The Impact of Ground Delay Program (GDP) Rationing Rules on Passenger and Airline Equity

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Abstract— **The discrepancy between the demand for arrival slots at an airport and the available arrival slots on a given day is resolved by the Ground Delay Program (GDP). The current GDP rations the available arrival slots at the affected airport by scheduled arrival time of the flights with some adjustments to balance the equity between airlines. Current rationing rules do not take into account passenger flow efficiency in the rationing assignment tradeoff.**

This paper examines the tradeoff between flight delays and passenger delays as well as airline equity and passenger equity in GDP slot allocation. A GDP Rationing Rule Simulator (GDP-RRS) is developed to calculate efficiency and equity metrics for all stakeholders. A comparison of alternate GDP rationing rules identified that passenger delays can be significantly decreased with a slight increase in total flight delays. Compared to the traditional Ration-by-Schedule, Ration-by-Aircraft size (RBAc) decreased the total passenger delay by 10% with 0.4% increase in total flight delay, and Ration-by-Passengers (RBPax) decreased total passenger delay by 22% with only 1.1% increase in total flight delay. The disutility of implementing a GDP is minimized with Ration-by-Passengers (RBPax) when passengers as well as airlines are considered in the decision. The current scheme, Ration-by-Schedule (RBS), is preferred only when the system solely focus on airlines. The tradeoffs between airline and passenger equity, and the implications of these results are discussed.

I. INTRODUCTION

The purpose of the air transportation system is the cost-effective, rapid, safe transportation of passengers and cargo. In this way the air transportation system is a significant "engine" of the national economy and provides a service that cannot be achieved by other modes of transportation (Duke and Torres, 2005).

Passenger and cargo demand for air transportation has been growing steadily over the years and is forecast to grow at the same rate for several decades (FAA Forecast, 2007). The growth of air transportation capacity to meet this demand has been lagging (MITRE, 2007). Denver International (DEN), Dallas Fort Worth (DFW) and George Bush Intercontinental (IAH) airports are the only new airports opened in the last 40 years. The capacity of these airports is helpful, but does not solve the current congestion problems at the nation's busiest airports, such as Newark (EWR) or Chicago O'Hare (ORD). The most congested airports cannot expand due to land and/or environmental problems (Howe et.al. 2003). Further, the full capacity improvement benefits of Next Generation Air Transportation System are not expected to be operational before 2025.

This imbalance between demand for flights and available capacity is estimated to cost passengers $3 billion to $5 billion a year in trip delays (Robyn, 2007). Congestion related flight delays are estimated to cost the financially fragile U.S. airlines an estimated $7.7 billion in direct operating costs in 2006 (MITRE, 2007). These delays also have environmental and climate change implications as well as regional economic repercussions (Miller and Clarke, 2003).

In the presence of over-scheduled arrivals at airports, Traffic Flow Management (TFM) initiatives are used to resolve the daily demand-capacity imbalance. In particular, the Ground Delay Program (GDP) collaborates with the airlines to manage the scheduled arrival flow into airports consistent with the airport's arrival capacity. The current GDP rations the arrival slots according to the scheduled arrival time of the flights. This rationing scheme is adjusted to account for penalties suffered by long-distance (e.g. transcontinental) flights when arrival capacity increases (e.g. due to improving weather) and the GDP is cancelled. The rationing scheme is also adjusted to more equitably allocate arrival slots between airlines to ensure that one airline (e.g. with a hub operation) is not excessively penalized.

Previous research has examined alternative rationing schemes to: (i) maximize throughput while preserving equity amongst airlines (Hoffman, 2007), (ii) improve airline fairness (Vossen, 2002), and (iii) improve airline efficiency by trading departure and arrival slots (Hall, 1999, 2002).

This paper examines the impact of passenger flow efficiency during a GDP. Three alternate GDP rationing rules were applied to a GDP at Newark Airport. A comparison of the alternate GDP rationing rules identified that passenger delays can be significantly decreased with a slight increase in total flight delays. For example, compared to the traditional Ration-by-Schedule, Ration-by-Aircraft size (RBAc) decreased the total passenger delay by 10% and Ration-by-Passengers (RBPax) decreased total passenger delay by 22%. The tradeoffs in airline and passenger equity, and the implications of these results are discussed.

Section II provides an overview of the GDP's and previous

research on GDP rationing rules. Section III describes the GDP Rationing Rule Simulator (GDP-RRS). Section IV describes the results of a case study of the alternate rationing rules for a GDP at Newark airport. Section V discusses the implications of these results and future work.

II. BACKGROUND

A. Ground Delay Program (GDP)

The Ground Delay Program (GDP) is a mechanism to decrease the rate of incoming flights to an airport when the arrival demand for that airport is projected to exceed the capacity for a certain period of time. The motivation behind GDP is to convert the foreseen airborne delays into cheaper and safer ground delays (Ball and Lulli, 2004).

FAA first implemented GDPs in times of major-weather-related-capacity reductions at airports after the air traffic controllers strike in 1981 (Donohue, Shaver and Edwards, 2008). Since 1998, GDPs have been implemented under Collaborative Decision Making (CDM). CDM is a joint government-industry effort, which tries to achieve a safer and more efficient Air Traffic Management through better information exchange, collaboration, and common situational awareness. Air Traffic Control (ATC) specialists and CDM participating airlines use Flight Scheduled Monitor (FSM), developed by Metron Aviation Inc., to monitor and model TFM initiatives and evaluate alternative approaches. Fig.1 shows a visualization of a demand-capacity imbalance that warrants a GDP similar to charts available in FSM. In the figure, the airport capacity drops from 100 flights to 75 flights per hour between hours of 17:00 and 22:00. Thus, demand is in excess of capacity during this time period. When GDP is implemented, it brings the scheduled demand to match the airport capacity by delaying flights on the ground. Blue bars in Fig.2 shows the delayed flights, which spill into the hours after the GDP program.

If the ATC specialist decides a GDP is needed, there are three parameters to be set before issuing the program. The first parameter is GDP Start Time and GDP End Time. These are the start and the end times of the program, and they are determined by the scheduled demand and forecasted weather profile at the time of the GDP planning. If a flight is scheduled to arrive at the constraint airport between these times, it will be controlled by the GDP. The second parameter is the "scope" of the program. It specifies the flights departing from which origin airports will be controlled by the GDP. There are two types of scope: 1) Tier-scope identifies the airports included in the program by ATC centers. 2) Distance scope specifies a radius around the GDP airport and exempts any flights departing from origins outside the specified radius. The third parameter is the GDP Program Airport Acceptance Rate (PAAR). It depicts the number of aircraft that can safely land in an hour during GDP.

The overall GDP process under CDM can be summarized as follows: ATC specialists continuously monitor the demand and capacity of airports. When an imbalance between demand and capacity exists for any reason, they model GDP using FSM. If time allows, they send an advisory to all airlines
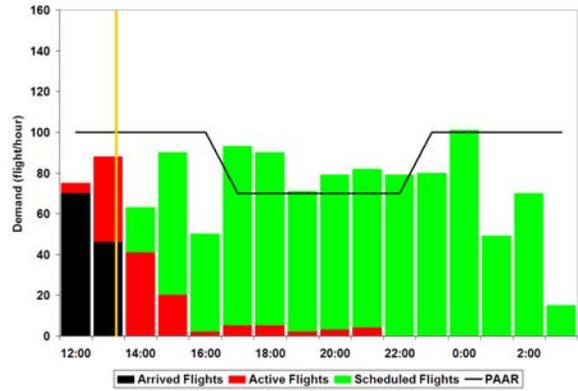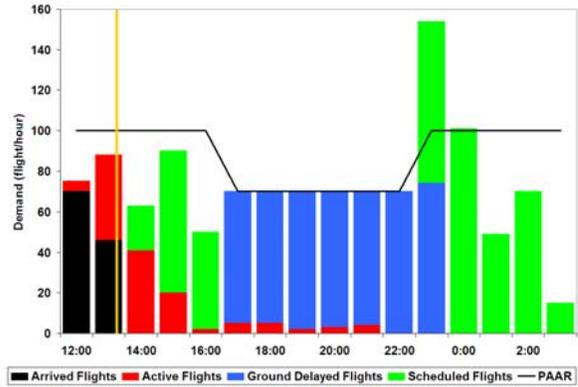

Figure 1: Demand Capacity before GDP (FSM View)

Figure 2: Demand Capacity after GDP (FSM View)

before implementing the program. Airlines check the impact of this proposed GDP on their operations and may opt to cancel some of their flights. Then, specialists reevaluate whether a GDP is still needed. If it is, they run a Ration-by-Schedule (RBS) algorithm and issue each flight its Controlled Time of Arrival (CTA) and Controlled Time of Departure (CTD). Once flight controlled times are received, airlines get a chance to respond by substitutions and cancellations. CTAs depict the arrival slots assigned to each airline, and these slots are now considered to be "owned" by that airline, and airlines can swap any two flights as it fits their business needs as long as both flights can depart by their new CTDs. Following the airline substitutions and cancellations, compression is run. Compression is an inter-airline slot swapping process that fills open slots that airlines are unable to fill through substitutions and cancellations. Compressions are now run automatically whenever an open slot is created. During the GDP, program parameters might need to be revised to account for changing conditions. GDP revisions may lead to further substitutions and cancellations, followed by compression. GDP ends when the GDP End Time is reached or the program is cancelled.

Arrival slots in a GDP are time intervals to achieve PAAR. If PAAR is set at 60 aircraft per hour, the airport can safely land 1 aircraft every minute; therefore, there will be 60 arrival slots to be allocated in an hour during GDP. These slots are uniformly spaced in an hour. The interpretation of an arrival

slot during GDPs is different than that of a "regular" arrival slot. International Air Transport Association (IATA) scheduling guidelines explicitly state that flight schedules planned at the biannual conferences for available airport slots has nothing to do with adjustments to these schedules on the day of operation for air traffic flow management, such as GDPs. The two types of slot allocation are quite different and unrelated (IATA, 2000). The slots owned by airlines under the High Density rule are often interpreted as "the right to schedule or advertise a flight at a specific time", which entails no explicit connection to a right on the day of operation (Vossen, 2002). Thus, allocation of arrival slots during GDPs can be based on different rationing rules than every day operations.

In a GDP, the available arrival slots are allocated on a "first-scheduled, first-served" basis. This allocation scheme is called "Ration-by-Schedule" (RBS). In other words, arrival slots are allocated based on the flight's original scheduled time of arrival as published in the Official Airline Guide (OAG) rather than reported departure time on the day of operation. When flights are cancelled or delayed, airlines retain their rights to these arrival slots and can assign flights to these slots based on their own business models. RBS algorithm creates three distinct queues; exempt flights are assigned to slots first, followed by previously GDP controlled flights, then non-exempt flights. A flight can be exempt because the flight is active when GDP is issued or the flight is departing from an origin outside the scope.
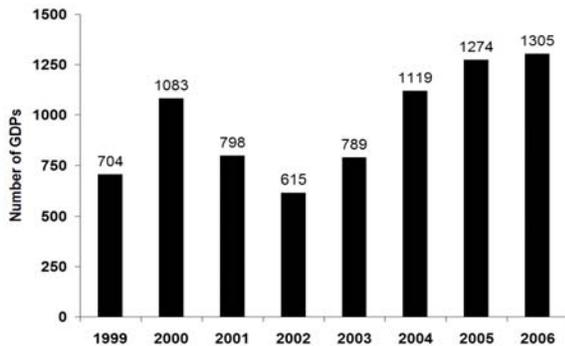
B. Trends in GDP Use

Figure 3: Total Number of GDPs by Year (1/1/1999-12/31/2006)

The use of GDPs has been growing over time as has the number of airports affected by GDPs. Fig.3 shows the growth in the number of GDPs per year as the growth in flight demand increased after 2001.

Fig.4 shows the number of GDPs implemented on a given day between 2000 and 2006. On any given day, there is an 86% probability that flights into at least one airport will experience a GDP. Note: the high number of GDPs per day (10 and above) were GDPs implemented to address airspace congestion due to rare national severe weather days. This use of the GDP is now obsolete and has been replaced by Airspace Flow Programs (AFP).
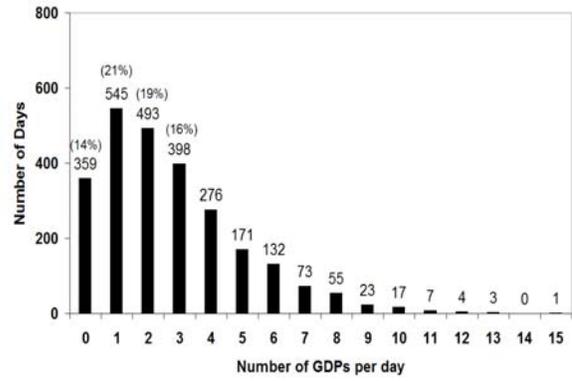
Figure 4: Histogram for Number of GDPs per Day (1/1/2000-12/31/2006)

C. Previous Research

Vossen (2002) examined different GDP rationing rules to achieve fairness among airlines. Fairness was interpreted as allocating delays equally among airlines. Several methods were used to decide how to distribute delays. The "Proportional Random Assignment (PRA)" scheme assigns an available slot to an airline with a probability that is proportional to the number of flights with earlier scheduled arrival times than the slot, following preset axioms. Results show that both RBS and PRA result in similar average airlines delays, even though their underlying philosophies are fundamentally different. PRA may introduce a substantial amount of variance in the assigned delays, which may not be acceptable by airlines. Vossen (2002) also examined methods to deal with achieving slot allocation fairness in the presence of flight cancellations, substitutions and GDP exemptions. These methods are alternatives to the compression where available slots are re-rationed whenever there is an open slot. The results indicate that Greedy Procedure (favors the airline with the earliest flight that can use the slot) and Compression result in very similar flight-slot assignments.

Hoffman (2007) developed a rationing scheme, known as "Ration-by-Distance (RBD)" to maximize airport arrival flight throughput while preserving equity among airlines under changing arrival capacity (due to improving weather). RBD puts flights in order of their distance from the GDP airport and gives preference to long-haul flights. Equity among airlines is total amount of delay assigned to each airline. Results show that if RBS assignment is assumed to have the "perfect" equity, then RBS with distance scope has perfect equity when the GDP is not cancelled, since RBS calculates the slots based on a GDP End Time. When a GDP is cancelled early, RBD significantly reduces delays. Both RBD delay and equity savings gets better when GDP is cancelled 3 or 4 hours early.

Hall (1999, 2002) examined "Arrival-Departure Capacity Allocation Method (ADCAM)". This rationing method allocates both arrival and departure capacity to airlines according to the published schedule. Airlines can then trade arrivals for departures. The results show that airlines achieved a greater objective value with ADCAM compared to RBS, because it allows airlines to have better connectivity without using more airport capacity. However, some airlines with a

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small number of operations can get penalized to a greater extent. Hall (1999, 2002) also examined "Objective-based Allocation Method (OBAM)". This method assigns arrival slots to GDP flights by maximizing the collective value produced by the airlines. It uses airline objective functions to assign slots, but airlines cannot represent combinatorial or stochastic objectives directly. The motivation behind OBAM is to prevent airlines from scheduling flights they don't intend to fly. In practice, OBAM requires airlines to pay fees for the slots they receive and these fees may be viewed by airlines as means to introduce new taxes.

Previous research has examined the impact of GDP rationing rules on only airline efficiency and equity. This research is directed toward examining the impact of GDP rules on passenger flow efficiency.

III. GDP RATIONING RULE SIMULATOR (GDP-RRS)

GDP Rationing Rule Simulator (GDP-RRS) developed by Center for Air Transportation Systems Research at George Mason University, investigates the impact of different GDP rationing rules on airlines, passengers, and airports. GDP-RRS calculates GDP efficiency and equity metrics that result from GDP planning for airlines, passengers and the GDP airport. Fig.5 shows three main components of the model.

First module inputs a flight schedule and airport capacity profile, and then determines whether a GDP is needed. This module captures the decision making process of an ATC specialist. If a GDP is needed, then the second module is activated.

"GDP Slot Assignment Module" assigns slots to flights that are scheduled to arrive at the GDP airport during the program. Fig.6 shows the pseudo algorithm with nine main steps. Steps 1-5 result in Planned CTDs and CTAs, which are sent to airlines for substitution and cancellations. Steps 6-7 show the simulated decision making for airlines in Airline Substitutions and Cancellations module. Steps 8-9 input airline updated CTDs and CTAs, and result in the main CTDs and CTAs that airlines are expected to comply with after the compression algorithm.

1. <u>Calculate Required Variables for Each Flight:</u> Scheduled Gate Time of Arrival and Scheduled Gate Time of Departure for each flight are inputs to the model. Scheduled runway times, which are used in the GDP slot assignment, are calculated from these inputs assuming 10 minute taxi times. Estimated Time Enroute (ETE) for each flight is the difference between Scheduled Runway Time of Arrival (SRTA) and Scheduled Runway Time of Departure (SRTD). "Available Seats" is the average yearly number of seats for a given aircraft type assigned to each flight (ETMS database). "PAX" is the number of passengers on-board and is calculated as Available Seats on a flight multiplied by its load factor. Load factor is the average yearly monthly load factor for a given airline from a given origin (BTS database). For international origins and airlines coming from unknown origins, the default load factor is 100%.

2. <u>Find Flights in GDP:</u> All flights going to the GDP airport are assigned control times. However, the delay as a
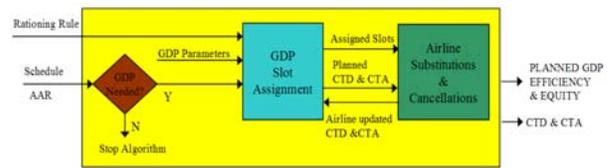

Figure 5: GDP Rationing Rule Simulator

result of the capacity reduction is only distributed among the flights that are controlled by the GDP. For a flight to be controlled, it needs to fulfill the below requirements:

   a. Flight's SRTA is between GDP Start and End Time.

   b. Flight is not originated from an international airport.

   c. Flight's departure airport is in GDP scope.

3. <u>Create Priority Queues:</u> Two priority queues are created for all flights scheduled to arrival at the airport between GDP Start and End Times. Exempt Flights queue has precedence over the remaining flights. Exempt Flights queue contains international flights and flights departing from airport outside the GDP scope.

4. <u>Create Slots:</u> The number of slots available for distribution depends on the PAAR. Airport capacity profile is an input to the model. Slot size is the time in minutes between two available slots. The number of slots created depends on the number of scheduled flights. Slot times are uniformly distanced based on Slot Size starting from GDP Start Time.

5. <u>Assign Slots to Flights:</u> The assignment of slots to flights is done by queue type. Exempt Flights are assigned their slots first based on an ordering of increasing SRTA. Then, non-exempt flights are assigned their slots based on an ordering depicted by the GDP rationing rule. For each flight, algorithm searches for the earliest slot which has the slot time equal to or later than the flight's SRTA. When such a slot is found, if the flight's SRTA is later than the slot time, the flight's CTA is the same as the slot time. If the flight's SRTA is between the chosen slot time and the next slot, then the flight's CTA is the same as its SRTA. CTD is back-calculated using CTA and ETE for the flight. These CTAs and CTDs are sent to Airline Substitutions and Cancellations Module.

6. <u>Cancel Flights:</u> Each flight is cancelled randomly based on a probability distribution for a given airline from a given origin airport in the year that GDP is implemented.

7. <u>Substitute Flights:</u> Substitution for an airline is only possible if that airline has cancelled a flight. If there is a cancellation, the slot opened can be used by a flight from the same airline if the new flights CTA is later than the open slot time or the flight can arrive at the new assigned slot. If such a substitution is made, the flight's CTA and CTD are recalculated and its previous slot is open for another possible substitution. Substitution algorithm stops when there is no further substitutions can be made. Substitution algorithm uses two different strategies to simulate airline behavior. Strategy 1 orders an airline's all flights by increasing SRTA and gives earlier scheduled flights precedence for substitution. This strategy minimizes an airlines overall GDP flight delay. Strategy 2 orders an airline's flights by decreasing PAX and

gives precedence to flights carrying more passengers. This strategy results in less overall GDP passenger delays. At the end of this step, passenger delays are calculated as well as flight delays. It is assumed that a cancelled flights passengers will be transferred to another flight from the same origin. However, due to high load factors, some passengers may not be accommodated. It is assumed that these passengers will leave the airport the next day at 6am.

8. <u>Run Compression:</u> Compression tries to fill in the unused slots after airline substitutions and cancellations. All slots are sorted in order of their slot times. If an unassigned slot is found, algorithm checks if the delay of any non-cancelled flight can be reduced by assigning the flight to this slot instead. First, flights from CDM member airlines are considered in the order of their ranking due to the chosen GDP rationing rule, followed by the remaining flights. Assignment is done only if the flight can make it to its new assigned slot. If such a flight is found, flight's CTA and CTD are recalculated. If no such flight is found, then slot remains unassigned. Algorithm stops when all unassigned slots are checked.

9. <u>Issue CTA and CTD:</u> The last step in the algorithm is to validate the slot assignments before CTDs and CTAs are issued. Algorithm checks if each flight is assigned to only one slot, if each slot is assigned to only one flight, and if each flight's SRTA is equal to greater than assigned slot time. If there is a problem, algorithm goes back to Step-5. If not, Planned GDP efficiency and equity metrics are calculated.

Steps 1-5 and Steps 8-9 are simplified versions of the current GDP algorithm. Differences between GDP-RRS and the current GDP algorithm are shown in italics in Fig.6. These additions are required to simulate new GDP rationing rules and calculate passenger-based metrics. Current GDP algorithm only runs Ration-by-Schedule (RBS) scheme, and only calculates flight-based metrics.

IV. RESULTS

To examine the impact of passenger flow efficiency and airline equity in a GDP, three alternate rationing rules are examined.

1. <u>Ration-by Schedule (RBS)</u> allocates available slots among GDP flights in the order of their scheduled arrival times. The earlier flights are given precedence over later flights. If there are two flights scheduled to arrive at the same time, one of them is randomly selected to be the first for slot assignment.

2. <u>Ration-by-Aircraft Size (RBAc)</u> rations available slots by aircraft size. RBAc creates three priority queues for three categories of aircraft size considered: Heavy, Large and Small. Flights under Heavy category are assigned their slots first, followed by Large and Small categories. 23% of the flights in the study fall under Heavy, 77% in Large, 1% in Small category. Heavy, Large, and Small category flights are re-ordered by their scheduled arrival times in a given category. Thus, if there are two flights in the same category (Heavy-Heavy), RBAc chooses the flight with the earlier scheduled arrival time for slot assignment first. If two flights are in the same category and are scheduled to arrive at the same time, one of them is picked randomly to be the first for the slot assignment.
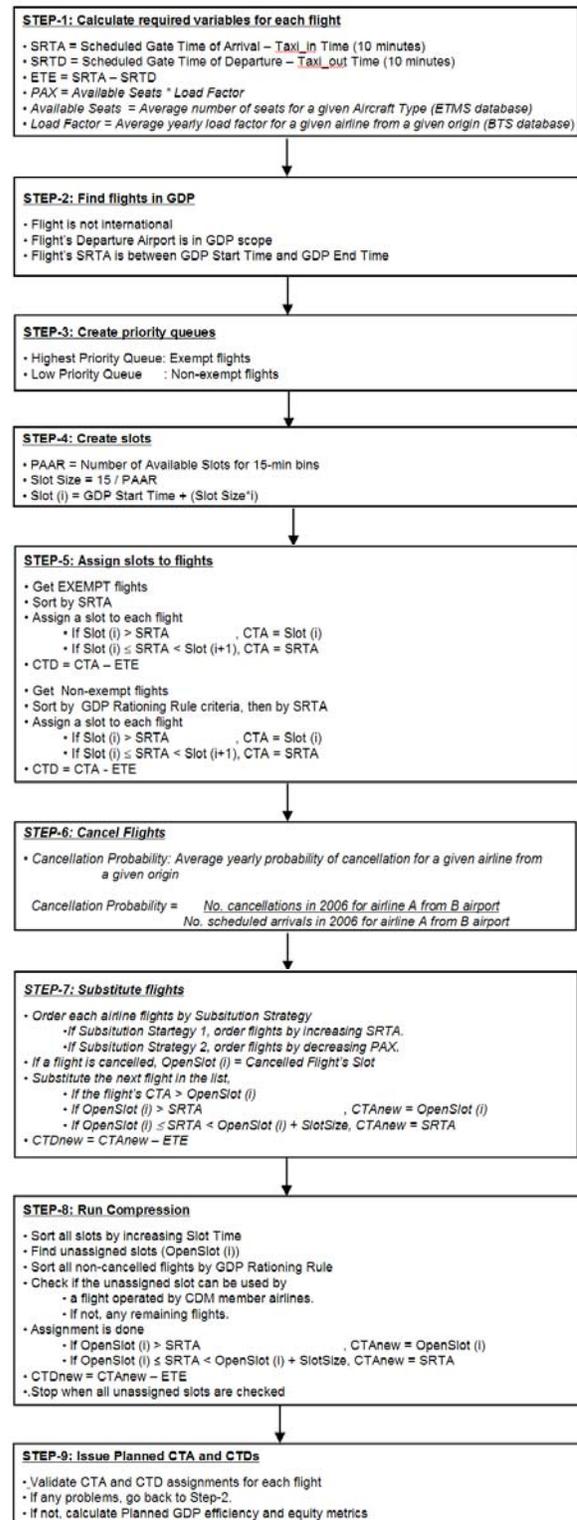

Figure 6: GDP Slot Assignment Module Pseudo Algorithm

3. Ration-by-Passengers (RBPax) rations available slots by the number of passengers carried on each flight. RBPax algorithm puts flights in the order of passengers on board. Flights carrying more passengers are given precedence over flights carrying fewer passengers. If there are two flights scheduled to arrive at the same time carrying the same number of passengers, RBPax chooses the flight with the earlier scheduled arrival time for slot assignment first. If two flights are in the same category and are scheduled to arrive at the same time, then one of them is chosen randomly to be the first for slot assignment.

Substitution strategy 1 is used in this case study.

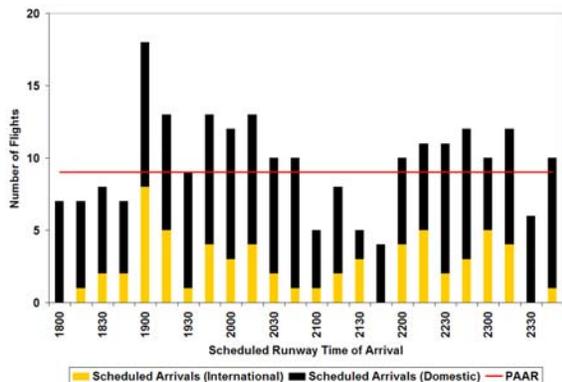*Case Study GDP at Newark Liberty Airport*

Figure 7: Flight List before GDP is Implemented

A GDP is implemented at EWR on June 10th, 2006 starting at 18:00 and ending at 23:59 GMT time. Fig.7 shows the scheduled flights arriving at EWR during this time before any cancellations or substitutions. Projected Airport Arrival Rate (PAAR), the red line, is set at 9 flights per 15 minutes. This PAAR value falls in the historic range for EWR GDPs. Scope is chosen as all domestic airports (Tier scope: All) with international flights being exempt. Yellow bars in Fig.7 represent the exempt flights.

There are 231 flights between GDP Start and End Time, 63 of which are international. GDP delay is split among 168 domestic flights. There are 26 major airlines coming from 109 different origins carrying 25,501 passengers (11,516 international and 13,985 domestic passengers). Among these origin airports, the most number of scheduled flights are from Chicago (ORD: 7), Atlanta (ATL: 6), Los Angeles (LAX: 6), and Boston (BOS: 6). It is interesting to see departure airports in 100 nautical miles radius from EWR (LGA, FRG, and BDL). Even though the number of passengers on these flights is not very large, the flight categories can be different. For example, the flight from La Guardia (LGA) is a "Small" carrying 8 passengers, whereas the flight from Windsor Locks, CT (BDL) carrying 32 passengers is a "Large". There are 15 cancellations, and the cancelled flights are kept the same in all three rationing rule simulations.

The results of the case study are summarized in Fig.8. All three rationing rules result in different trade-offs for the system. Both RBPax (blue) and RBAc (red) trades off more

flight delays with less passenger delays compared to the current rationing rule (RBS). Compared to RBS, RBAc (red) decreases total passenger delay by **10%** (67,288 minutes less delay) with a 0.4% increase in total flight delay (12 minutes). The biggest improvement in efficiency is achieved by using RBPax. Moving to RBPax from RBS decreases total passenger delay by **22%** (144,407 minutes less delay) with only 1.1% increase in total flight delay (31 minutes).
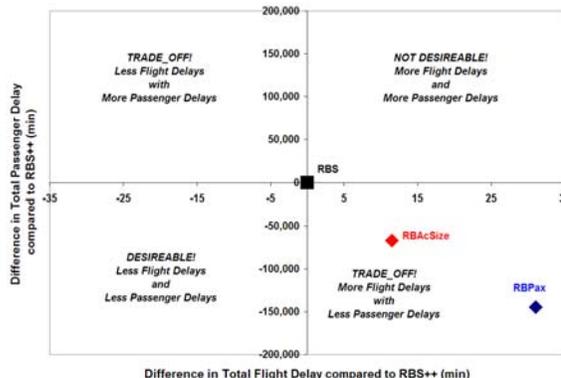

Figure 8: GDP Efficiency Comparison between RBS, RBPax and RBAc

Since all GDP rationing rules result in a trade-off, a decision can be reached using utility theory. Disutility of implementing a GDP can be calculated using different weights for two efficiency metrics calculated; Total flight delay and total passenger delay as a result of a chosen rationing rule. Below is the disutility calculation for RBS as an example:

$$Disutility_{RBS} = w_{TFD} * \left[\frac{TFD_{RBS}}{TFD_{RBS}+TFD_{RBAc}+TFD_{RBPax}} \right]$$
$$+ (1- w_{TFD}) * \left[\frac{TPD_{RBS}}{TPD_{RBS}+TPD_{RBAc}+TPD_{RBPax}} \right]$$

w_{TFD} : Weight of Total Flight Delay
$(1-w_{TFD})$: Weight of Total Passenger Delay
TFD_{RBS} : Total Flight Delay as a result of RBS
TFD_{RBS} : Total Passenger Delay as a result of RBS

Fig.9 shows the disutility calculated for EWR case study using different weights. As the weight of the total flight delay gets larger, the system focus moves further away from passengers to airlines and flights. Fig.9 shows that current rationing rule (RBS) is acceptable only when the system solely focus on flights. However, when the passengers are considered, RBPax gives the minimum system disutility, followed by RBAc.

Total flight and passenger delay values are important metrics. However, they don't imply any information about the fairness of the delay distribution. Equity becomes an issue whenever goods, in this case available arrival slots, which are held in common by a group of users, airlines, must be allotted to them individually (Young, 1994). In the case of GDPs, equity means distributing fairly among all involved stockholders. Airline Equity by Flights (Fig.10) and Passenger Equity by Distance (Fig.11) captures this from the view point of airlines and passengers.
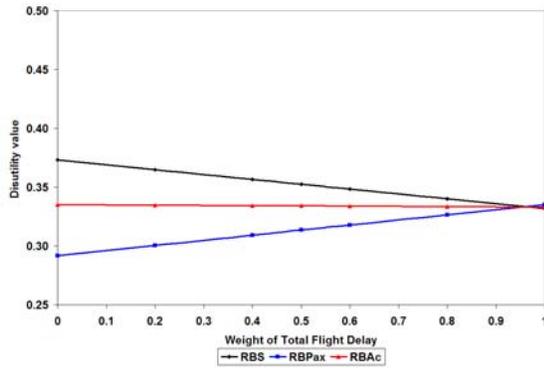
Figure 9: Disutility of GDP for RBS, RBPax and RBAc

From airlines' perspective, the more flights an airline has the more delay it should be assigned. Airline Equity by Flights is calculated as the ratio of an airline's flight delays over the total GDP flight delay divided by the ratio of that airline's flights in the GDP over all GDP flights. "Perfect equity" is represented as 1. If an airline's equity is smaller than 1, the airline is given less delays than is fair. Conversely, if an airline's equity is greater than 1, than the airline is given more delays than its fair share. Fig.10 shows the equity for airlines in the GDP. Airlines which have only international flights are omitted in this figure, since all their fights will be exempt. For each airline, the number of flights in GDP is also given in parenthesis.
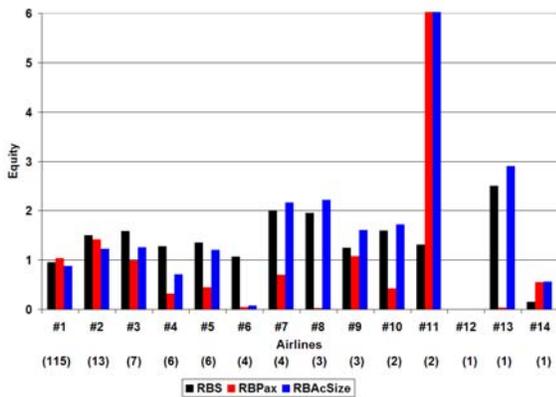

Figure 10: Airline Equity by Flights under RBS, RBPax and RBAc

As expected, the results are different for different airlines. For Airline 1, the dominant carrier, the three rationing rules do not make much difference in its overall delays. However, for Airline 2, the main competitor, the equity does not reach 1 but it moves in the right direction with new rationing rules. All airlines have less delay with RBPax, except for airlines 2 and 11. Airline 11 has two flights, one from Cleveland (CLE) and one from Long Island (FRG). FRG flight is assigned the same slot in all rationing rules and is cancelled later on. CLE flight is a general aviation flight carrying only 6 passengers, scheduled at 19:05. As seen from Fig.7, this is a very busy period for EWR, and RBPax assigned this flight a delay of 306 minutes. Since there are only 2 "small" category flights, RBAc also assigned a very high delay. On the other hand,

Airline 7 enjoys RBPax whereas RBS and RBAc results in the same unfair equity level. It has 4 flights, 3 of which are from DTW. All four flights are "large", carrying 71-95 passengers. RBS gives these flights higher delays than RBPax because they are scheduled at the busy times of EWR. RBAc also gave high delays because all flights are "large". Since 77% of all flights are large, the RBAc delay assignment is very close to RBS. However, RBPax further distinguishes flights with the number of passengers on board and assigned less delay to these flights. *(Note: Equity metrics are calculated over a long-term. For the purposes of this case study, only one day of data is used.)*
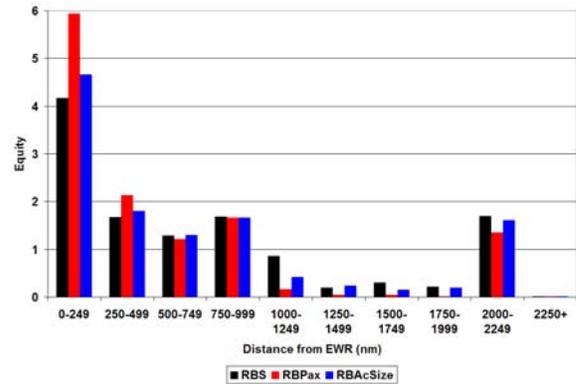

Figure 11: Passenger Equity by Distance under RBS, RBPax and RBAc

From passengers' perspective, the passenger delay they encounter is important rather than the flight delay itself. Flight-based metrics cannot accurately reflect passenger travel experience (Wang, 2007). Flight cancellations reduce total flight delay while increasing total passenger delays, especially when the load factors are high. Passenger Equity by Distance (Fig.11) compares how much passenger delay is assigned to passengers flying from a distance group compared to the total number of passengers in the GDP. In other words, the more passengers a distance group has, the more passenger delay it will be assigned. Passenger Equity by Distance is calculated as the ratio of passenger delays for a given distance group over the total GDP passenger delay divided by the ratio of the number of passengers from that distance group over all passengers encountering the GDP. "Perfect equity" is again represented as 1. Fig.11 shows that the long-haul passengers are encountering much less delays than short-haul passengers in all three rationing rules. This is due to the fact that longer-haul flights are scheduled less frequently with larger aircraft having more seats, whereas short-haul flights are scheduled more frequently with smaller aircraft. The higher load factors (100% for international flights) also result in favorable passenger delays for longer-haul flights. Difference in equity is more pronounced for RBPax than the other two rationing rules. *(Note: Equity metrics are calculated over a long-term. For the purposes of this case study, only one day of data is used.)*

Fig. 12 shows the total inequity as a result of all rationing rules. Total inequity for a given rationing rule is calculated as the sum of absolute differences between a category's equity and the "perfect" equity (1). Figure shows RBS clearly results

in the smallest airline inequity compared to the other rules. Passenger inequity is also smaller with RBS. However, the favorable equity by RBS is achieved at the expense of 144,407 minutes more passenger delays. Passenger equity values are very dependant on the airline scheduling choices and can be improved by upgauging.
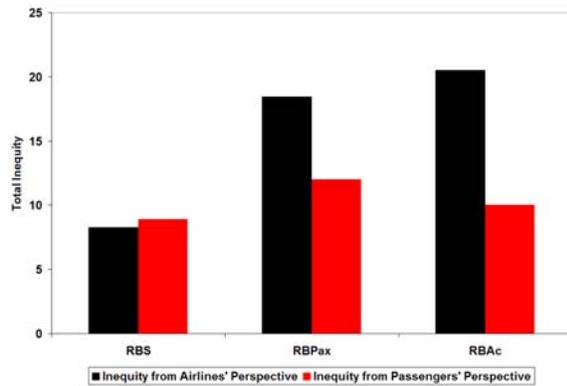

Figure 12: Inequity Comparison for RBS, RBPax and RBAc

V. CONCLUSION

The case study of GDP with alternate rationing rules at EWR demonstrates the impact of GDP rationing rules on passenger flow efficiency and on airline equity. Adjusting the rationing rules to maximize the flow of passengers (and cargo) results in significant reductions in overall passenger trip delays. These delays are achieved with small changes in overall flight delay. Airline equity is adjusted in favor of larger airlines. Addressing this issue is an area of future work.

The results of the case study at Newark Liberty International Airport (EWR) are as follows:

- All three GDP rationing rules resulted in the different trade-offs between airlines and passengers.

- Ration-by-Aircraft size (RBAc) decreased the total passenger delay by 10% compared to RBS with a 0.4% increase in total flight delay.

- Ration-by-Passengers (RBPax) decreased total passenger delay by 22% compared to RBS with 1.1% increase in total flight delay.

- Ration-by-Passengers (RBPax) results in the minimum disutility for the air transportation system when both airlines and passengers are concerned. RBS is preferred choice only if airlines are the main focus of the system.

- Ration-by-Schedule (RBS) results in the minimum total inequity for both airlines and passengers. However, this is achieved at the expense of a large efficiency loss due to high passenger delays.

The application of alternate GDP rationing rules has broader implications. In principle, GDP rationing rules create priority queues which give preference to the compliant flights. As a consequence the rationing rules incentivize airline behavior. For example, the Ration-by-Passengers rule could,

in the long-run, result in the migration of airline fleets to larger sized aircraft that would increase the passenger flow capacity. This would improve the efficiency of the air transportation system. This incentive does not directly result in reduced frequency, but reduced frequency may be a by-product of upgauging.

Results presented here are the outputs of the GDP Planner with substitution strategy 1. For future work, these results will be compared against the results of GDP Flight Simulator to see the differences between planned and actual metrics. Results can be further improved by comparing airport metrics to airline and passenger metrics.

REFERENCES

(Ball and Lulli, 2004) M.O. Ball, and G. Lulli, "Ground Delay Programs: Optmizing over the included flight set based on distance," Air Traffic Control Quarterly, vol.12, pp. 1-25, 2004.

(Donohue, Shaver and Edwards, 2008) G.L. Donohue, R.D. Shaver, and E. Edwards, "Terminal chaos: Why U.S. air travel is broken and how can we fix it," AIAA press, forthcoming Spring 2008.

(Duke and Torres, 2005) J. Duke, and V. Torres, "Multifacctor productivity change in the air transportation industry," Monthly Labor Review, March 2005.

(FAA Forecast, 2007) U.S. Department of Trasnportation Federal Aviation Administration Policy and Plans, "FAA aerospace forecast fiscal years 2007-2020," 2007.

(Hall, 1999) W.D. Hall, "Efficient capacity allocation in a collaborative air transportation system," PhD Thesis in Operations Research, Supervisor: A. Odoni, Massachusetts Institute of Technology, Cambridge, MA, 1999.

(Hall and Peterson, 2002) W.D. Hall, and E. Peterson, "ASCENT: A network-wide simulation of air traffic flow management incorporating airline decisions," Proceedings of the American Control Conference, Anchorage, AK May 8-10, 2002.

(Hoffman, Ball, and Mukherjee, 2007) R. Hoffman, M. Ball, and A. Mukherjee, "Ration-by-Distance with equity guarantees: A new approach to Ground Delay Program planning and control," the 7th ATM R&D Seminar, Barcelona, Spain, 2007.

(Howe et.al, 2003) B.Howe, C. Richardson, M. Gordon, S. Russell, S. Sprague, G.L. Donohue, and F. Wieland, "Potential air traffic congestion solution: Slot allocation by auction method," Proceedings of the 2003 Systems and Information Engineering Design Symposium, 2003.

(IATA, 2000) International Air Transport Association, Worldwide Scheduling Guidelines, 3rd Edition, December 2000.

(MITRE, 2007) The MITRE Corporation, Center fir Advanced Aviation System Development, "Capacity needs in the national airspace system 2007-2025: An analysis of airports and metropolitan area demand and operational capacity in the future," May 2007.

(Miller and Clarke, 2003) B. Miller, and J.P. Clarke, "The hidden value of air transportation infrastructure," The 7th International Conference on Technology Policy and Innovation, Monterrey, Mexico, June 10-13, 2003.

(Robyn, 2007) D. Robyn, "Reforming the air traffic control system to promote efficiency and reduce delays," The Brattle Group, October 29, 2007.

(Vossen, 2002) T. W.M. Vossen, "Fair allocation concepts in air traffic management," PhD thesis, Supervisor: M.O. Ball, University of Martyland, College Park, Md, 2002.

(Wang, 2007) D. Wang, "Methods for analysis of passenger trip performance in a complex networked transportation system," PhD thesis in Information Technology, Supervisor: L.Sherry, George Mason University, Fairfax, VA, 2007.

(Young, 1994) H. P. Young, "Equity: In theory and practice," Princeton University Press, Princeton, New Jersey, 1994.