

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

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Abstract— The discrepancy between the demand (scheduled and unscheduled) 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 airline equity and passenger flow efficiency in GDP slot allocation. A GDP Rationing Rule Simulator (GDP-RRS) was 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 without any increase in total flight delays. Compared to the traditional Ration-by-Schedule, Ration-by-Aircraft size (RBAC) decreased the total passenger delay by 32% and Ration-by-Passengers (RBPax) decreased total passenger delay by 60%. Flight delays of most airlines are also decreased with this scheme. 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 (Wang, 2007) 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) Airports. Most of these airports cannot expand due to land and/or environmental problems (Howe et.al., 2003). Further, the capabilities mentioned in 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).

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 (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 without any 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 32% and Ration-by-Passengers (RBPax) decreased total passenger delay by 60%. The tradeoffs in airline 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 Simulation (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 Scheduling 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 18:00 and 23:00. 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 in flight minutes around the GDP airport and exempts any flight which has an enroute time greater than the specified radius. The third parameter is the GDP Program Airport Acceptance Rate (PAAR). Airport Acceptance Rate (AAR) is set by the GDP airport’s tower depending on the airport conditions. However, ATC specialists have the option to set the PAAR above or below the AAR to account for uncertainties in the future, such as weather and unscheduled demand. When the PAAR is determined, it depicts the number of aircraft that can safely land in an hour.

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 before implementing the program. Airlines check the impact of this proposed GDP on their operations and may opt to

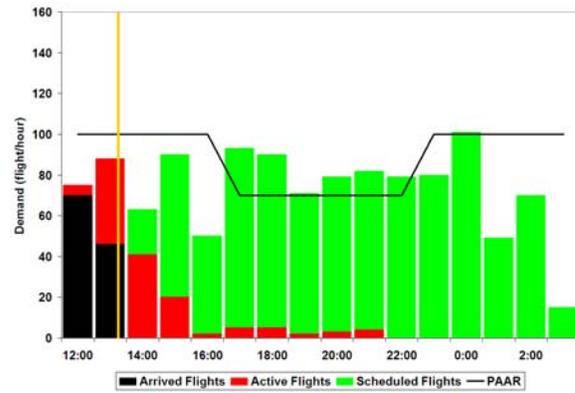


Figure 1: Demand Capacity before GDP (FSM View)

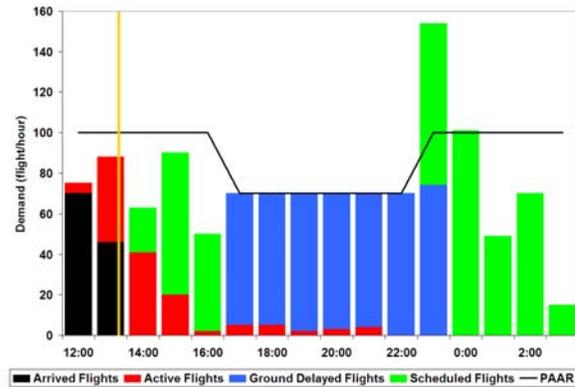


Figure 2: Demand Capacity after GDP (FSM View)

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 “regular” arrival slots. 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

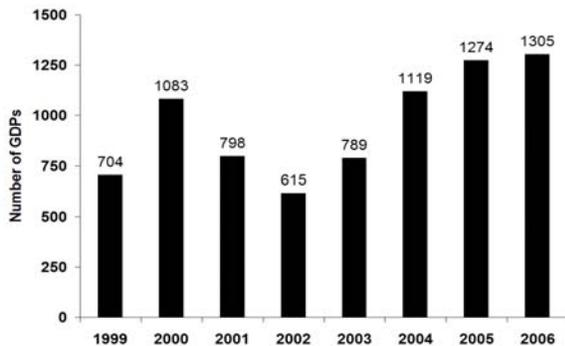


Figure 3: Total Number of GDPs by Year (1/1/1999-12/31/2006)

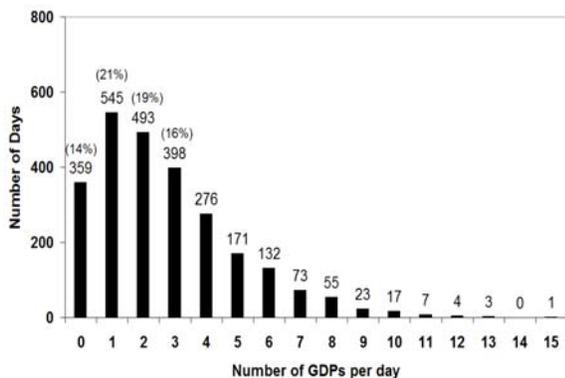


Figure 4: Histogram for Number of GDPs per Day (1/1/2000-12/31/2006)

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).

C. Previous Research

Vossen (2002) examined different GDP rationing rules to achieve fairness (delay allocations) among airlines. The “Airline-based Allocation” scheme assigns each airline its proportional share of the overall delay. This method works well for airlines whose schedule tends towards the GDP End Time, however penalizes airlines with flights earlier in the GDP. The application of Shapely Value to GDPs resulted in problems, such as the instability of assignment when a flight is cancelled or the equal claim of all flights to all slots, even if the flight cannot use the slot. 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 the airline has, 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. 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. 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.

All of the previous research examined the impact of GDP rationing rules on 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. Fig.5 shows two main components of the model: GDP Planner and GDP Simulator.

GDP Planner calculates GDP efficiency and equity metrics that result from initial GDP planning for airlines, passengers and the GDP airport. It is composed of three modules. 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. If the rationing rule is RBS, it mimics the slot assignment algorithms used today. If a different GDP rationing rule is chosen, it creates an additional flight queue called “incentivized flights”. Incentivized flights are the flights which are compliant with the GDP rationing rule and they are ranked in order of their characteristics. Fig.6 shows the pseudo algorithm with seven main steps:

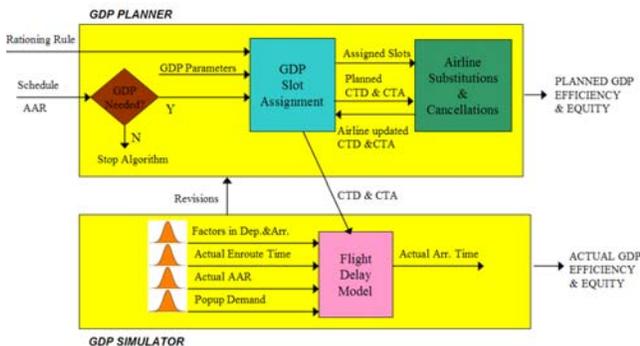


Figure 5: GDP Rationing Rule Evaluator

1. Calculate Required Variables for Each Flight: Scheduled Runway Time of Arrival (SRTA) and Scheduled Runway Time of Departure (SRTD) for each flight are inputs to the model. Estimated Time Enroute (ETE) for each flight is the difference between SRTA and SRTD. “Available Seats” is the average number of seats for the aircraft type assigned to each flight. “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 monthly load factor for that specific flight on that route.

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:

- Flight’s SRTA is between GDP Start and End Time.
- Flight is not active between GDP Start and End Time.
- Flight is not originated from an international airport.
- Flight’s departure airport is in GDP scope.

3. Create Priority Queues: Three 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 Incentivized Flights queue, which has precedence over the remaining flights. Exempt Flights queue contains flights that do not satisfy the conditions given in Step 2. Incentivized Flights are the flights which are compliant with the GDP Rationing rule. The remaining flights are placed in the third queue with low priority.

4. Create Slots: 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. Assign Slots to Flights: The assignment of slots to flights is done by queue type. First, Exempt Flights are assigned their slots followed by Incentivized Flights, then the remaining flights. 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, the flight is assigned to that slot and its CTA is the same as the slot time. CTD is back-calculated using CTA and ETE for the flight. These CTAs and CTDs are sent to Airline Substitutions and Cancellations Module.

6. 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 flight can be reduced by assigning the flight to this slot instead. Flights operated by the airline which vacated the slot are given preference, followed by the “incentivized flights” in order of their ranking. Assignment is done only if the unassigned slot time is equal to or greater than the flight’s SRTA or Estimated Time of Arrival (ETA is the updated SRTA). If such a flight is found, flight’s CTA and CTD are recalculated. If no such flight is found among all GDP flights, then slot remains

unassigned. Algorithm stops when all unassigned slots are checked.

7. Issue CTA and CTD: 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 or ETA 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.

"Airline Substitutions and Cancellations" module captures the airline decision making process after the initial slot assignment. It inputs the assigned slots, probability of canceling a flight, airline strategy, and delay-cancel trade-off parameters, and outputs the assigned CTDs and CTAs for each flight. These are the CTDs and CTAs sent to compression section of the GDP Slot Assignment module.

The purpose of GDP Simulator is to calculate realized GDP efficiency and equity at the end of the day. Due to uncertainties, such as airline operations, weather conditions, and unscheduled demand, GDP will not be executed exactly as it is planned. GDP Simulator investigates the likely impact of these factors that can change the GDP metrics based on historical data. The Flight Module simulates the related flight metrics based on assigned CTDs, CTAs, and historical data, and outputs the actual arrival time and compliance metrics for each flight. The changes in some of these factors, such as weather conditions, may also cause changes in the GDP parameters. The resulting GDP revisions are fed back to the GDP Planner to update the associated variables.

IV. 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 the aircraft's 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. 12% of the flights in the study fall under Heavy, 85% in Large, 6% 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 slot assignment.

3. Ration-by-Passengers (RBPax) rations available slots by the number of passengers carried on each flight. All flights are

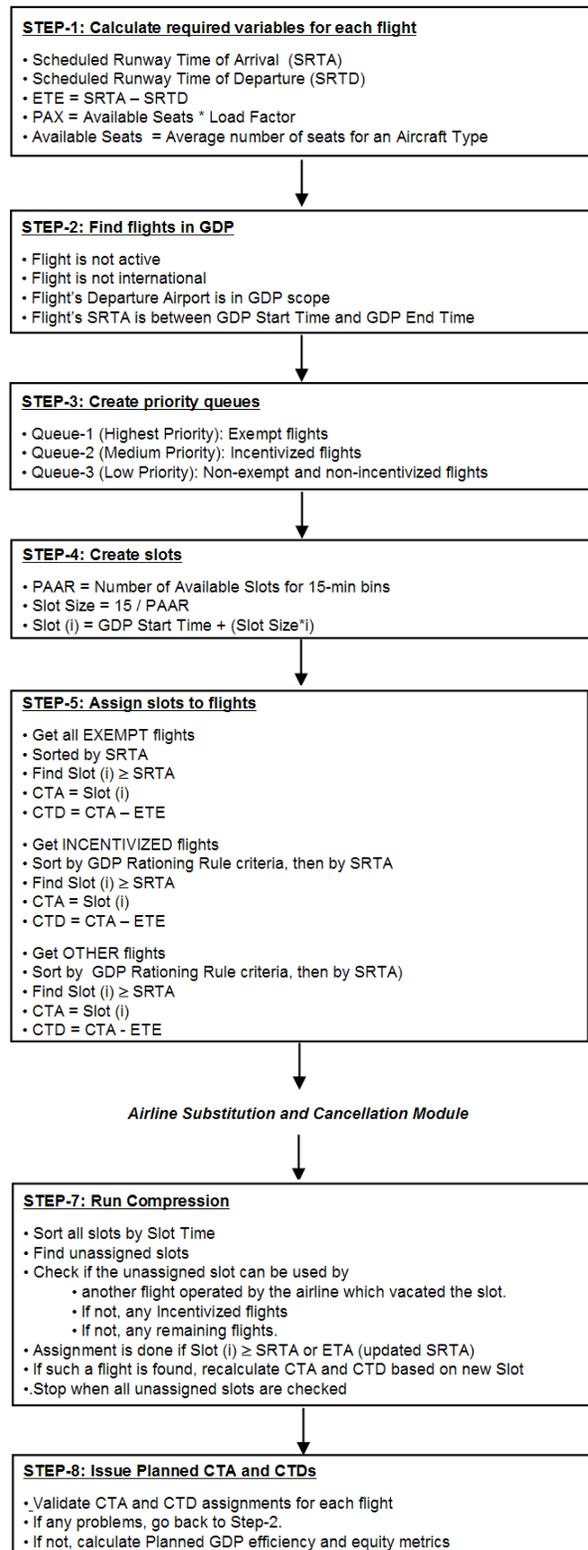


Figure 6: GDP Slot Assignment Module Pseudo Algorithm

assumed to have 100% load factor, therefore the number of passengers carried equals the number of available seats on each aircraft. 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.

Case Study GDP at Newark Liberty Airport

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. 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 248 flights between GDP Start and End Time, 68 of which are international. GDP delay is split among 180 domestic flights. There are 27 major airlines coming from 70 different origins carrying 30,551 passengers (12,374 international and 18,177 domestic passengers). Among 70 airports, the most number of scheduled flights are from ORD (7 flights), LAX (6 flights), and BOS (6 flights) during GDP period. It is interesting to see departure airports in 100 nautical miles radius from EWR. However, flights coming from these airports have different characteristics. For example, there are two flights coming from LGA carrying a total of 16 passengers whereas the only flight coming from JFK carries 452 passengers.

Fig.8 shows the impact of exempt flights on the overall flight delay. One of the misunderstandings about GDP delays is that when the demand is above the capacity (bins with black bars above red line), the excess demand is assumed to fill the different time periods with under-capacity (bins with black bars below the red line). This assumption is shown in Fig.7 by gray arrows. However, this is not the case. Since RBS assigns slots based on an ordering of scheduled arrival times, the excess demand in a bin (one bar) is moved to the next bin, and therefore pushing the flights which are below the capacity limit from their own time bins into next periods. Since exempt flights are given preference, yellow bars in Fig.8 are exactly the same as in Fig.7. The blue bars in Fig.8 show the number of flights which are delayed into further time bins than their own during RBS assignment.

The results of the case study are summarized in Fig.9. These results show Planned GDP efficiency before any airline substitutions and cancellations. All three rationing rules result in **8,102** minutes if total flight delay. Compared to RBS (blue), RBAC (red) decreases total passenger delay by **32%** (272,826 minutes less delay). The biggest improvement in efficiency is achieved by using RBPax. Moving to RBPax from RBS decreases total passenger delay by **60%** (509,732 minutes less delay) with no change in total flight delay.

Fig.10 shows the total flight delay distribution by airline under three rationing rules. Airlines having less than five flights during the GDP are aggregated into the “Other” category. Airline1 has 2/3 of all flights and seems to be the dominant carrier. Figure also shows the number of scheduled flights for each airline during the GDP period.

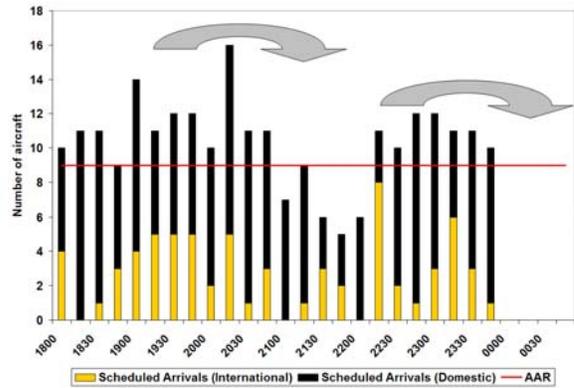


Figure 7: EWR Case Study: FSM View before GDP is Implemented

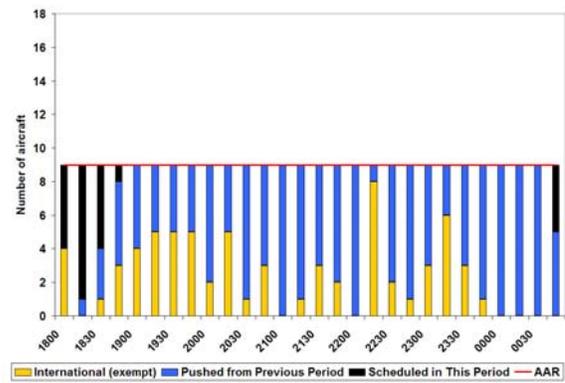


Figure 8: EWR Case Study: FSM View after GDP is implemented

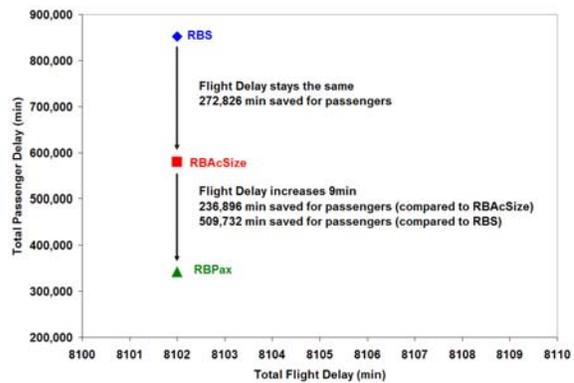


Figure 9: GDP Efficiency Comparison between RBS, RBAC and RBPax

All airlines, except “Other category, have the highest flight delays under RBS, and less flights delays under RBAC and RBPax. Airline1 flights are assigned the least delay in RBAC, followed by RBPax and RBS. The reason Airline1 does better

with RBAC rather than RBPax is that RBAC orders flights by aircraft size, then by their scheduled arrival times. 26% of Airline1 flights are Heavy, 61% of which is domestic. Most of Airline1 flights are assigned closer to their scheduled times by RBAC. However, RBPax further distinguishes Heavy flights with the number of seats. This time, most of these flights have to compete against other Heavy aircraft carrying more passengers.

Results indicate the decrease in flight delays for most of the airlines with RBPax and RBAC compared to RBS comes at the expense of "Other" airlines. There are 19 flights in this category, 6 of which are penalized with high delays. These flights are scheduled at the busy times of the airport with relatively small aircraft carrying 4-12 passengers. That's why, RBS gives them advantage in delay assignments, but RBAC and RBPax puts them towards the end of the GDP queue. These flights are either unscheduled operations or coming from origin airports that have frequent schedules. Utica Airport (UCA) seems to be the only origin which might have a negative impact on accessibility.

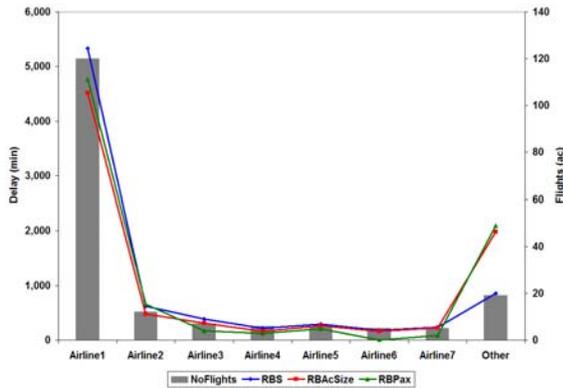


Figure 10: Total Flight Delay Comparison by Airline under RBS, RBAC and RBPax

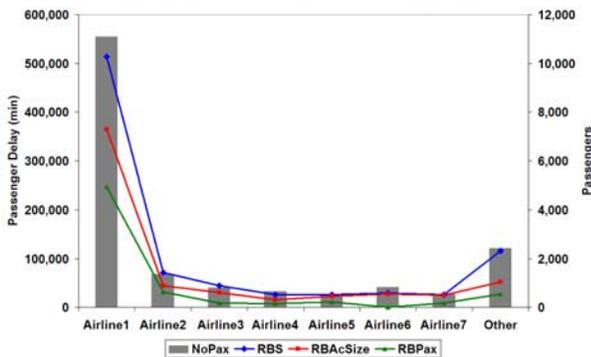


Figure 11: Total Passenger Delay Comparison by Airline under RBS, RBAC and RBPax

Fig.11 shows total passenger delay by airline for three rationing rules. Passengers on all airlines experience the least delays with RBPax, followed by RBAC. This is in line with the objective of RBPax and RBAC. Airline1 has the biggest drop in passenger delays, followed by "Other". It is noticed that

"Other" passengers enjoy less delays with RBPax and RBAC, even though the "Other" flights are assigned more delays.

Total flight and passenger delay values are important metrics. However, they don't imply any information about the fairness of the delay distribution. Airline Equity by Operations (Fig.12) and Passenger Equity (Fig.13) captures this from the view point of airlines and passengers. "Perfect equity" is represented as 1. If an airline's equity is smaller than 1, the airline is given less delays than is fair. If the equity is above 1, the airline has more delays than is fair. Airline Equity by Operations compares how much flight delay is assigned to an airline compared to its number of scheduled operations. In other words, it assumes the more flights an airline has, the more flight delay it should be assigned. Passenger Equity compares how much passenger delay is assigned to passengers flying with an airline compared to the total number of passengers that airline carries. In other words, the more passengers an airline has, the more total passenger delay it will be assigned.

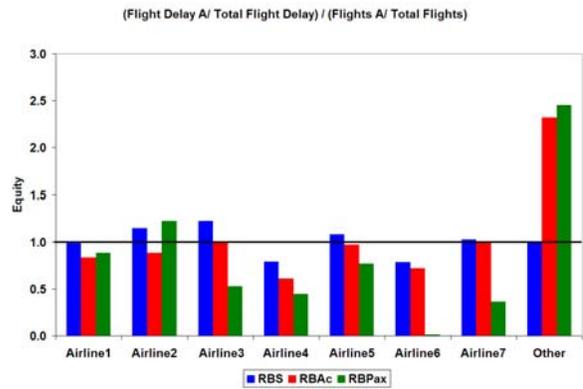


Figure 12: Airline Equity by Operations under RBS, RBAC and RBPax

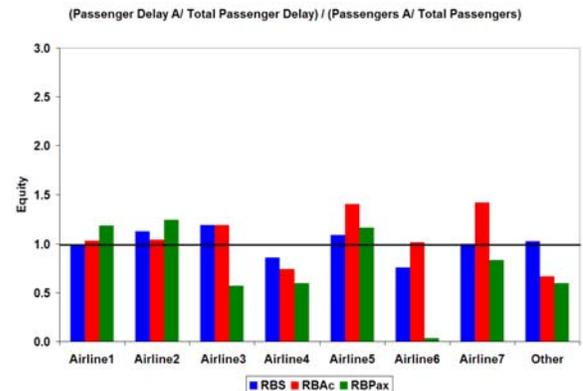


Figure 13: Passenger Equity by Airline under RBS, RBAC and RBPax

Fig.12 shows that the change in Airline1's equity due to rationing rules is very small because of Airline1's dominant position at EWR. This impact is more pronounced for airlines with a smaller number of operations, such as "Other" airlines. Fig.12 shows "Other" airlines are unfairly penalized in RBAC and RBPax if the fairness standard is the number of flights. Six small flights (among 19 total flights) are highly penalized

so that this category, on aggregate, has very high proportion of delays. However, Fig.13 shows that “Other” airline passengers are assigned less than fair delays with RBPax and RBAC. The delay reduction for passengers on 13 large flights (among 19 flights) is considerable so that this category, on aggregate, has smaller proportion of the passenger delays.

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 no impact on 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 same total flight delay but different levels of total passenger delay.
- Ration-by-Aircraft size (RBAC) decreased the total passenger delay by 32% compared to RBS.
- Ration-by-Passengers (RBPax) decreased total passenger delay by 60% compared to RBS. Even though the distribution of delays was different among airlines, passengers from all airlines encounter fewer delays with Ration-by-Passenger. Flight delays of most airlines also decrease with this scheme.
- However, this was achieved at the expense of airlines with very small number of flights. Utica Airport (UCA) seems to be the only origin which might have a negative impact on accessibility.

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 upgating.

Results presented here are the outputs of the GDP Slot Assignment Module of the GDP Rationing Rule Evaluator. As explained above, this simulation model is composed of three integrated modules. For future work, the planned GDP efficiency and equity metrics will be compared with actual GDP metrics for EWR case study. Planned metrics will be calculated using Airline Substitution and Cancellation Model together with GDP Slot Assignment Module, and actual metrics will be calculated using the Flight Delay Module. Results can be further improved by comparing airport metrics to airline and passenger metrics.

ACKNOWLEDGMENT

Thanks for technical comments and suggestions from Mark Klopfenstein, Michael Brennan, Terry Thompson (Metron Aviation), Maria Consiglio, Brian Baxley, and Kurt Nietzsche (NASA-LaRC), George Donohue, John Shortle, Michael Bronzini, Rajesh Ganesan, David Smith, Vivek Kumar (GMU/CATSR), Joe Post, Dan Murphy, Stephanie Chung, Kimberly Noonan (FAA ATO-P). Thanks for program support to Harry Swenson, Michael Landis (NASA). This research was funded by NASA NRA NNA07CN23A, and internal GMU/CATSR Foundation Funds.

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