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POTENTIAL AIR TRAFFIC CONGESTION SOLUTION: SLOT ALLOCATION BY AUCTION METHOD

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ABSTRACT

The purpose of this design study is to design and evaluate, by way of an initial existence proof, the premise that slot allocation via an auction is a possible solution to the air traffic congestion problem surrounding high demand/capacity ratio airports. By demonstrating the existence of such a method for allocating slots at congested airports, this project would lead to further research in much greater detail in creating an overall system design of slot allocation that could be implemented. A successful implementation of a slot allocation system would generate capital for Air Transportation System Modernization and reduce delay into and out of the high traffic airports. This in turn is directly correlated to an increase in safety due to a decrease in the number of safe separation conditions that currently occur.

To demonstrate potential existence the project is broken down into three primary parts. Several sets of auction rules are used to simulate potential fleet assignment to the airports included within the slot allocation system. Various sets of auction rules are then used as input parameters to generate multiple schedules. Once the schedule is determined a network delay simulation is run to measure delay and demand met by that particular schedule. Finally, the data collected from the simulation runs is analyzed and the results indicates that an auction is a feasible method of allocation for airport time slots for commercial airlines.

1 INTRODUCTION

1.1 BACKGROUND

With over 2500 public and private airports, 50 commercial Airlines, business, general, freight, and military aviation demand, eight million departures, six-hundred million passengers a year, and an estimated growth rate of 3.6 percent a year, the National Airspace System, (NAS), serves a major public interest and significantly contributes to the economy. With 60 of these airports representing over 90 percent of the traffic, the NAS is a finite resource in terms of the aircraft that it can support at any one time. Title 41, U.S. Code tasks the Federal Aviation Administration, (FAA) with the safe and efficient use of said airspace over which the United States Government has exclusive sovereignty. Currently, commercial airlines are able to schedule flights from any location to any other location provided there is infrastructure in place to support the aircraft. Also, limited restrictions exist to prevent or dissuade the airlines using commercial airports to schedule flights beyond the safe separation standards. The airlines ability to over schedule flight operations is a major cause of flight delay, and research demonstrates that a correlation exist between an increase in delay and an increase in the number of safe separation and dual runway occupancy violations (Haynie). Figure 1 illustrates two separate days when the actual operations exceeded the capacity at LaGuardia Airport in November 2001.

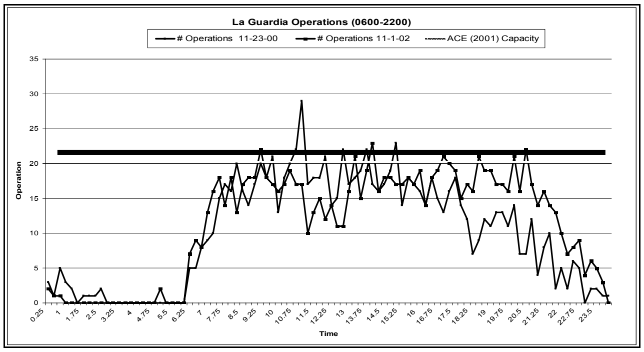

Figure 1 : Operations versus time at LaGuardia Airport, 2001 and the demand exceeding capacity. [http://www.apo.data.faa.gov/]

Flight delay also negatively contributes to the economy. Another negative contributor of the NAS to the economy is the existence of air carrier dominated airports. These are airports with a Hirschman-Herfindahl Index,(HHI), of 1800, which the Department of Justice uses to measure the competition within a market place. It is the sum of the market share squared ranging between 100 and 10000. In a market place with an index over 1800, the market begins to demonstrate a lack of competition. These airports demonstrate a lack of sufficient competition among the airlines allowing the dominating airlines to utilize finite resources inefficiently. This lack of competition is also compounded by the profit margins associated with an airlines operating smaller regional jets being larger than those of larger jets due to crew salary differences.

Efficiency is the measure of the potential number of persons that may be transported from one airport to another airport via commercial or small business aircraft per operation. Figure 2 illustrates the correlation between the decrease in market competition and the decrease in efficiency.

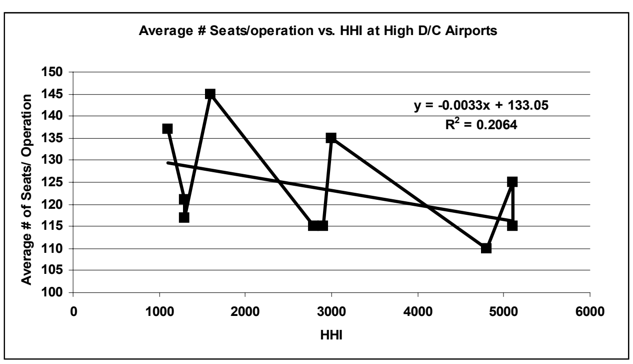

Figure 2 : Average # of seats/operation vs. HHI at High Demand to Capacity Airports. [http://transtats.bts.gov]

As demand increases air traffic will continue to increase until a saturation point is reached. The top-level problems become the following: Firstly, how to deal with the growing demand for air travel in an environment with finite resources. Secondly, how to reduce delay and the inefficient use of these same finite resources. Thirdly, how to balance the ability of a company to perform its service with the FAA responsibility to manage the safe and efficient use of the NAS.

Three distinct problems emerge upon examination of the overall issue of reducing delay and efficient use of the national airspace system. Additional issues may be present but will not be covered here. The three distinct problems are movement of air traffic into and out of airports, in-route air traffic management, and the non-use of technology that would allow more aircraft to use the airspace without reduction in safety. The focus here will be on the problems involved in moving air traffic into and out of airports. It is important to that an integrated solution will involve interfaces between the system designed to reduce delay into and out of airports with the in-route and technology systems.

The current status of the national airspace system is that of an asynchronous network with varying demand and cost functions across all arcs in the network. This is the result of the airlines being allowed to over schedule flights at commercial airports and varying business plans. This leads to the inefficient use of the finite airspace resource and delays in the NAS. This can be described mathematically as a queuing problem associated with asynchronous networks. Therefore the root cause of these delay issues is the asynchronous nature of the network.

To solve the problems of delay and those created by the asynchronous nature of the network several immediate potential solutions present themselves: the creation of new infrastructure to increase the airport capacity, additional regulations to curtail over scheduling of arrival and departure operations, or to synchronize the network. The creation of new infrastructure would increase capacity but is limited in its potential effectiveness as some airports cannot expand due to land, monetary, time, political, and environmental constraints and this will be shown. Also, much of the planned infrastructure improvement is at airports that do not have the greatest need for it which will be discussed later. In the last two decades, only two hub airports have been built, Denver International in 1995 which cost more than $4 billion, and Dallas/Forth Worth in 1974. Although building new airports would increase the National Air System capacity significantly, the high cost of construction, the large acquisition and use of land and environmental impact of an airport make the solution very unlikely . Therefore another ways to improve the National Air System capacity have to be developed. For example, the construction or extension of new runways is another method being used to increase an airport's capacity. One of the drawbacks of this solution is that the construction time of a runway is at least ten years.

Another method that is being implemented to increase the capacity of the National Air Space is the conversion of military airfields into civilian airports called the Military Airport Program (MAP). Many of these airfields are located near congested metropolitan areas and have the potential to provide capacity gains with relatively small investments by state and local governments. Although they are located near big cities, they are not located near the airports that need it the most such as Los Angeles or La Guardia.

Further regulation are also infeasible as a potential solution in this instance because the FAA does not have direct control over specific airports. The absolute synchronization of the airspace is unnecessary because 60 of over the of the 2500 airports represent more than 90 percent of the traffic in the system, and only a portion of these 60 airports demonstrate significant delay.

A partial synchronization of the air traffic at these airports exhibiting the worst behavior in terms of delay represents a realistic and potentially feasible solution. The network will experience little or no benefit if the airports included are not relevant to the delay problem. Utilizing queuing theory mathematics, the demand to capacity ratio, (D/C), of .65 will be the threshold for airport inclusion in this investigation. These airports are as follows: Atlanta Hartsfield International, (ATL), Newark, (EWR), Las Vegas, (LAS), Los Angeles, (LAX), LaGuardia, (LGA), Minneapolis, (MSP), Chicago O-Hare, (ORD), Phoenix, (PHX), Seattle, (SEA), and St. Louis, (STL). These airports also represent 10 of the 25 busiest airports in regards to operations and passengers serviced each year. Table 1 list these 10 airports with their D/C ratio, FAA defined hourly capacity under Visual Flight Rules (VFR), HHI index, and their percentage of commercial operations at each airport.

Table 1 : 10 Airports included in partially synchronous network. Historical data from weekdays, August 2001 between 0700 and 1900. [http://transtats.bts.gov] [http://www.apo.data.faa.gov/]

Airport Code	D/C	Capacity (VFR)	HHI	% Commercial
ATL	0.69	200	5100	96%
EWR	0.66	108	2800	70%
LAS	0.69	85	1600	86%
LAX	0.8	150	1100	81%
LGA	0.78	81	1300	75%
MSP	0.69	120	5100	69%
ORD	0.76	202	2900	83%
PHX	0.74	110	3000	78%
SEA	0.72	91	1300	61%
STL	0.72	112	4800	73%

1.2 PROBLEM STATEMENT

The primary focus is on the partial synchronization of the air traffic network via the inclusion of specific airports relevant to the delay problem and strategic allocation of slots for operations at these airports. The term "slot" means a reservation for an instrument flight rule takeoff or landing by an air carrier of an aircraft in air transportation and commercial airlines will require a slot to perform an operation at an included airport. Due to the small percentage of operations other aviation demand represents and to ensure their continued access to these airports, a proportional number of slots will not be allocated to the commercial airlines. This other demand will continue to utilize the current paradigm. Also, due to weather, economic changes, and evolving business plans, a need for a secondary market exist for the tactical reallocation of these slots. This investigation only focuses on the initial strategic allocation of slots. In order to accomplish this the FAA must possess some form of property right and authority in controlling air traffic at these included airports. While airports are usually owned by local regional governments, The United States government has exclusive sovereignty of the airspace of the United States.

Departure and arrival operations involved in the air traffic problem will be examined. The current principal problem is that over scheduling into and out of commercial airports creates significant delays and these delays are then propagated throughout the entire airspace system. The safety issue involved here is the violation of safe separation distance as set forth in current FAA regulations. These safety issues reside primarily at the aforementioned congested airports. This is primarily due to air traffic controllers trying to recover from delays induced by the over scheduling of air traffic into that specific airport. The primary issues at this level are to prevent delays due to over scheduling and to reduce the asynchronous effects upon the NAS. The implementation of a quasi-synchronous heuristic on the current airspace network will regulate congestion on inter-nodal arcs thereby reducing delays and thus improving the safety and economic implications upon the NAS. Therefore, an allocation of slots to the commercial airlines at these airports is required.

This assignment procedure could be by direct assignment by the FAA or DOT. This approach would contradict the intent of the deregulation of the airline industry, would not ensure efficient use of the resources, and would be inequitable. An equitable and potentially optimal approach, would be to auction the slots at each included airport as the method of assignment. The problem now is to determine what auction rules will provide the best method for assigning individual aircraft to specific slots to minimize delay.

Thus, the motivation of this research is to determine the feasibility of utilizing an auction for the allocation of scare public resources (slots) for the following purposes: Firstly, reduce delay and thus reduce the effects it has upon the safety of the NAS and the impact it has upon the economy. Secondly, investigate the effects of this allocation upon the competition within the market place. Thirdly, investigate the efficiency within the NAS this allocation process permits. Fourthly, balance the needs of the Airline Industry and the responsibilities of the FAA.

2 DESIGN

2.1 BASELINE

The baseline of this research was to simulate the current NAS as it is today and how it is to be in the future including the planned infrastructure improvements and potential capacity increases at the aforementioned 10 airports. This also served as the initial design alternative. Table 2 list the planned infrastructure improvement and the capacity enhancements through 2007. It is vital to notice that only 4 of the 10 high D/C ratio airports have any planned improvements: MSP, ATL, SEA, and STL.

Table 2 : New Runways and their capacity improvement [http://www1.faa.gov/programs/oep/htm]

Airport Code	Year Runway to Open	Increase in Capacty (VFR)
DTW	2001	25%
DEN	2003	18%
MIA	2003	10%
MCO	2003	23%
IAH	2003	35%
MSP	***2004***	***29%***
ATL	***2006***	***31%***
CVG	2005	26%
SEA	***2006***	***52%***
STL	***2006***	***14%***
IAD	2007	46%

2.2 AUCTION

Many verities of auctions exist; however, they all possess similar characteristics. First, they all determine a winner based upon established criteria. Second, they all have duration criteria. The Federal Communication Commission's Spectrum Auctions continue multiple rounds until all bidding ceases; while E-bay auctions have a fixed duration. Third, they all possess specific bidding protocols. An auction could have verbal bids where the participants know what everyone is bidding or an auction may have silent or sealed bidding. Depending on the purpose of the auction, the style of the auction will vary to ensure the auctioneer certain results. Usually, these desired results include maximize the revenue and products sold. However, this auction design must facilitate other objectives such as minimize the cost in money and time to participate for the airlines, reduce delay, meet passenger demand, and ensure competition with the market place.

The general proposed auction design for this allocation process is a simultaneous sealed-bid, multiple round design. This design will facilitate the auctioning off of numerous identical commodities while minimizing the possibility of collusion among the airlines. Also, this style of auction allows for evolving behavior. If an airline looses with one bid, said airline is able to either re-bid on same commodity or place a bid for a different commodity. Finally, a precedent exists with the FCC's Spectrum Auctions that illustrates the functionality of this style of auction by performing a similar task with the allocation of Band-Width Licenses. This auction will also continue until all bidding ceases. Time slots 15 minutes in duration were auctioned off between 0600 and 2200.

With this auction design, two specific auction rules were tested. The first rule was the minimum bid increment each round and the effects it has on the length of auction. The bid increment ranged from 5 percent to 20 percent with an increase of 5 percent. The second rule tested the percentage of slots auctioned at each airport based on the airports capacity and percentage of commercial operations to test its effect upon the resulting HHI, delay, and demand met. This range was between 70 percent and 100 percent of an airports capacity times the percentage of commercial operations with an increment of 10 percent. After each round, the high bids are the ones with the highest dollar value.

3 SIMULATION

3.1 OVERVIEW

Two separate simulations were built in C++ to test the feasibility of this new paradigm. First, an agent-based auction simulation was built to test the effects of bid increment and percentage of slots auction have on the length of the auction and the resulting HHI. The output of the agent-based auction simulation was a flight schedule. The second simulation as an 11 node network simulation built in C++. The 11 nodes consisted of the 10 high D/C ratio airports and an eleventh node, external, that represented the asynchronous part of the NAS. The purpose of the network simulation is to measure, in ordinal terms, the amount of demand that a particular flight schedule would meet and the delay in increments of fifteen minutes that would be incurred in the network. Only demand and delay will be measured because the demand accounts for the users of the system and the delay is directly correlated to safety. The probability of delay functions use a distribution constructed from historical data from the weekdays on August 2001 from the Bureau of Transportation Statistics. The values used to asses the nodal demand in the network was also acquired from the Bureau of Transportation Statistics for the same time period.

Finally, the auction simulation was also used to develop the baseline schedules based on the current demand in the system and the proposed future demand. This was also tested on the network simulation.

3.1.1 AUCTION

3.1.1.1 ASSUMPTIONS

The auction simulation was comprised of two separate entities. First, agents that placed bids, and second the auction. Each possible combination, 16 total, of the two rules being tested were ran in 30 auction simulations with each auction run being tested in the network simulation. The assumptions for the agents were significant in number, and here the most important ones will be mentioned.

- Each agent, 38 total, was based off of one of the airlines that operates at these 10 airports.
- Each agent tried to maintain its airlines current operational demand.
- Each of the agent's aircraft were available at any airport until it was assigned to a specific airport.
- Each aircraft type by airline had a calculated seating capacity, (SC), and load factor,(LF).
- Each agent had a calculated ticket price, (TP), between each city pair.
- Each flight had a potential revenue, (PR) based off of the following formula:

$$PR = SC * LF * TP$$

- Each agent had two thresholds that had to be checked before a bid was placed. If the potential bid would violate either threshold, no bid was placed.
- The first was an individual airport cost/revenue threshold. This was to simulate an airlines willingness to loose money in one specific market to either allow growth or maintain its dominating position. This was a calculated based on the following formula:

$$1 + \sqrt{(AirlineMarketShare - AverageMarketShare)^2 + AverageMarketShare^2}$$

- The second, was the overall cost/revenue threshold to represent a desired profit margin. Because each airlines desired business plan is not public knowledge, this was a uniform random number between .94 and .98.
- Each agent built a schedule with each slot having an equal probability for any one specific flight based in the number of flights between said city pair and the number of time slots (64).
- Each aircraft had a turn around time of one hour
- Once an initial schedule was built, the agent spent the remainder of the auction attempting to achieve that schedule.
- For every arrival won, an agent was guaranteed a departure, but it had to be scheduled.
- Departures took priority over arrivals
- Each agent searched the adjacent time slots to find the least expensive bid to place.
- If an agent was placing a new bid it had to be the current highest bid value plus the minimal bid increment.
- An agent could not retract a bid if winning.
- If an arrival was lost, the flight was rerouted through the external node.
- All input data was based off of August 2001 historical data.

3.1.1.2 METRICS

Both to validate our simulation and to measure the performance of the aforementioned auction rules, the following metrics were calculated and analyzed:

- Airline Cost – The sum of the airlines expenditures.
- Hirschman-Herfindahl Index – calculated as Sum of (Market share)^2. This number ranges between 100 and 10000. A market with a score above 1800 begins to lack sufficient competition.
- Total number of rounds.

3.1.1.3 ALGORITHIM

The auction simulation took many steps to read in historical data on each airline. The follow steps are taken by the auction simulation to initialize:

1. A 2x2 grid is created to prepare to receive bids. The grid encapsulates all of the top 10 demand/capacity delayed airports as well as an eleventh airport to represent the airport external to our system (the external node)
2. Airport specific data regarding the number of operations per slot, the airport abbreviation, the distances between airports (measured in fifteen minute slots), the time zone each airport is located in, the percentage of commercial operations, and the average ticket prices are read into the simulation and stored in tables for later retrieval.
3. Airline specific data regarding available fleet, specific city-pair ticket prices, and demand at each airport are read in and stored into tables for later use when creating a schedule. An airline can only place bids for planes he has available.
4. Fleet characteristics are read in for each airline about their specific plane types: number of a plane type available to a single airline, average

seat capacity, average load factor (how many seats on average are used), and their corresponding r-values (the number of flights taken in a day).

After initialization, using the input data, each airline:

5. Determined the bid order between city pairs – each city-pair is ranked based upon the airlines demand for flights between that city pair. This would be where the first bids are placed. It is assumed an airline would be more interested in acquiring flights between this city pair then another that is ranked lower. This order can be different for each airline.
6. For the initial round, each airline places bids, in the order determined by the previous step, at each airport until all demand has been met or no planes are available.
7. A schedule is printed off to be used as a baseline comparison.
8. Bids are ranked by value and airlines are notified about losing bids. For example, if a slot has a capacity of fifty operations and our auction limits the demand to capacity ratio to 100%, then the fifty highest bids are kept and all others are removed from the schedule.
9. Intermediate rounds ensue as airlines compete over slots and reschedule flights to adjacent slots. Lastly if neither can be done, flights are marked for rerouting.
10. After all bidding has been completed, either because all airlines have met their demand OR have reached their bidding thresholds, the remaining flights are rerouted to the external node. This represents the fact that airlines will probably not ground the airplane but schedule a new flight pattern.
11. A schedule is then printed in a format ready to be fed into our network simulation.

3.1.2 NETWORK DELAY SIMULATION

3.1.2.1 ASSUMPTIONS

The complexity of such a simulation requires that several assumptions need to be made.

- Due to the use of two simulations being used in combination, the assumption that the auction will handle certain issues and need not be accounted for in the network simulation will be made.
- The primary assumption in this area is that the auction generates a feasible potential flight schedule to be passed to the network simulation.
- The auction simulation must account for turnaround time and insure that each plane can make its next slot assignment.
- The network simulation will also assume that there is a system in place to handle such issues as the need for some planes to pass each other on the same flight path in order to make the assigned slot assignment at the destination airport. Making this assumption allows for the assumption that delay will not propagate through the network due to air traffic controllers being able to actively control slot jumping insuring airport capacity restrictions are not violated.
- Controlled slot jumping is used to make up for excessive ground delay incurred at an originating airport. The controller could speed up at least one aircraft in each slot prior to the slot that was originally assigned to the plane that will be excessively delayed. The controller can speed up one plane in each slot until a slot will be available for the delayed plane without exceeding the capacity of the destination airport. This way a different plane could use the delayed plane's slot so that no slots go unused.

There are also assumptions that need to be made for the internal operations of the network simulation.

- We assume that the airlines do not pad their flight schedule. Based on historical data, aircraft will be allowed to cut flight time by up to 20% to make an attempt to account for ground delay incurred.
- No flights will be cancelled.
- Only non-holiday weekdays are simulated to stay within the historical delay distributions.
- Maintenance, emergency, and weather conditions are accounted for by the use of historical data.
- Once aircraft are assigned to an airport they are not tracked individually.
- We are assuming a continuous clock (i.e. Friday goes into Monday).
- No general aviation will be included in the simulation; to account for general aviation, the capacity of each airport will be reduced by a certain percentage. This percentage of the whole will represent the entire commercial capacity.
- Only non stop flights will be simulated and all demand is assumed to be one way.
- Slots, delay, and flight times are all in blocks of 15 minutes (i.e. one unit equals 15 minutes).
- We are making the assumption, based on total load factor throughout the entire NAS

currently, that our load factor will have a mean of 0.66 and a standard deviation of 0.01.

- Finally, all aircraft types are considered to have equal probability for ground and in flight delay.

3.1.2.2 ALGORITHIM

1. The simulation reads in a flight schedule from the auction and assigns the planes to the proper airports.
2. The simulation of a flight includes the determination of whether or not the plane incurred and delay on the ground in which case the ground delay is attributed to the originating airport.
3. The flight time is then calculated and a corresponding operation is accounted for at the destination airport.
4. Flight delay is then calculated using the individual node to node delay distributions.
5. The flight delay that is incurred is attributed to the destination airport.
6. The amount of demand that was satisfied by the flight is then determined.
7. Finally, it is determined whether the airport is over capacity and a linear penalty function is called.

This sequence is repeated for all flights on the schedule at each airport for each time slot for a five day period. After all flights have been completed the output is generated.

3.1.2.3 METRICS

Ground delay - the delay incurred on the ground at an airport
In-flight delay - the amount of delay incurred in flight.
Average delay per operation. Takes into account the capacity of the airport.
Demand met –The number of passengers serviced versus historical demand

4 ANALYSIS

4.1 Objective Hierarchy Derivation

The following is the reasons for the subjective weights utilized in the utility function. These metrics were the outputs from the simulations.

- Auction Metrics (AM): .50
- Delay Metrics (DM): .50
- Reasoning: Both simulation metrics are equally important in the design of a slot allocation system.

- Auction Metrics—number of rounds (NR): .3
- Auction Metrics—airline expenditures (AE):.4
- Auction Metrics—HHI: .3
- Reasoning: One goal of this research was to minimize the airlines expenditures along with the number of rounds; however, figure 3 shows that a significant reduction in the number of rounds may be possible but this will not result in a significant reduction in the amount of airline expenditure. Therefore, airline expenditure is more important than the number of rounds with a weighting of .4. The HHI metric is also important, and figure 4 supports this by illustrating the correlation between a reduction in the percentage of slots auctioned and in increase in the HHI. This increase results in smaller airlines being unable to meet their respective demand. Thus, this metric is also important to ensuring the balance between the Airlines desire to conduct business and the FAA responsibility to ensure the safe and efficient use of the Airspace, thus it is also weighted at .3.

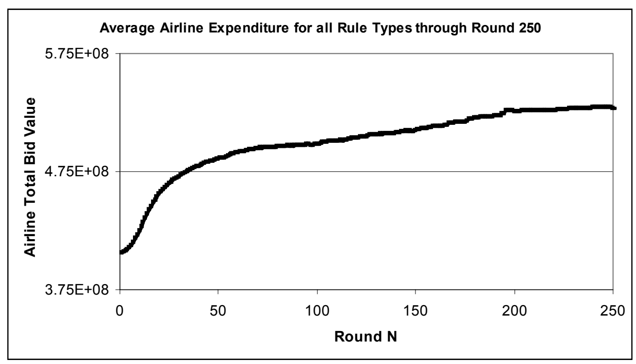

Figure 3 : Curve of airline expenditure versus round ‘n’ for all 16 rule combinations.

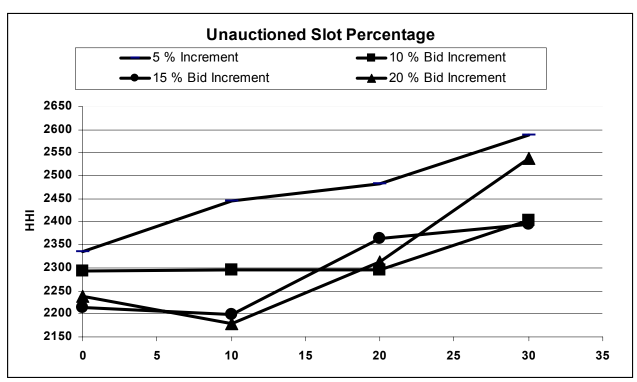

Figure 4 : Non-auctioned slot percentage versus HHI

- Delay Metrics—Delay (D): .7

- Delay—Ground Delay(GD): .4
- Delay—Flight Delay(FD):.3

- Delay—Delay per operation(DO):.3
- Delay Metrics—Demand Met (DNM): .3
- Reasoning: Because the network simulation did not account for the potential increase in the load factor due to fewer flights, the demand met was not as important as the delay within the network. Thus the delay metrics are weighted with a .7 while the demand met metrics are weighted with .3. Within the delay metrics, grounds delay represented the most important metric because an aircraft may make up time in the air, and airlines intentionally build in extra time into their schedules. Therefore the ground delay is weighted with a .4, flight delay is weighted with .3, and the delay per operation is weighted with a .3.

4.2 UTILITY FUNCTION

With the 16 different combinations of auction rules, the 30 auction runs for each set of rules, and the 100 network delay simulation runs of each set of auction rules, the compiled results were ranked according to the following utility function.

$$U = (.3NR + .4AE + .3HHI)*.5 + ((.4GD + .3FD + .3DO)*.7) + .3DNM)*.5$$

5 CONCLUSION

The best set of auction rules was when the bid increment was 20 percent and the percent of slots auctioned was 90 percent with a utility score of .77. The baseline based on historical data received a utility of .5. Also, figure 5 illustrates the projected growth in delay if the NAS airspace solely relies on infrastructure improvements and if the improvements are not made. This figure demonstrates that the NAS will approach a saturation point and congestion will continue to grow if the current paradigms do not evolve with the demand for growth in the system. This figure shows the results of the best set of auction rules average delay per operation of .39 and the baseline's delay per operation at .58.

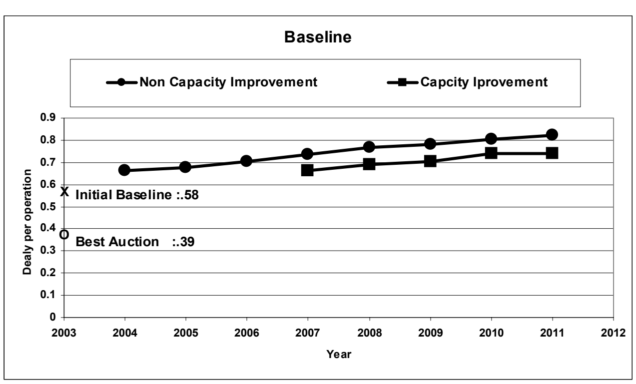

Figure 5 : Projected delay growth with and without capacity improvements after 2007.

Based upon the simulation results, it seems imperative that the NAS undergoes significant changes to ensure the viability of the service it provides to the public while ensuring their safety. Commercial airlines also will serve an important role in this change in paradigms. Some of these changes may be to move to larges aircraft that will be able to service more people per operation, and thus, allow the NAS to operate more efficiently. Also, airlines may determine that it is more profitable to reroute flights through underutilized airports such as Denver, (DEN), or Dallas Fort Worth, (DFW). Both of these airports have tremendous capacity and may handle additional operation to alleviate the burden on these other 10 high D/C ratio airports and thus also help balance the load across the NAS network. This may lead to less propagation in delay. Finally, based upon the results of this research, the FAA auctioning of time slots appears to be a feasible solution to the current congestion in the NAS and deserves further research. Through an auction, the FAA may be able to maintain the balance between an air carrier's desire to perform business and its responsibility for their maintaining of a safe and efficiently utilized airspace.

6 FUTURE

Based on the completed research, a tremendous amount of future research is required to better understand the complexity of the NAS congestion problem. This research may include the following areas: Simulation refinement, larger data sets to build distributions for demand between city pairs, the introduction of metrics such as the HHI per round within the auction, percent of airline demand met per round, the affects upon the balancing of the load upon the NAS network, the simulating of more airports to better represent the external node, and the introduction of agents that utilize linear or integer programming to create evolving decisions throughout the auction that best maximize their individual business plans. Other rules must also be thoroughly investigated. These rule types include the following: bid retraction, HHI thresholds, auction activity, and eligibility rules.

It is possible to create a linear program to determine what the optimal fleet of planes would be to minimize the general cost to the air carriers while meeting passenger demand within the capacity constraints of the current system. The general costs of each plane is considered to be the costs associated with mechanically operating a plane; these general costs may represent the time and cost of scheduled maintenance and the fuel that is required to fly the plane. These costs do not include any personnel costs such as the flight crews; these costs are omitted to avoid the issues introduced by different flight crew salaries due to unions and individual airline business models. If such an optimal fleet were found, the auction may be tailored in an effort to drive the resulting schedule towards this fleet.

Negative attributes of this new paradigm do exist, and the are relative to the stakeholder of the system. The larger air carriers may argue they can not afford to purchase slots or that they also have property rights at the airports that conflict with the property right of The United States Government. Also, this may be the catalyst that pushes the non-profitable airlines in to bankruptcy. Thus, the airlines that are able to make a profit may flourish with this new paradigm.

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