Impact of Ground Delay Program 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 according to the scheduled arrival time of the inbound flights. Current rationing rules do not take into account passenger flow and fuel burn efficiency in the rationing assignment tradeoff.

This paper examines the performance (flight delays, passenger delays, extra fuel burn) and equity (inter-airline equity, passenger geographic equity) in alternative GDP slot allocations. 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 and extra fuel burn can be decreased with no change in total flight delays relative to the Ration-by-Schedule scheme. When the performance considerations are weighted more heavily than equity, rationing to maximize passenger throughput performs best. When equity considerations are weighted more heavily than performance, rationing by schedule performance best. The tradeoffs between airline and passenger equity, and the implications of these results are discussed.

Keywords: Ground Delay Program, rationing rule, equity, efficiency.

1. INTRODUCTION

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 [1]. The growth of air transportation capacity to meet this demand has been lagging [2]. Building new airports does not resolve congestions at existing airports. Building new runways at congested airports in prohibitive due to lack of space and environmental concerns [3]. Proposed capacity improvements through technology (e.g. NextGen) are not expected to be fully operational before 2025.

The imbalance between demand for flights and available capacity is estimated to cost passengers $3 billion to $5 billion a year in trip delays [4]. 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 [5]. These delays also have environmental and climate change implications as well as regional economic repercussions [6].

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) 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 [7], (ii) improve airline fairness [8], and (iii) improve airline efficiency by trading departure and arrival slots [9, 10].

This paper examines the impact of alternative GDP rationing schemes on performance (flight delays, passenger delays, extra fuel burn) and equity (inter-airline equity, passenger geographic equity). A case study for Newark airport is presented.

2. BACKGROUND

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 [11].

Fig.1 illustrates a demand-capacity imbalance at an airport. 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. A GDP adjusts the scheduled demand to match the airport capacity by delaying flights on the ground. Blue bars in Fig.2 represent the delayed flights, which spill into the hours after the GDP program.

Three parameters are set for a GDP. The first parameter is GDP Start Time and GDP End Time. All flights scheduled to arrive at the constraint airport between these times, will be controlled by the GDP. The second parameter is the “scope” of
the program. It specifies the geographic region from which departing flights will be delayed by the GDP. The third parameter is the GDP Program Airport Acceptance Rate (PAAR) which defines the number of aircraft that can safely land in an hour during GDP.

The allocation of GDP arrivals can be done using different rationing rules than the normal First-Come-First Served operations [12]. 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). The RBS algorithm creates two distinct queues; exempt flights are assigned to slots first, followed by 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.

Previous Research

Vossen (2002) examined different GDP rationing rules to achieve fairness among airlines. 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.

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 compared to the RBS. 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 small number of operations can get penalized to a greater extent.

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.

3. 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. 4 shows three main components of the model.

Figure 4. GDP Rationing Rule Simulator

First module, “GDP Slot Assignment Module”, inputs the flight arrival schedule for the day and the GDP parameters, then...
creates slots and assigns these slots to GDP flights based on a given GDP rationing rule. The steps 1-5 below take place in this module. It results in Planned CTD and CTAs for each flight that is sent to airlines for substitutions and cancellations.

Second module, “Airline Substitutions and Cancellations”, inputs sent information for each flight and cancels and substitutes flights following the steps 6-7 below.

Third module, “Compression”, inputs the changes made by the airline and tries to fill the unused arrival slots as explained in Step 8. Flights have to comply with the CTDs and CTAs given at the end of compression in a 5 minute window.

1. Calculate Required Variables for Each Flight: Scheduled runway times, used in the GDP slot assignment, are calculated from scheduled gate times assuming 10 minute taxi times. Estimated Time Enroute (ETE) for each flight is the difference between scheduled runway arrival and departure times of the flight. “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). For international origins and origins not listed in BTS, the default load factor is assumed to be 100%.

2. Find Flights in GDP: All flights going to the GDP airport are assigned control times. However, the delay as a 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. Create Priority Queues: Exempt Flights queue has precedence over the remaining flights (Non-exempt Flights). Exempt Flights queue contains international flights and flights departing from airport outside the GDP scope.

4. Create Slots: The number of slots available for distribution depends on the PAAR. 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. Assign Slots to Flights: 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. CTD is back-calculated using CTA and ETE for the flight. These CTAs and CTDs are sent to Airline Substitutions and Cancellations Module.

6. Cancel Flights: 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. In the case study, the cancellations are taken as it happened in 2007.

7. Substitute Flights: 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 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 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. Run Compression: 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 no such flight is found, then slot remains unassigned. Algorithm stops when all unassigned slots are checked. GDP efficiency and equity metrics are calculated at the end of this step.

Extra fuel burn due to GDP delays are also calculated in the simulation. There are two fuel burn rates used for each flight, both of which are based on aircraft type (EDMS). Flights use all engines during 15 minutes of their delay. If the assigned delay for the flights is more than 15 minutes, APU fuel burn rate is used for the delay excess of 15 minutes. GDP algorithms today do not calculate fuel burn metrics.

Steps 1-5 and Step 8 are simplified and modified versions of the current GDP algorithm. The main difference between GDP-RRS and the current GDP algorithm is that current GDP algorithm only runs Ration-by-Schedule (RBS) scheme, and only calculates flight-based metrics (flight delays and airline equity), whereas GDP-RRS calculates passenger and fuel burn metrics as well as flight metrics. Another difference is that GDP-RRS simulates airline substitution and cancellation behavior, whereas airlines themselves make their own decisions in the current GDP process.

4. RESULTS

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

1. Ration-by-Schedule (RBS) 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. Ration-by-Aircraft Size (RBAc) 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. If two flights are 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.

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, 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

This case study analyses the 197 GDPs at EWR in 2007. The GDP parameters, airline cancellation and scheduling decisions are taken as it happened in 2007, but the GDPs are implemented using the new three rationing rules explained above. The planned duration of these GDPs are shown in black bars in Fig.5. The red dots in the figure depicts the time each GDP is planned. Figure shows that GDPs often start in the early afternoon lasting till the end of the operating day. In 2007, the average GDP duration at EWR was 10 hours and GDPs are planned on average 96 minutes prior to the GDP start time.

Figure 5. EWR GDP Duration (2007)

Figure 6. Scheduled Demand vs. Available Capacity

Fig.6 shows the average scheduled demand against the average available capacity in 15 minutes bins at EWR during the GDP periods. As seen from the figure, average available capacity fluctuates around 10 flights per 15 minutes.

The results of the case study are summarized in Fig.7. Fig.7 shows the GDP efficiency comparison between RBS, RBPax (red) and RBAc (blue). All three rationing rules result in the same amount of total flight delay but different levels of total passenger delays and total extra fuel burn. Compared to RBS, RBAc (blue) decreases total passenger delay by 8% (23,863,040 minutes less delay) and decreases total extra fuel burn due to GDP by 18% (1,653,813 kg less fuel) with no change in total flight delay. The biggest improvement in efficiency is achieved by using RBPax. Moving to RBPax from RBS decreases total passenger delay by 23% (66,946,723 minutes less delay) and decreases total extra fuel burn due to GDP by 57% (5,191,606 kg less fuel) with no change in total flight delay.

Figure 7. GDP Efficiency Comparison

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 available arrival slots, which are held in common by airlines, must be allotted to them individually [14]. In the case of GDPs, equity means distributing fairly among all involved stockholders. Airline Equity (Fig.8) and Passenger Equity (Fig.9) captures this from the view point of airlines and passengers.

Figure 8. GDP Equity by Flights

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.8 shows the GDP equity for airlines at the end of year 2007 under three GDP rationing rules. The airlines in the figure are ranked in an increasing order their flights in the GDP (the percentage of total GDP flights an airline has in 2007 are shown in parenthesis) and they constitute 91% of the GDP arrival operations. The rest of the airlines are grouped into the “Other” category.
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. Equity values for all airlines are similar between RBS and RBAc. RBAc only distinguishes between the three aircraft category and uses scheduled arrival time of flights whenever two flights are in the same category. Since most flights are in the “large” category, the delay assignment of RBAc looks similar to RBS. However, RBPax further distinguishes flights with the number of passengers on board. “Other” category airlines have very low number of flights in the GDP and their equity is very tightly connected to the scheduled arrival time and type of aircraft used. If the smaller aircrafts are used during busy hours of the airport, RBPax penalizes these flights strongly. All airlines have less delay with RBPax, except for airlines 2 and “Other”.

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 [15]. Flight cancellations reduce total flight delay while increasing total passenger delays, especially when the load factors are high. Passenger Equity (Fig.9) is calculated as the ratio of passenger delays for an origin group over the total GDP passenger delay divided by the ratio of the number of passengers from that origin group over all passengers encountering the GDP. In other words, the more passengers an origin group has, the more passenger delay it should be assigned. “Perfect equity” is again represented as 1. Fig.9 also shows the number of domestic origin airports in a given category in parenthesis. The passengers from origin airports with the smallest average seat size (0-19) and the largest average seat size (300+) are penalized the most. The high passenger equity is closely connected to the scheduling practices of airlines as well as the number of flights from the same origin for connection purposes. The data shows that these two origin groups have the highest percentage of cancellations.

Total inequity for a given rationing rule is calculated as the sum of squared differences between a category’s equity and the “perfect” equity (1). RBS results in the smallest airline equity (0.75) and passenger inequity (84.40) compared to the other rules (RBPax (5.02, 176.13) and RBAc (2.33, 104.77).

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 the two efficiency metrics (total GDP passenger delay and total extra fuel burn due to GDP) and two equity metrics (total airline inequity and total passenger inequity). Fig.10-11 shows the disutility values calculated for three rationing rules in EWR for the year 2007 using different weights.

- If the system performance is the only concern, RBPax minimizes the total GDP disutility (Fig.10).
- If the stakeholders’ equity is the only concern, RBS minimizes the total GDP disutility (Fig.11).
- If all performance and equity metrics are weighted equally, RBAc minimizes the total GDP disutility.

5. 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 as well as extra fuel burn due to GDPs. These reductions are achieved with no change 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 8% and total extra fuel burn by 18% compared to RBS with no change in total flight delay.

• Ration-by-Passengers (RBPax) decreased total passenger delay by 23% and total extra fuel burn by 57% compared to RBS with no change in total flight delay.

• Ration-by-Passengers (RBPax) results in the minimum disutility for the air transportation system when performance is the main focus of the system. RBS is preferred when equity is 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 and extra fuel burn.

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.

It is planned to extend this work to include more alternative rationing schemes (e.g. Ration-by-Environmental impact), the impact of different airline substitution strategies (substitution strategy 1 vs. strategy 2 described), the impact of GDP scope and the impact of airline cancellation policy. Results can be further improved by comparing airport metrics to airline and passenger metrics.

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6. REFERENCES


