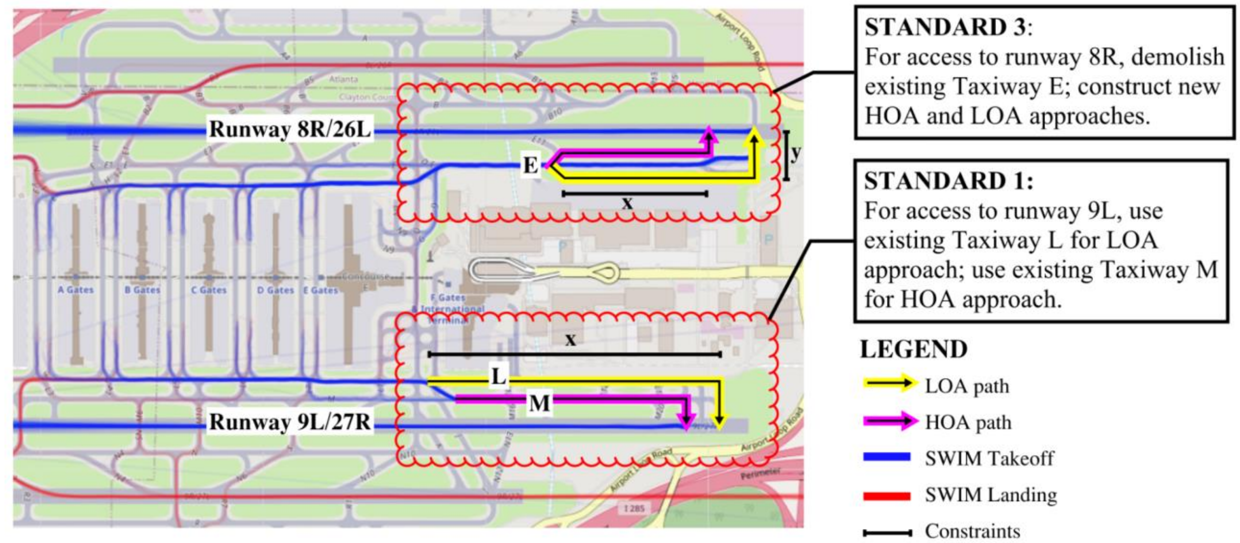

Fig. 14. ATL Constructability

ORD demonstrates potential for multiple standard implementations as proposed in Figure 15. Runway 4R/22L in the southeast region has sufficient space for construction of parallel taxiways. The new construction bypass on the existing Terminal 5 apron becomes HOA path while existing Taxiway V becomes LOA approach. This application is constrained by minimum taxiway separation. The complex configuration at ORD also warrants wildcard designs where all standard implementations are not feasible on Runways 10C/28C and 9C/27C. Primarily, the tight arrangement of approach Taxiway N, between the Terminal Apron area and runway, are limiting constraints. Thus, this report proposes construction of a new taxiway, around Runway 10L/28R clearway, for arrivals from runway 10C/28C for terminal access. Taxiways LL and GG are reallocated as HOA and LOA approaches. Alternatively, proposed management style suggests using the currently nonoperating runway 9C for exclusive HOA departures. Both wild card options require greater study or additional ATC staffing compared to standard implementation and customized to particular airport conditions.

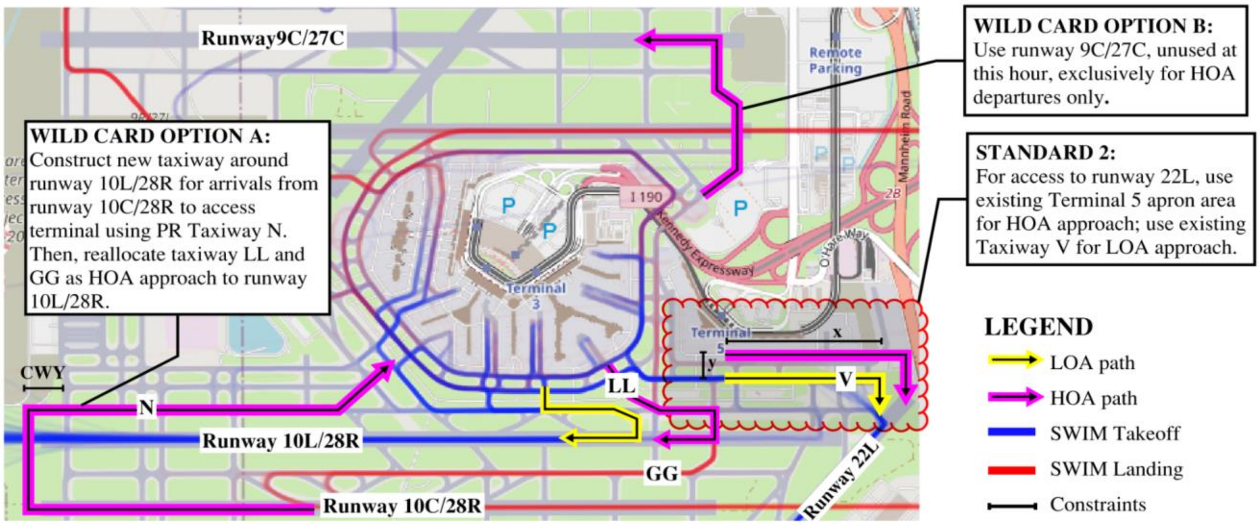

Fig. 15. ORD Constructability

4.5. Summary

Combining all the methods, this comparison reveals that DEN and ATL contain a greater delay and capacity improvement potential, and have a lower construction cost compared to ORD. Hence, they are more suitable for the implementation of the HOA priority regime. However, the presence of low-cost airline hubs may pose considerable opposition on the ground. The implications of these stakeholder relationships will be discussed in Section 6.

Table 8 Evaluating Overall Feasibility at DEN, ATL and ORD

Factor	DEN	ATL	ORD
Immediate Passenger Delay Reduction in Current Conditions	11.8%	7.5%	4.0%
Potential Passenger Throughput Increase with an Ideal Fleet Mix	12.1% from 7 - 10 AM	12.4% from 7 - 10 AM	10.0% from 7 - 10 AM
Design & Construction Costs	Low to Medium	Medium	Medium to High
Stakeholders Present	City of Denver United Airlines Southwest Airlines Frontier Airlines	City of Atlanta Delta Airlines Southwest Airlines Frontier Airlines	Chicago Dept of Aviation American Airlines United Airlines Spirit Airlines

5. Interaction with Airport Operators

Our team worked in close collaboration with a diverse group of experts from the airports, airlines, consulting firms, and the FAA Air Traffic Control. As UC Berkeley maintains close collaboration with SFO, our initial interaction was with employees from SFO. Phone calls, Zoom meetings and emails were crucial in providing our team with practical understanding of the operations revolving around HOV operations.

Christopher DiPrima, Airport Planner at SFO, believes that HOA priority would create some incentive to fly one larger aircraft per day versus two smaller aircraft per day, but this would be driven by connection bank activity for a hub airline. He thinks that the question of HOA operations is a great question but the key question would be an investigation of the regulatory framework under which airlines and airports would implement the HOA priority regime. As a result, we researched current practices and found out the arrangement between United Airlines and American Airlines that moved 37 flights out of peak hours to reduce congestion at ORD in 2004. Moreover, they replaced some narrow-body aircraft with wide-body aircraft to maintain market shares (48.8% and 40.5% respectively at the time). Such examples of transparent accords that benefited airports, airlines, and passengers resemble the outcome that the HOA priority regime seeks to achieve.

Thomas Cornell, Director, and Prakash Dikshit, Senior Managing Consultant at Landrum & Brown, a Global Aviation Planning & Development consulting firm, were intrigued by the HOA priority idea and think that the greatest benefit would be in emissions reductions as a result of taxiway delay reductions. In addition, they pointed out that this concept, under current regulations, would be suitable at large airports that experience high taxi delays (such as DEN), and airlines that operate wide-body, long-haul aircraft that don’t have enough reserve fuel.

Byron Thurber, Aviation Leader with expertise in airport design at ARUP, San Francisco office, commented that prioritizing higher occupancy aircraft would be logical, but highly political because of FAA ATC regulations that require airports and FAA to treat each operation the same, to “level the playing field” for commercial carriers. The FAA and airports are supposed to be unbiased. For example, this idea would penalize Southwest vs. United/American/Delta, because Southwest only flies B737s. The rule would encourage fleet up-gauging, which is generally preferable from an overall capacity standpoint, but affects different carriers differently. As a response, we analyzed various scenarios and discovered unexpected synergies where the HOA priority regime could also result in less delay for LOAs if airlines slightly modify their fleet mixes, due to the combined departure time savings from flight consolidation.

Frank Ketchum, a pilot at Delta Airlines, thinks that the envisioned HOA priority regime would be useful in reducing congestion, which would subsequently reduce fuel burn and emissions on taxiways. It is interesting to note that his major question was also related to regulations, which inspired us to further investigate pre-pandemic collaborative practices and agreements between airlines at busy airports. We summarize findings in sections 6.2 and 6.3.

6. Design Impact

This section will examine the costs and benefits of our proposal and the potential limitations, impacts on stakeholders, synergies, and divergences.

6.1. Cost-Benefit Analysis

The impact of a HOA priority regime is largely contingent on the existing conditions of flow and the feasibility of constructing additional taxiway infrastructure. Each airport’s geometry is unique and will require different amounts of research and capital investment to identify and realize potential improvements. For the purposes of this cost-benefit analysis, we will focus on the highest cost scenario where a taxiway must be designed and built.

Table 9 Cost A. Research and Development (Alpha)

Item	Rate	Quantity	Subtotal	Remarks
Labor: University Design Competition				
Student Efforts	$30/hr	560 hr	$19,600	5 Students

Table 10 Cost B. Research and Development (Beta)

Item	Rate	Quantity	Subtotal	Remarks
Labor: Academic R & D				
Student Efforts	$45/hr	30hr	$1,350	Faculty Advisor

Table 11 Cost C. Design, Construction, and Maintenance of HOA Taxiway

Item	Rate/Unit	Quantity	Subtotal	Remarks
Planning and Design				
Environmental Assessment	LSUM	1	$100,000	Assessment for 8000-ft taxiway
Design and Construction, FAA, Project Controls	LSUM	1	$3,200,000	Includes soft costs of estimating, scheduling, process fees
Capital Construction Costs: Materials, Equipment, Labor				
Construction Costs	$3,700/LF	8000 LF	$29,600,000	Priced for 8000-foot parallel approach taxiway
Contingency Fee	LSUM	1	$2,090,000	10% of Construction Contract
Maintenance				
Surface Rehabilitation			$3,500,000	1 resurfacing at 10 years
Subtotal			$11,850,000	

Note: Cost data referenced from Los Angeles World Airports, 2018

As shown in Tables 9-11, the total cost of implementing an HOA priority model with a taxiway addition would be approximately $38,510,950.

The benefits of the HOA priority regime include reduced passenger taxi-out delay, and increased landing fees for airports. They will be presented as an average of our three study airports and use the FAA-recommended values as adjusted using U.S. Bureau of Labor Statistics employment cost index, which puts the average value of a passenger's time at $39.74 per hour. These benefits, measured over a year, are tabulated below:

Table 12 Benefits of HOA Taxiway Implementation

Item	Airport	Quantity	Unit Benefit	Total Benefit	Average of 3
Reduced Passenger Taxi-Out Delay	ATL	8961.04 min/day	$0.6623/pax-min	$2,166,237 / yr	*Current Conditions:* $1,086,120 / yr *Utopia:* $2,645,110 / yr
	DEN	1948.33 min/day	$0.6623/pax-min	$470,988 / yr	
	ORD	2569.41 min/day	$0.6623/pax-min	$621,128 / yr	
Increased Landing Fees for Airports		$20,500 /day	$4.00/1000 lb average	$7,482,500 / yr	

Note: This was based on the following assumptions:

- HOAs, approximated by B777-300ER, weigh 251 tons
- LOAs, approximated by B737-800, weigh 65 tons
- In Utopia conditions, the total delay and hence average delay was reduced by the same proportion as capacity, based on the shape of a queueing diagram.
- Each HOA consolidated from 2 LOAs adds 121 tons-worth to airport revenue

Over the 20-year operational life of taxiway pavement, the total benefits are $214,817,060.

6.2. Impacts to and Synergies between Stakeholder Groups

As a new form of demand management which upends the previous norms of slot allocation and first-in-first-out queueing, the HOA Priority regime may face heightened resistance by some stakeholders. Most notably, the airlines may feel that HOA Priority overturns their business model. This resistance is similar to that of the first HOV lanes on highways by highway users. However, results of this study yielded convenient synergies between HOA prioritization and goals of airports and airlines.

First, the application of HOA taxiways can lead to emergent airport capacity in multiple aspects: expansion of the airport's flight range and subsequent business opportunities. Givoni & Rietveld (2006) document the arrangement between United Airlines and American Airlines that moved 37 flights out of peak hours to reduce congestion at ORD in 2004. Moreover, they replaced some narrow-body aircraft with wide-body aircraft to maintain market shares (48.8% and 40.5%

respectively at the time). Such examples of transparent accords that benefited airports, airlines, and passengers resemble the outcome that the HOA priority regime seeks to achieve. In negotiations over slot retention, perhaps a framework where airlines are guaranteed the usage of the freed slots from flight consolidation can benefit all stakeholders.

Second, functionality of proposed operations speculates incentivization to consolidate LOAs into HOAs. This synergy is revealed in simulated scenarios where no case of projected ideal fleet mix leads to HOA congestion, affecting service to destinations which are unable to accommodate HOAs by limiting LOA departures. When first implemented, and assuming a gradual adoption of a HOA-heavy fleet mix during peak hours, LOAs may experience slightly longer queue times at the offset, as documented in the results section 4.2. However, this can further incentivize their consolidation into HOAs and subsequent reduction of LOA queues, benefiting both HOA and LOA operations. Thus, an efficient allocation of aircraft would be achieved, with HOAs serving qualified airports and LOAs serving airports incapable of handling them due to runway length constraint or low demand, with global delay minimized.

The impacts to passenger and network movements on a whole should be positive, because although present day travel revolves around waiting, proposed HOV management is about moving. HOV style operations aim to increase efficiency on airfield departures to accommodate a greater number of users, increasing the on-time performance and predictability of flight operations. However, some passengers may suffer from increased schedule delay resulting from less flight choices as a result of flight consolidation, in exchange for decreased actual delay. This regime may also result in greater usage of a hub-and-spoke model during peak hours, and more direct flights during off-peak hours.

Although these synergies portray constructive outlooks, the limitations are the initial capital costs associated with rescheduling flights and changing fleet mixes before actual capacity increases are observed.

6.3. Divergences between Stakeholder Groups

The biggest obstacle to implementing the HOA priority regime would be that it goes against the traditional "grandfathered rule" which gives greater slot negotiating power to airlines with a historical presence at airports, most notably at hub airports. It is possible that in some extreme cases, services to regional airports which service smaller populations may be delayed further in favor of heavy aircraft which serve larger regions. While this might appear to be the case initially, the eventual desired consolidation of eligible flights on non-heavy aircraft onto heavy aircraft should reduce congestion and delay for all aircraft, including smaller aircraft, but the temporal nature of this subtlety may require monitoring during the transition period. This regime may also give the impression of being biased against some low-cost airlines, which have a business model of maintaining an exclusive narrow-body fleet for more efficient internal operations. This goes against the precedent that demand management programs should be impartial (de Neufville & Odoni, 2013, Chapter 12).

6.4. Safety and Risk Assessment

In this section we describe inherent risks in our proposed design and describe how these risks should be addressed to ensure safe operations.

Our proposed design consists of (1) an algorithm/computer model for determining airport airfield throughput based on historical data and determining if modification of the existing taxiway layout is required, and (2) potential modification of physical structures (taxiways). First, we look at risk assessment of our algorithmic design from the Safety Management System (SMS) Manual -- Safety Risk Management (SRM) process, and the FAA Advisory Circular 150/5200-37 Introduction to Safety Management Systems for Airport Operations Safety Risk Assessment (SRA) points of view. The SRM Process under the SMS Manual consists of the following steps:

A. Document proposed NAS changes regardless of their anticipated safety impact

B. Identify hazards associated with a proposed change

C. Assess and analyze the safety risk of identified hazards

D. Mitigate unacceptable safety risk and reduce the identified risks to the lowest possible level

E. Accept residual risks prior to change implementation

F. Implement the change and track hazards to resolution

G. Assess and monitor the effectiveness of the risk mitigation strategies throughout the life-cycle of the change

H. Reassess change based on the effectiveness of the mitigations

Similarly, the FAA Advisory Circular 150/5200-37 lists these steps as phases for Safety Risk Management:

Phase 1. Describe the system

Phase 2. Identify the hazards

Phase 3. Determine the risk

Phase 4. Assess and analyze the risk

Phase 5. Treat the risk
(i.e., mitigate, monitor and track)

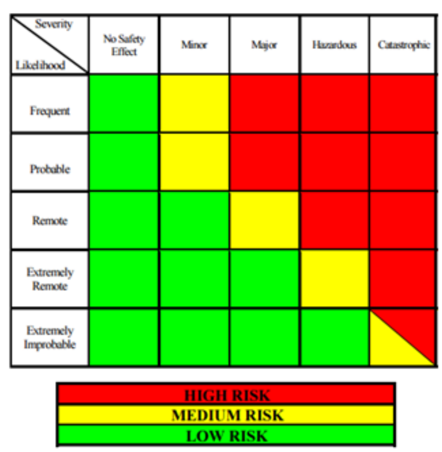

Fig. 16. The FAA Safety Risk Matrix

In addition, The FAA Safety Risk Matrix (FAA, 2007), as shown in Figure 16, was used as a guideline for identifying the level of risk imposed by our proposed design.

Results of the analysis model directly improve safety because segregating traffic over a taxiway system and reducing congestion and delays lead to less incidents and accidents on taxiways. The analysis model is a computer model, and therefore belongs to the software category. According to the SMS Safety Manual, "When a system includes software and/or hardware, the safety analyses consider possible design errors and the hazards they may create. Systematic design processes are an integral part of detecting and eliminating design errors." (p. 17). The other risk a software part of the Model might pose would be due to human error. The SMS manual states that "Human error is estimated to be the causal factor in 60 to 80 percent of aviation accidents" (p. 17). Because our analysis model should be an algorithm there should be no additional risk involved in human error. However, our design should require further safety analysis, since according to the SMS manual, "if the change is expected to introduce safety risk into the National Airspace System (NAS), there is need to conduct further safety analysis" (p. 23). Therefore, we must perform steps D through H in the SMS Manual SRM process to follow through Phase 5 in the FAA Advisory Circular 150/5200-37 SRM process. In summary, Figure 8 explains the design and construction feasibility workflow, indicating new taxiway design feasibilities. According to ATL, DEN and ORD case studies, and based on the FAA AC 150 document, locations of suggested new taxiways should inherently increase safety of operations as documented in section 4.4. Our proposal will improve safety and risk management in additional ways. The Model aims to decrease taxiing delays and field burn, which in turn can decrease the amount of harmful gases and CO_2 over the airfield. Being more efficient and contributing less greenhouse emissions makes the airport more sustainable overall. In accordance with the FAA Advisory Circular 150/5200-37 and the FAA Management System Manual, our proposal poses no new hazards. In an assessment of our proposal, it is clear that our proposal provides a safer way of utilizing a taxiway system.

6.5. Possible Limitations and Extensions

Although the proposed demand management model selectively prioritizes aircraft based on their passenger capacity, several modifications can be made to this model to achieve different desired results. Factors such as flight deviation from scheduled departure time, actual aircraft occupancy, number of transfer passengers, or fuel efficiency can be incorporated for a more dynamic priority model to achieve different immediate goals beyond congestion relief. To expand this analysis, further studies could also investigate traffic patterns under adverse conditions to determine additional subtleties about HOA-priority and other priority management models. Specifically, during recovery from bad weather events, prioritizing delayed departures could be further optimized through prioritizing flight restoration based on a number of the above factors.

7. Conclusion

Before the COVID-19 pandemic, an increasing number of airports across the world were reaching capacity and were running into difficulties expanding their airfields for new runways. Finding innovative ways to incentivize the use of HOAs is important to solve the “inefficient throughput problem” and allow airports to increase passenger throughput by allowing more passengers to use the same infrastructure at once. Our research shows that depending on the conditions of the airports, most notably fleet mix and actual time separations between aircraft, passenger delay reduction can be reduced by up to 12% and potential throughput could be increased by up to 13%. This increase in capacity is contingent on the airlines being successfully incentivized to change their schedules or fleet mixes to consolidate flights with 2 or more LOA operations within the peak 3 hours period into HOAs, which would lower the per-passenger delay by even higher numbers when implemented.

The many benefits of this regime would include not only a more efficient US air transportation system, but also open a new model and infrastructure by which the government or authorities can influence the industry to achieve strategic interests and objectives. Although air traffic levels have recently been depressed due to the ongoing COVID-19 pandemic, these conditions present a rare opportunity to rethink how air traffic is managed in preparation for the resumption of air travel in the years to come.

Appendix A: List of Complete Contact Information

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Appendix B: Description of the University

University of California, Berkeley is the world's number 1 public university in the Academic Ranking of World Universities for 2021. It serves as a home for higher education for 36,000 students, including 25,700 undergraduates and 10,300 graduate students. UC Berkeley holds 1,455 permanent faculties and 7,059 permanent staff serving among 14 colleges and schools with 130 academic departments and more than 100 research units. More than half of all UC Berkeley seniors have assisted faculty with research or creative projects and more UC Berkeley undergraduates go on to earn Ph.D.s than any other U.S. university. The Civil and Environmental Engineering department consistently ranks at the top of the best civil engineering programs in the country by U.S. News and World Report.

The Department of Civil and Environmental Engineering has fifty full-time faculty members and twenty-two staff dedicated to the education of more than 400 undergraduate students and 360 graduate students. The education in the department prepares students for leadership in the profession of civil and environmental engineering and sends approximately one-quarter of its undergraduates into graduate education. Our CEE laboratories for teaching and research are among the best in the nation, providing opportunities for hands-on experience for all students. There is no other location with comparable resources in the San Francisco Bay Area that can provide students with ground-breaking local civil and environmental engineering projects and participate in professional activities. UC Berkeley was chartered in 1868 as the first University of California in the multicampus UC system. The school houses a library system that contains more than 10 million volumes and is among the top 5 research libraries in North America. UC Berkeley's current faculty has 10 Nobel Laureates, 3 recipients of the A.M. Turing Award, 33 MacArthur Fellows, 369 Guggenheim Fellows, 4 Winners of the Pulitzer Prize, 251 Fellows of the American Academy of Arts and Sciences, 90 Members of the National Academy of Engineering, 144 Members of the National Academy of Sciences, and 49 Members of the American Philosophical Society. Just as important as academic excellence, UC Berkeley has held a respectable active history of public service. More than 7,000 UC Berkeley students every year do volunteer work in 240 service-oriented programs while there are more Peace Corps volunteers from UC Berkeley than from any other university. Clearly, UC Berkeley is not solely focused on academia as countless research and outreach initiatives focused on public benefits to the community, nation, and world.

Appendix C: Description of Non-University Partners

N/A

Appendix D: Sign-off Form

Airport Cooperative Research Program
University Design Competition for Addressing Airport Needs
Design Submission Form (Appendix D)

Note: This form should be included as Appendix D in the submitted PDF of the design package. The original with signatures must be sent along with the required print copy of the design.

University__University of California, Berkeley____

List other partnering universities if appropriate: ___N/A____

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Design Developed by: ☐ Individual Student ☒ Student Team

If individual student:

Name ____

Permanent Mailing Address ____

____

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Competition Design Challenge Addressed: ____Airport Management and Planning____________________

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I certify that I served as the Faculty Advisor for the work presented in this Design submission and that the work was done by the student participant(s).

Signed _______ ________________________________Date____April 14, 2021_

Name __Jasenka Rakas____

University/College __University of California, Berkeley____

Department(s) __Civil and Environmental Engineering ___________________________________

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Appendix E: Evaluation of Educational Experience

Students

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

The FAA Design Competition has been a rewarding learning experience for all of us. We bonded over our love of airports and aviation by discussing our home airports and ways we could improve them. Since we came from different parts of the country as well as the world, we were able to compare our international experiences as being tied together by the mode of aviation.FAA student competition gave us an opportunity to put our undergraduate class theories into practice to construct our study. Furthermore, it helped us create a network within our university as well as the aviation industry. We were able to use problem-solving skills when encountered with obstacles throughout the course of our study. This entire experience will help every single one of us in our future academic and professional endeavors.

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

One of the biggest challenges our team encountered was coming up with meaningful results from available resources. Our project and results were very data heavy and driven. Our case studies ranged across 3 different airports. Moreover, to obtain significant results we needed to study over 30 days worth of data. This data cleaning and processing was a big challenge for us due to sheer magnitude as well as time. We used Python primarily for our programming needs. Since most of us were only avid users of the language, we spent a lot of time researching the language in order to effectively apply algorithms to obtain our desired results. The data processing was split up amongst 3 of our members to make it more efficient. This also helped all of us improve our programming skills.

Additionally, this entire project took place during a global pandemic. Some of our members have never even had the opportunity to meet each other in person. Despite all circumstances, video-chats and screen-sharing made for effective meetings from any place, any time! We even got to receive input from professionals that otherwise would not be in a convenient location for us to access. All of these connections were made possible through Professor Rakas.

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

Our team was inspired by high-occupancy vehicle lanes on freeways and highways. We first chose the airports where we thought that our HOV-style priority queue would help alleviate the most delay. We did so by utilizing the choosing by advantages method. Once our airports were selected (ORD, ATL, DEN), we looked at the Aviation System Performance Metric (ASPM) data for each of the three airports to determine which three hour interval was the most congested. We also used the FAA's SWIM data set to provide geospatial data for each of our airports. SWIM data was used to find the average headway between each aircraft on each runway during these three hour time intervals. Departing aircraft at these airports were divided into four classes based on size. Using the given fleet mix, we calculated the impact to delay that giving the high occupancy aircraft (HOA) takeoff priority over the low occupancy aircraft (LOA) would produce. In another scenario, HOAs replace LOAs and the increase in throughput was calculated. The increase in passenger throughput was calculated using the headway and capacity difference between the LOA and HOA and taking into consideration the average capacity of the two types of aircrafts. Throughput increase was based on the possibility of combining flights between the same origin-destination pair so that a higher throughput could be achieved by utilizing less takeoff slots. Runway length, feasibility of separating HOAs from LOAs on a given airfield and constructability of new taxiways was also considered.

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

The participation by industry was definitely meaningful and useful in order to get input about our project in practice as well as for obtaining raw data. We had private entities from the industry contribute to our project by providing us with location and time specific data about airport departures for our 3 case studies. By receiving feedback and advice from aviation industry professionals and academics in transportation we were able to more specifically tackle the scope of our project. In addition, participation from academics and industry professionals allowed us to have a sense of confidence and inspiration for our research study. We greatly appreciate everyone that helped contribute in their own ways to our project.

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?

With part of our group entering the workforce at the conclusion of this project and the other half furthering their studies within engineering we were able to each have meaningful takeaways from the whole experience. In the realm of academia, we were able to formulate one of our first research papers in a group-research manner. Furthermore, it exposed us to the methods and structure of formulating a literature review prior to our graduate studies. For those of us entering the workforce, we were able to use analytical skills to study a problem we wanted to solve. Additionally, the FAA student competition allowed us to have exposure and networking opportunities during a pandemic that we would have not otherwise experienced this year. We learned much more about aviation and engineering problem-solving skills than we would have otherwise had in the classroom alone.

Faculty

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

My students gained tremendous educational value from this Competition. They went through the entire creative process of designing a model for the HOV Taxiway System from the initial stages to the end by designing a concept, applying it to three busy airports, and testing its feasibility. As some of the students are planning to attend various graduate programs, this educational experience was an ideal means for them to learn about how to start creating new concepts and new knowledge. Once they start their graduate programs, the experience gained while participating in this Competition submission process will help them make a smoother transition towards conducting more advanced research that is expected in any graduate program.

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

The learning experience was quite appropriate for the context in which the competition was undertaken. It tested the intellectual capability of the students at the right level, and offered challenging insight into practical, real-world problems. The research group consisted of four students who learned valuable lessons about how to efficiently cooperate, be organized, and designate tasks within a complex goal-oriented endeavor.

3. What challenges did the students face and overcome?

The students faced and successfully overcame many challenges. First, these are undergraduate students with no prior experience in conducting research. Furthermore, they came from a civil engineering background, and had little previous knowledge or understanding of aviation or airport systems. The student-team members never took any formal aviation classes. The Airport Design class was their only formal education in aviation. Hence, the beginning of the research process included a long learning process about how to conduct research and how to understand more advanced aviation concepts, such as the concept of taxiway operations, taxiway management, airside design issues and opportunities. Another challenge the students faced was the initial resistance of their proposed concept by some airport operators and industry experts, and the industry's initial "suspicion" about the proposed design, since the proposed method suggested airline-airport-ATC data collaboration. Whenever the experts commented on their design from a more tactical, today's operational perspective, the students very professionally and patiently would explain their paradigms and strategic goals. Consequently, their communication with the airport operators and industry experts was a very positive and productive enterprise.

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

I would definitely use this Competition as an educational vehicle in the future. In previous years I conducted a significant amount of undergraduate research through the UC Berkeley Undergraduate Research Opportunities (URO) program. This program was designed to assist undergraduate students in developing research skills early in their college education. On average, half of my students from the Airport Design Class would participate in aviation research projects in the following semester and would formally be funded and sponsored by URO. By using this Competition as an educational vehicle, I am not only continuing research with undergraduate students, but also teaching them how to structure, organize, and present their work to many experts in the field.

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

I would expand Challenge Areas by adding more emphasis on the Next Generation Air Transportation System (NextGen) requirements and expectations, as well as on aviation sustainability, climate change.

Appendix F: References

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