

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

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CENTER FOR AIR TRANSPORTATION SYSTEMS RESEARCH



Outline



1. Introduction & Objective
2. Ground Delay Programs (GDP)
3. GDP Rationing Rule Simulator
4. EWR Case Study
5. Observations & Future Work

Introduction

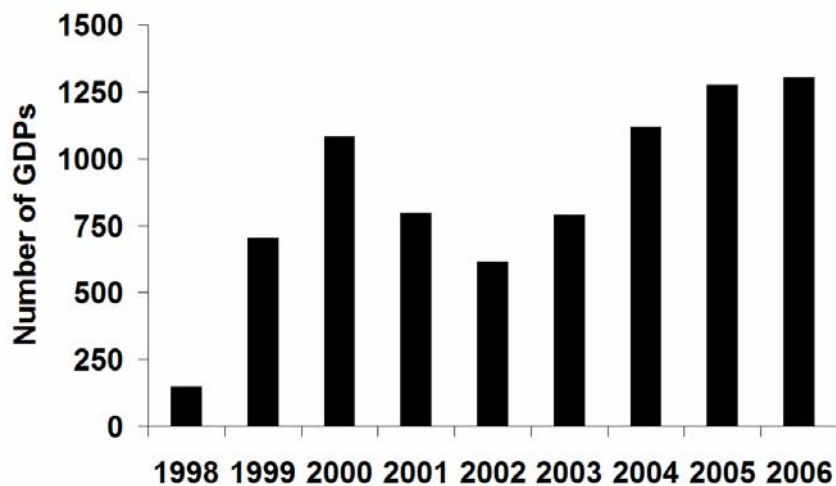


- Demand growth for air transportation is forecast beyond the capacity growth.
- This imbalance between demand and capacity on a given day is addressed by GDP.
- Ration-by-Schedule (the current GDP rationing rule) focuses on flight delays and does not take into account passenger delays as a result of it.
- What will be the system impact if passenger delays are weighted as well as flight delays?
 - ***Ration-by-Passenger (RBPax)*** decreased total passenger delay by **22%** and decreased total extra fuel burn (due to GDP delays) by **63%** but increased total flight delay by **1.1%** compared to RBS.
 - ***Ration-by-Aircraft size (RBAc)*** decreased total passenger delay by **10%** and decreased total extra fuel burn (due to GDP delays) by **25%** but increased total flight delay by **0.4%** compared to RBS.

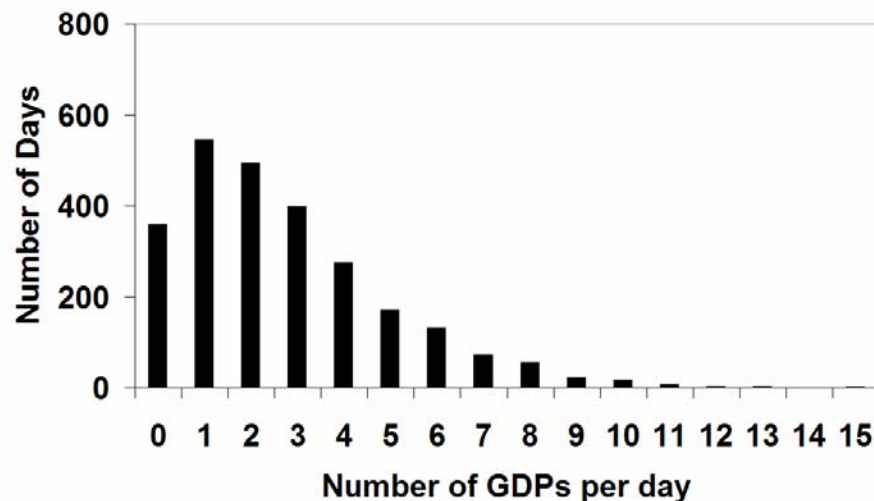
GDP occurs almost everyday...

- Over-scheduling is a systematic phenomenon.
- The number of GDPs is steadily increasing over the years.
- There is a 86% chance that at least one GDP will be implemented in the NAS every day.

Total GDPs by Year (9/8/1998 - 12/31/2006)



GDP Histogram (1/1/2000 - 12/31/2006)

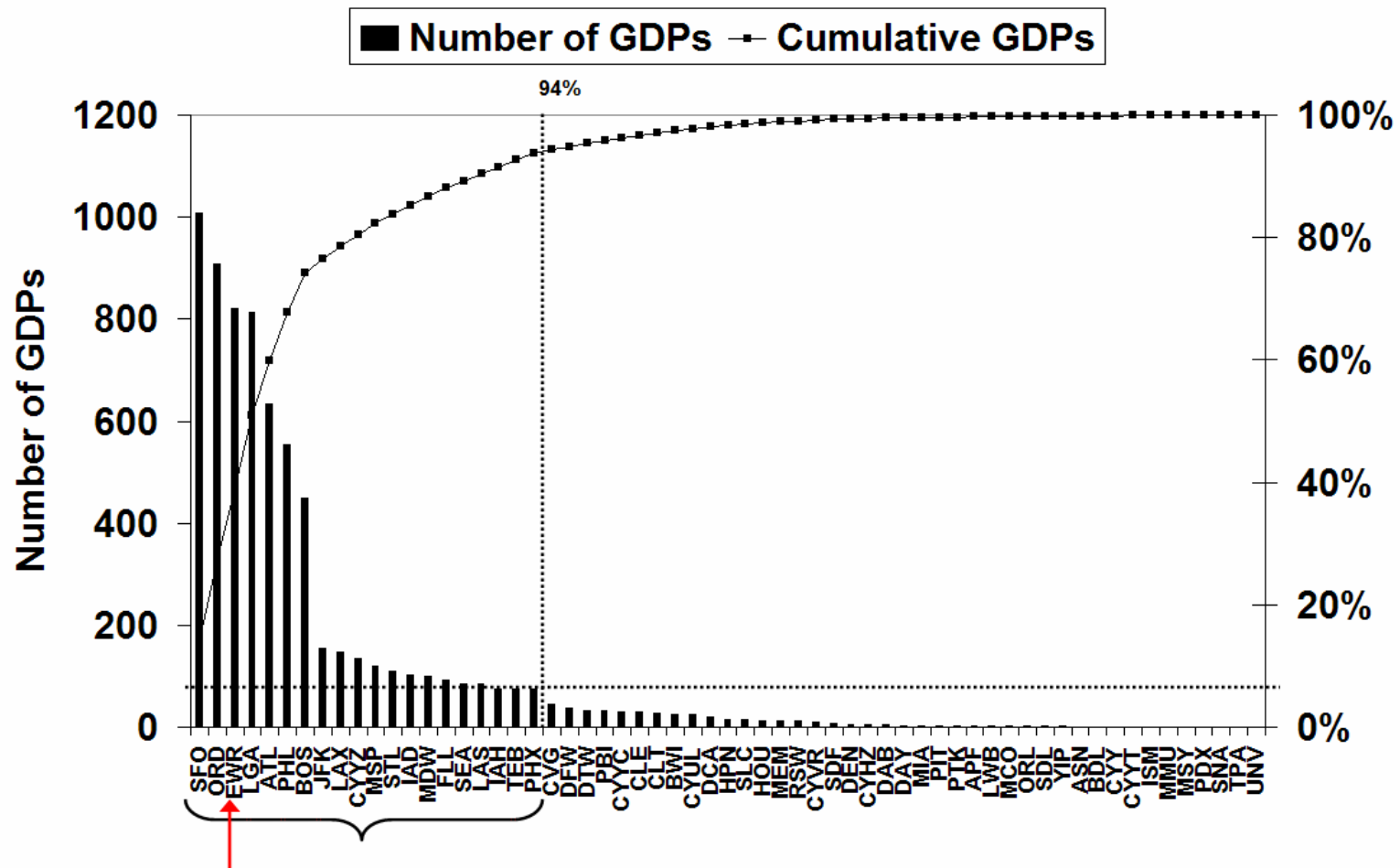


20 airports generate most of the GDPs....



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Ranking of Airports by Total GDP (1/1/2000 - 12/31/2006)



Objective of this Research

- To investigate the impact of rationing rules used in Ground Delay Programs (GDP) on efficiency and equity of air transportation system agents.
- To develop an analytical infrastructure to evaluate alternate rationing schemes in GDPs (GDP Rationing Rule Simulator).
- Hypothesis: “Different GDP rationing rules result in different efficiency and equity trade-offs for different agents of the air transportation system.”

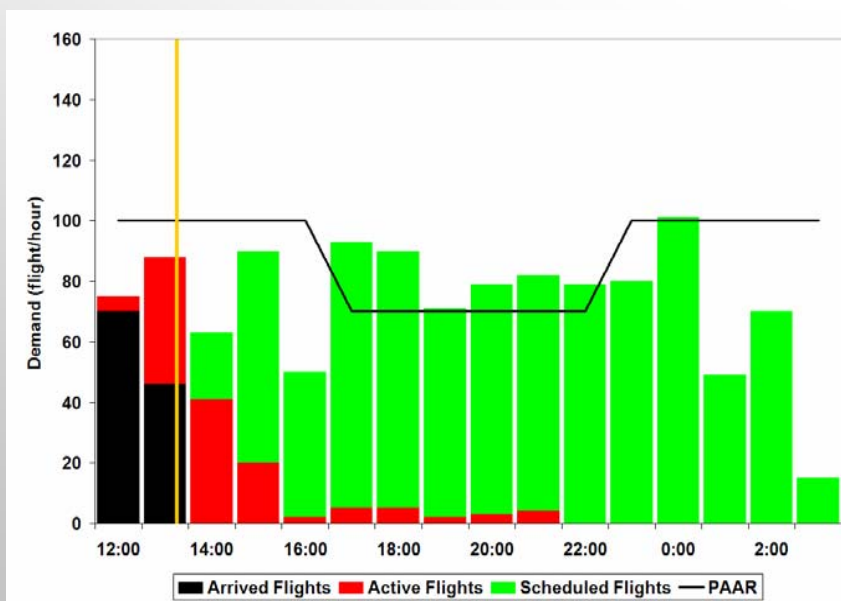
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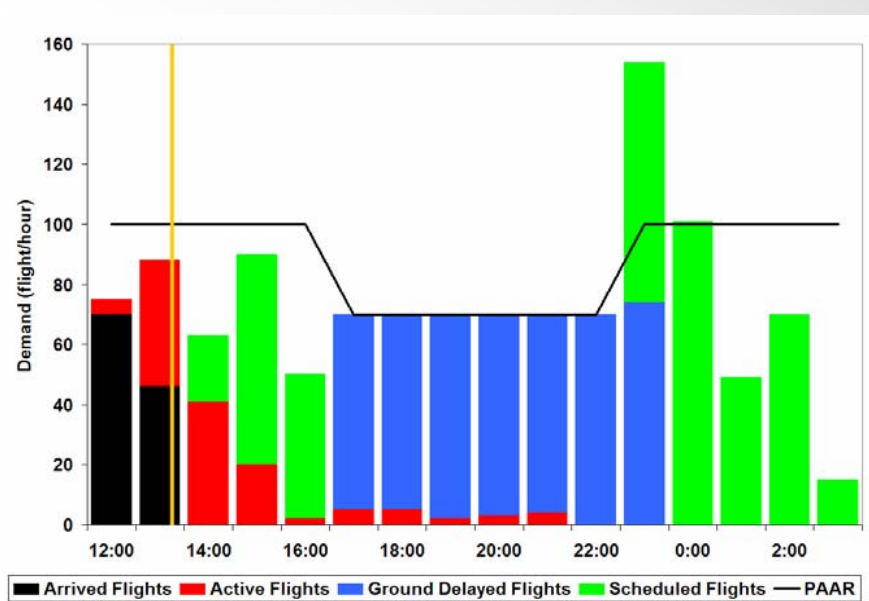
What is a GDP?

- GDPs are traffic management initiatives used to strategically manage arrivals at an airport by controlling the departure times of flights going to that airport.
- A GDP is run in two situations:
 - Airport arrival **capacity is reduced** (e.g., weather)
 - **Arrival demand to the airport is high** (e.g., local convention)



8

Before GDP



After GDP

GDP Parameters



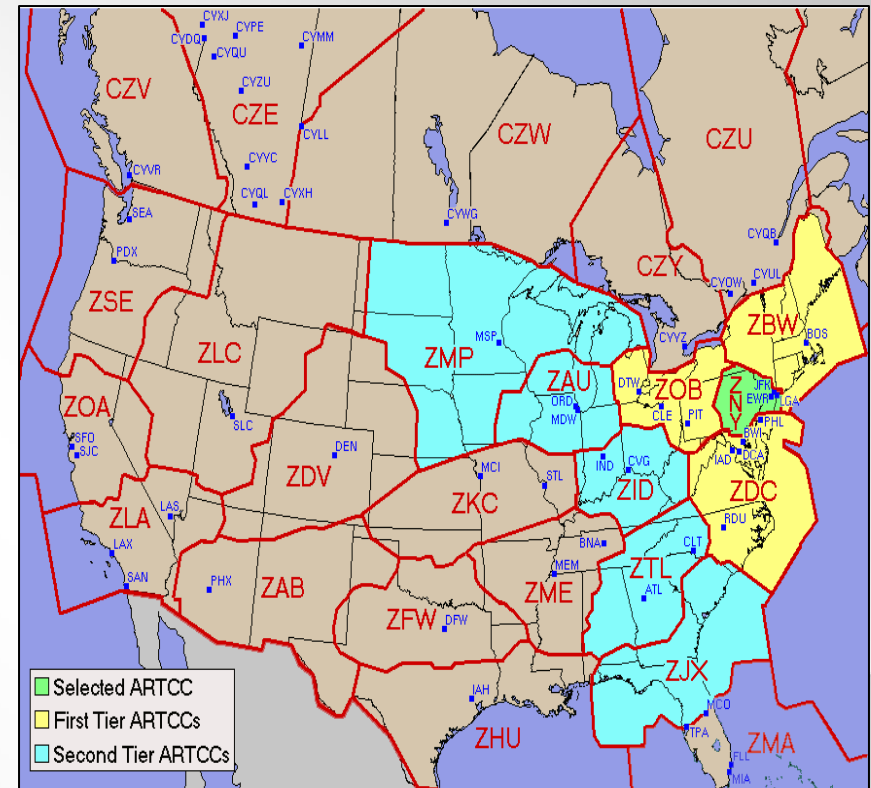
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1. GDP Start Time and GDP End Time

- If a flight is scheduled to arrive between GDP Start and End Time, it is controlled by the GDP.

2. Scope

- It specifies flights departing from which origin airports are controlled by the GDP.
- There are 2 types of scope:
 1. Tier Scope (control by centers)
 2. Distance scope (control by a radius)



3. Program Airport Acceptance Rate (PAAR)

- PAAR specifies the capacity at the airport during GDP hours.

GDP Arrival Slots

- The slots given to airlines during GDPs are not considered as “regular” slots.
 - IATA scheduling guidelines explicitly state that planned schedules decided on biannual conferences and adjustments to these schedules with ATFM initiatives are quite different and unrelated. [IATA 2000]
 - The slots under High-Density rule are often interpreted as “the right to schedule or advertise a flight at a specific time”, which entails no explicit right on the day of operation. [Vossen 2002]
- *Allocation of slots during GDPs can have different rationing rules than every-day operations.*
 - *Ration-by-Passengers? Ration-by-Environment-Friendly?*
- *Arrival Slots in GDPs are time intervals to achieve PAAR.*
 - AAR = 62 ac/hr
 - GA factor = 2 ac/hr
 - PAAR = AAR – GA factor = 62 - 2 = 60ac/hr = 1 ac/min





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Ration-by-Schedule (RBS)

incentivizes early flight scheduling

- RBS = Ration-by-Schedule
 - “First scheduled, First served”
 - Slots are assigned to flights based on their **published** scheduled times of arrival (*not reported arrival times*).
 - RBS incentivizes airlines to schedule early.

			Before GDP		After GDP		
	Flt.No	OAG	Ava.Slot	Delay	Ava.Slot	SLOT	Delay
	F1	13:00	13:00	0	13:00	13:00	0
Cancelled	F2	13:01	13:01	0	13:02	13:04	3
	F3	13:02	13:02	0	13:04	13:06	4
Exempt	F4	13:02	13:03	1	13:06	13:02	0
	F5	13:02	13:04	2	13:08	13:10	8
	F6	13:05	13:05	0	13:10	13:12	7
	F7	13:06	13:06	0	13:12	13:14	8
Exempt	F8	13:07	13:07	0	13:14	13:08	1
	F9	13:10	13:10	0	13:16	13:16	6
	F10	13:10	13:11	1	13:18	13:18	8
Total Delay				4			45
Capacity			60 ac/hr		30 ac/hr		

What is Equity?

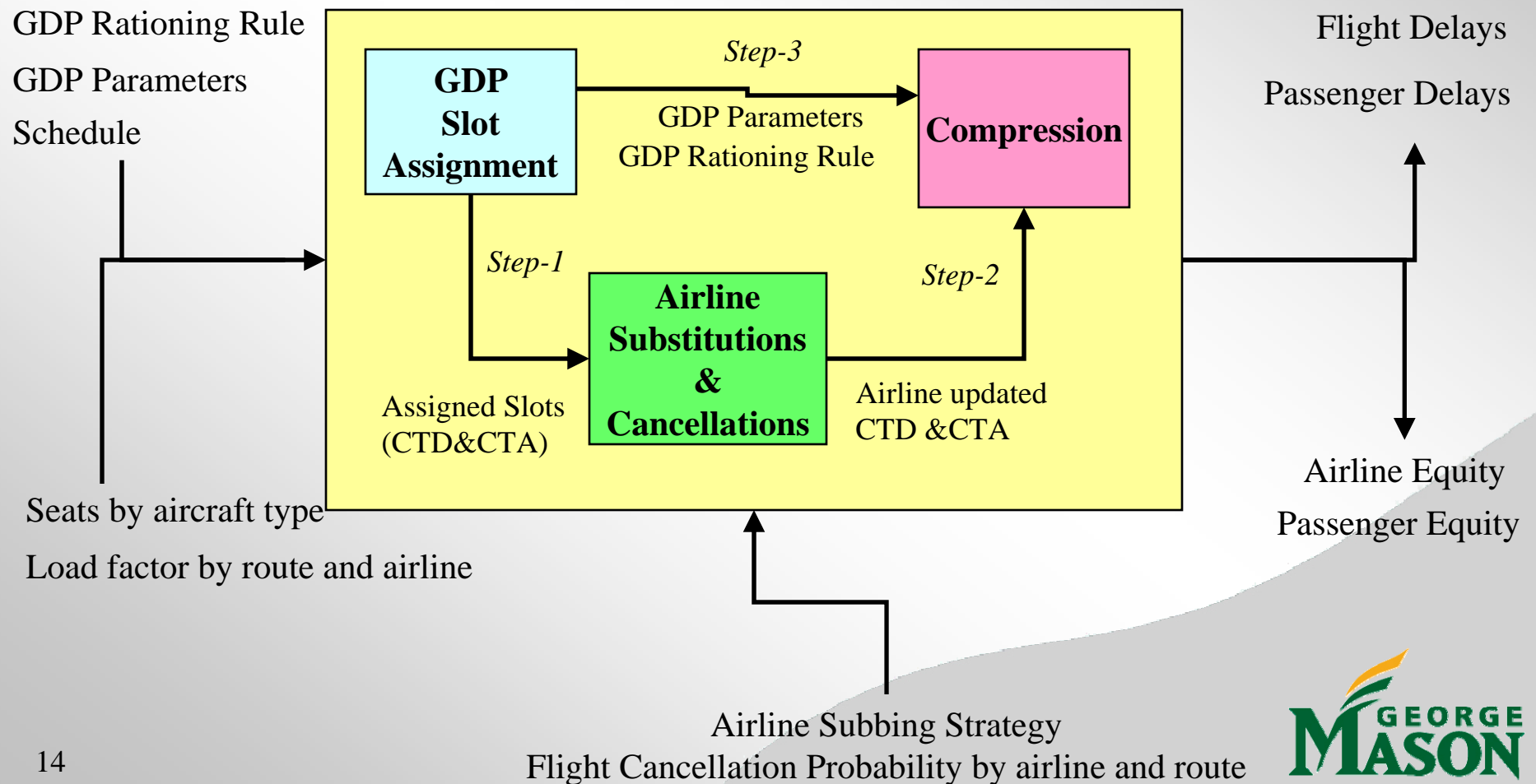
- Equity becomes an issue whenever available **arrival slots at an airport (goods)**, which are held in common by a group of users, must be allotted to them individually.
- **Equity means distributing cost (receiving delay) or distributing benefit (receiving a slot) fairly** when the arrival demand exceeds the capacity at an airport .
- An allocation is usually the result of three different types of decisions:
 1. **Supply decision** : Amount of good/burden to be distributed (*Arrival Slots*)
 2. **Distributive decision**: the principle by which the good/burden is distributed among eligible parties. (*GDP Rationing Rule*)
 3. **Reactive decision**: the response of individuals to two institutional decisions made above. (*Impact of the GDP Allocation on Airlines, Passengers and the Airport*)

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GDP Rationing Rule Simulator



GDP Rationing Rule Simulator : Slot Assignment Pseudo Algorithm



STEP-1: Calculate required variables for each flight

- SRTA = Scheduled Gate Time of Arrival – Taxi_in Time (10 minutes)
- SRTD = Scheduled Gate Time of Departure + Taxi_out Time (10 minutes)
- ETE = SRTA – SRTD
- PAX = Available Seats * Load Factor
- Available Seats = Average number of seats for a given Aircraft Type (ETMS database)
- Load Factor = Average yearly load factor for a given airline from a given origin (BTS database)

STEP-2: Find flights in GDP

- Flight is not international
- Flight's Departure Airport is in GDP scope
- Flight's SRTA is between GDP Start Time and GDP End Time

STEP-3: Create priority queues

- Highest Priority Queue: Exempt flights
- Low Priority Queue : Non-exempt flights

STEP-4: Create slots

- PAAR = Number of Available Slots for 15-min bins
- Slot Size = 15 / PAAR
- Slot (i) = GDP Start Time + (Slot Size*i)

STEP-5: Assign slots to flights

- Get EXEMPT flights
- Sort by SRTA
- Assign a slot to each flight
 - If Slot (i) > SRTA , CTA = Slot (i)
 - If Slot (i) ≤ SRTA < Slot (i+1), CTA = SRTA
- CTD = CTA – ETE
- Get Non-exempt flights
- Sort by GDP Rationing Rule criteria, then by SRTA
- Assign a slot to each flight
 - If Slot (i) > SRTA , CTA = Slot (i)
 - If Slot (i) ≤ SRTA < Slot (i+1), CTA = SRTA
- CTD = CTA - ETE

GDP Rationing Rule Simulator : Airline Substitution and Cancellation



STEP-6: Cancel Flights

- *Cancellation Probability: Average yearly probability of cancellation for a given airline from a given origin*

$$\text{Cancellation Probability} = \frac{\text{No. cancellations in 2006 for airline A from B airport}}{\text{No. scheduled arrivals in 2006 for airline A from B airport}}$$



STEP-7: Substitute flights

- *Order each airline flights by Substitution Strategy*
 - *If Substitution Strategy 1, order flights by increasing SRTA.*
 - *If Substitution Strategy 2, order flights by decreasing PAX.*
- *If a flight is cancelled, OpenSlot (i) = Cancelled Flight's Slot*
- *Substitute the next flight in the list,*
 - *If the flight's CTA > OpenSlot (i)*
 - *If OpenSlot (i) > SRTA, CTAnew = OpenSlot (i)*
 - *If OpenSlot (i) ≤ SRTA < OpenSlot (i) + SlotSize, CTAnew = SRTA*
- *CTDnew = CTAnew – ETE*
- *Move passengers to the next flight if there are available seats.*

GDP Rationing Rule Simulator : Compression Pseudo Algorithm



STEP-8: Run Compression

- Sort all slots by increasing Slot Time
- Find unassigned slots (OpenSlot (i))
- Sort all non-cancelled flights by GDP Rationing Rule
- Check if the unassigned slot can be used by
 - a flight operated by CDM member airlines.
 - If not, any remaining flights.
- Assignment is done
 - If $\text{OpenSlot (i)} > \text{SRTA}$, $\text{CTA}_{\text{new}} = \text{OpenSlot (i)}$
 - If $\text{OpenSlot (i)} \leq \text{SRTA} < \text{OpenSlot (i)} + \text{SlotSize}$, $\text{CTA}_{\text{new}} = \text{SRTA}$
- $\text{CTD}_{\text{new}} = \text{CTA}_{\text{new}} - \text{ETE}$
- Stop when all unassigned slots are checked



STEP-9: Issue Planned CTA and CTDs

- Validate CTA and CTD assignments for each flight
- If any problems, go back to Step-2.
- If not, calculate Planned GDP efficiency and equity metrics

GDP Rationing Rule Evaluator: Metrics and Stakeholders



1. *Airlines* : Users of NAS resources.

- Efficiency metric:
 - Flight delays
 - Fuel burn
- Equity metric:
 - By number of flights

2. *Passengers* : The “real” customer of ATS.

- Efficiency metric:
 - Passenger delays (due to flight delays and cancellations)
- Equity metric: By distance (origin airport)

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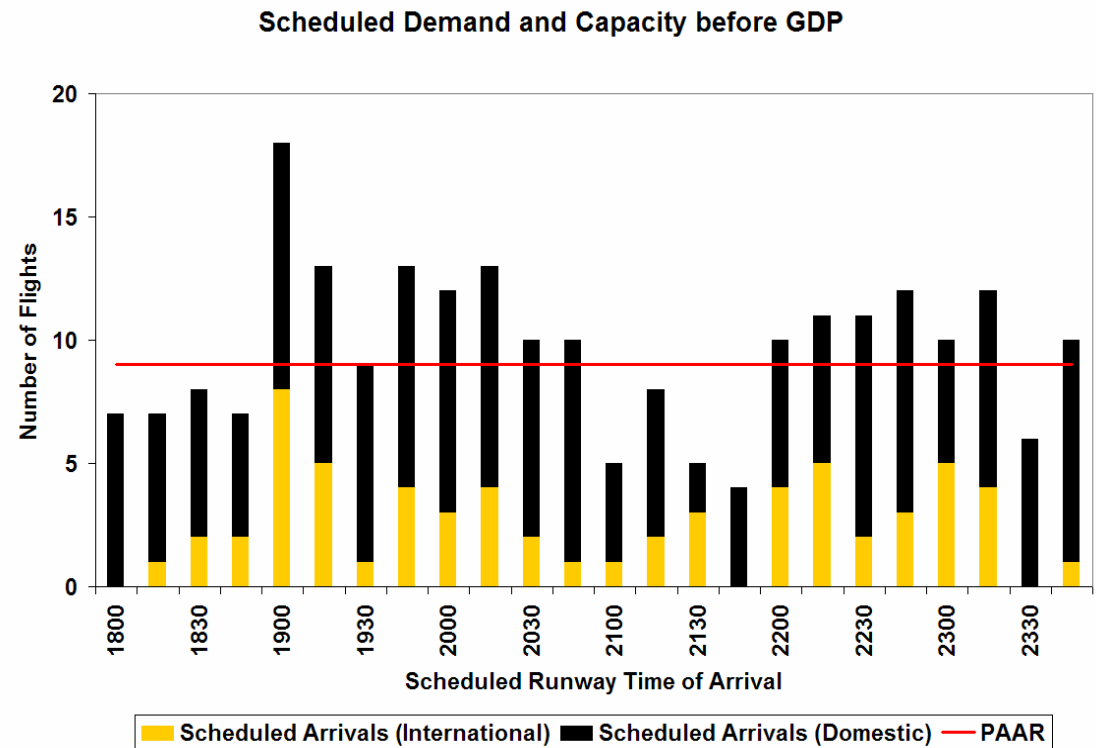
EWR Case Study (6/10/2006)



- GDP Start Time: 18:00
- GDP End Time : 23:59
- PAAR : 9ac/15min
- Scope: All
- Exempt: International

- Total Flights: 231 flights
 - International (exempt): 63 flights
 - Domestic (affected): 168 flights

- Total passengers: 25,501 pax
 - International: 11,516 pax
 - Domestic: 13,985 pax
- 26 major airlines
- 109 origin airports



EWR Case Study:

Alternate Rationing Rules



- Three different rationing rules are implemented:
 1. Ration-by-Schedule (RBS)
 - Earlier scheduled arrival time, earlier assigned slot.
 2. Ration-by-Aircraft Size (RBAcSize)
 - Larger the aircraft size, earlier the assigned slot.
 - If two flights have the same aircraft size, the earlier slot is assigned to the earlier scheduled flight.
 - Heavy (23%)
 - Large (77%)
 - Small (1%)
 3. Ration-by-Passengers (RBPax)
 - Larger the number of passengers on-board, earlier the assigned slot.
 - If two flights have the same number of passengers, earlier slot is assigned to the earlier scheduled flight.

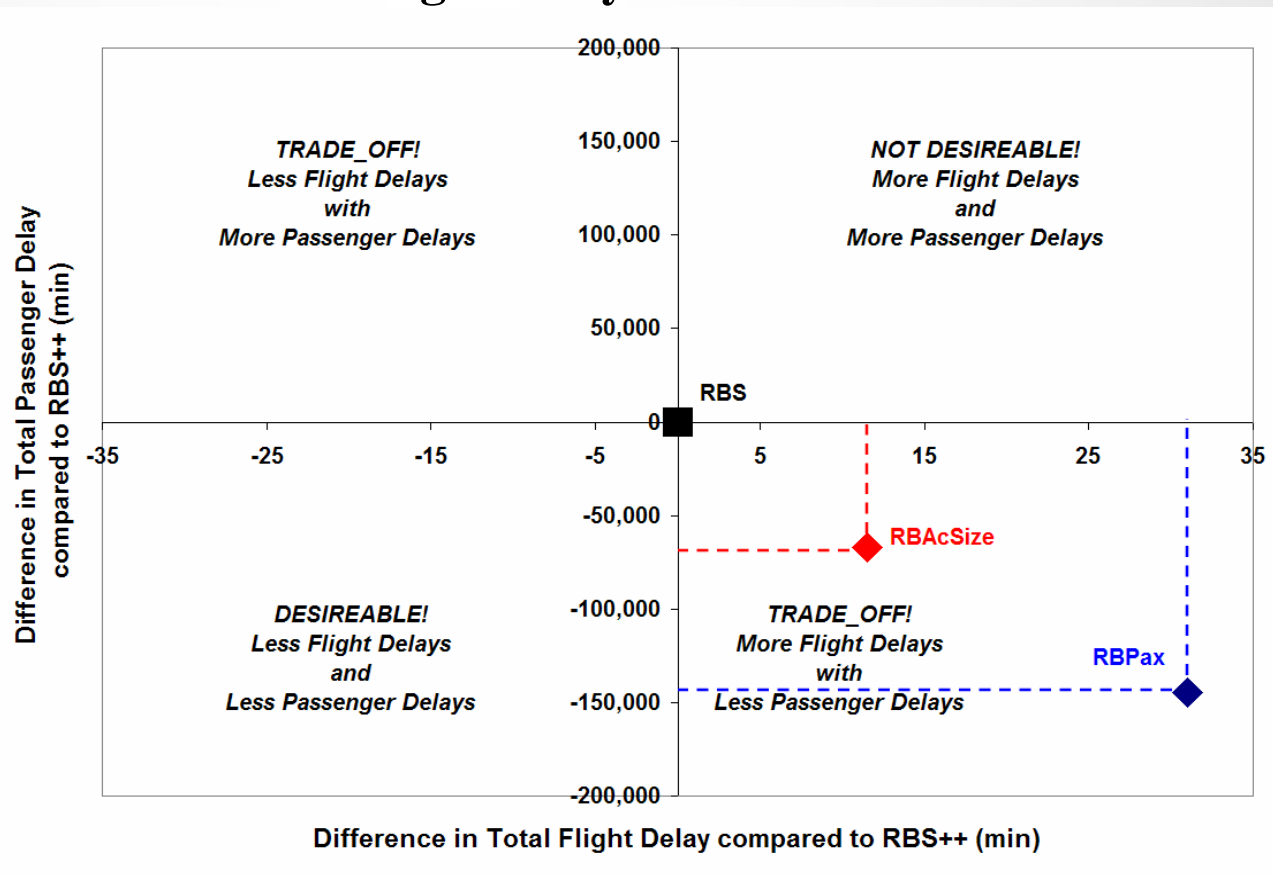
EWR Case Study:



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Comparison of GDP Efficiency

- Compared to RBS, **RBACSize** results in **10% decrease in total passenger delay** but a **0.4% increase in total flight delay**.
- Compared to RBS, **RBPax** results in **22% decrease in total passenger delay** but a **1.1% increase in total flight delay**.



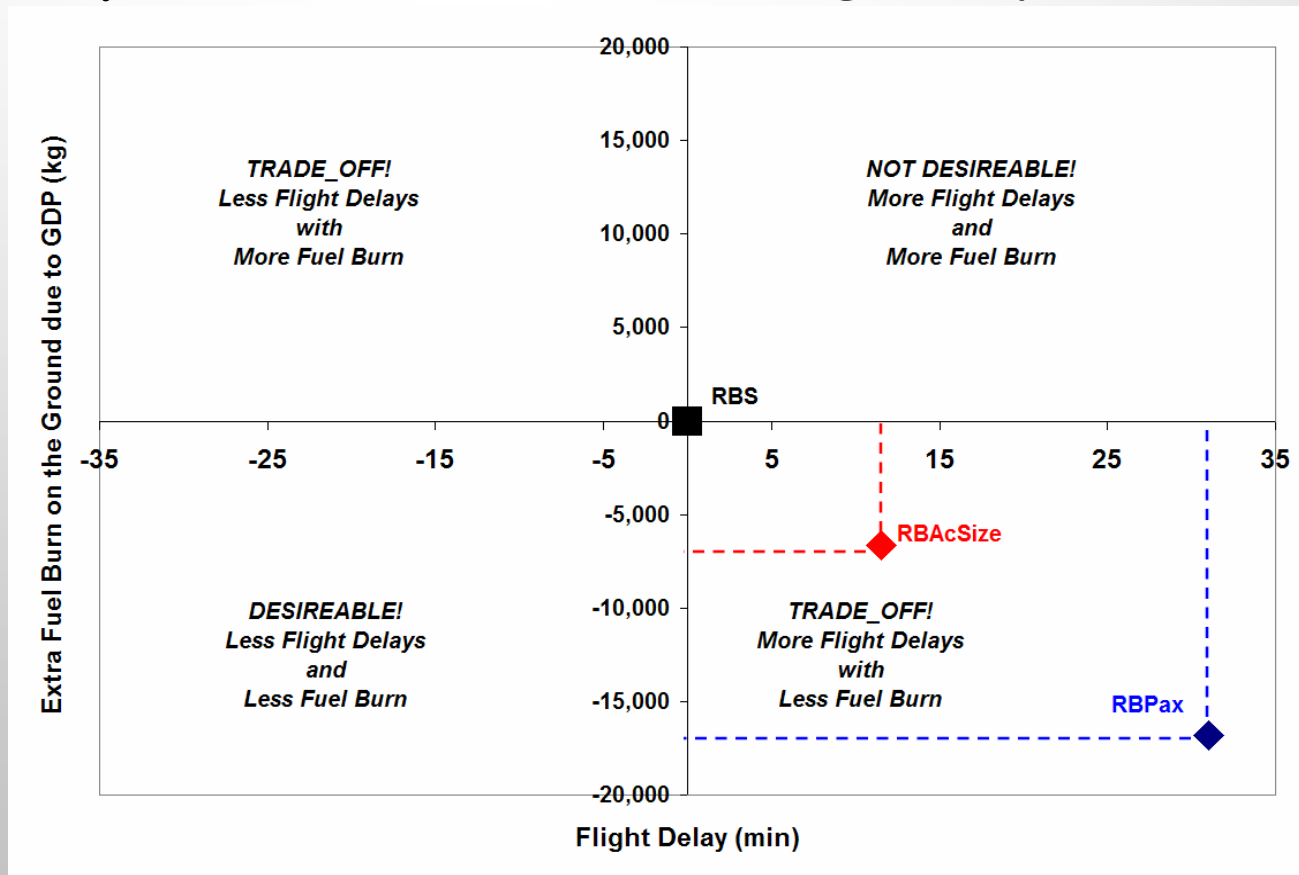
EWR Case Study:



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Comparison of GDP Efficiency

- Compared to RBS, **RBACSize** results in **25% decrease in total extra fuel burn** due to GDP delays but a **0.4% increase in total flight delay**.
- Compared to RBS, **RBPax** results in **63% decrease in total extra fuel burn** due to GDP delays but a **1.1% increase in total flight delay**.



EWR Case Study: Dis-Utility of GDP

- Since all GDP Rationing Rules result in a trade-off, the decision can be made using utility theory.
- Disutility of implementing a GDP using a given rationing rule can be calculated using two efficiency metrics.

$$\text{Disutility}_{\text{RBS}} = w_{\text{TFD}} * \left(\frac{\text{TFD}_{\text{RBS}}}{\text{TFD}_{\text{RBS}} + \text{TFD}_{\text{RBAC}} + \text{TFD}_{\text{RBPax}}} \right) + (1 - w_{\text{TFD}}) * \left(\frac{\text{TPD}_{\text{RBS}}}{\text{TPD}_{\text{RBS}} + \text{TPD}_{\text{RBAC}} + \text{TPD}_{\text{RBPax}}} \right)$$

w_{TFD} : Weight of Total Flight Delay

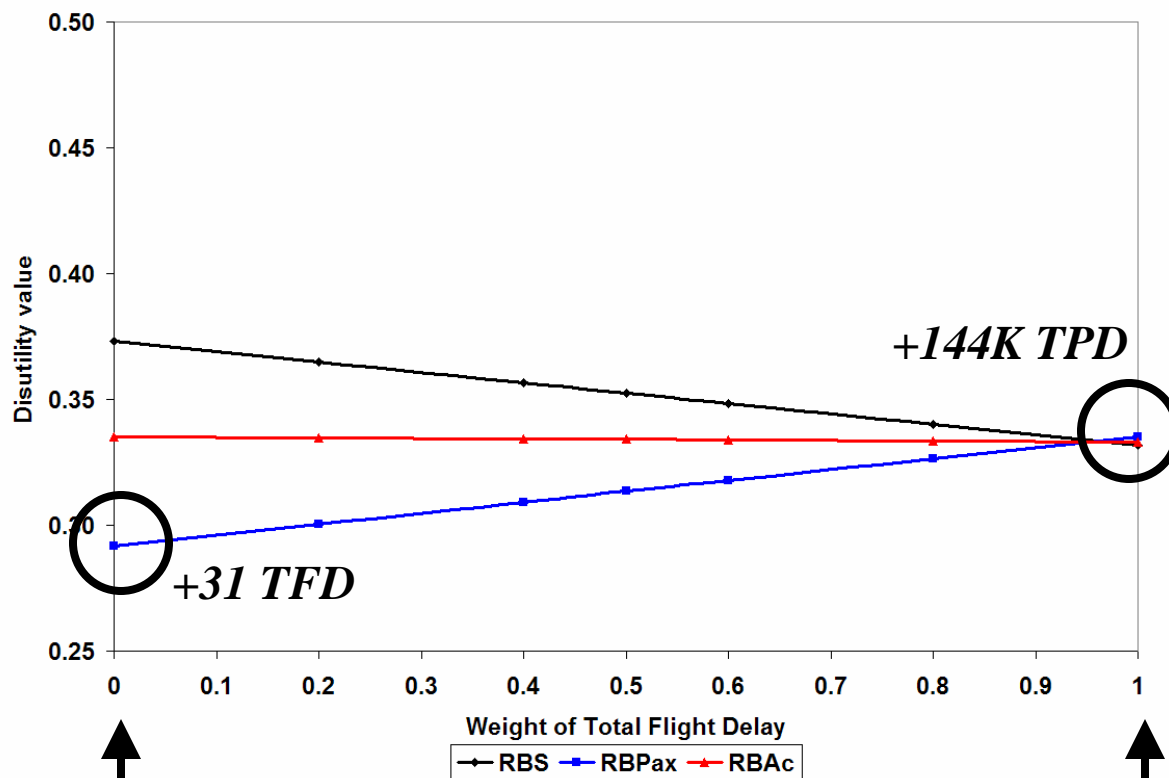
$(1 - w_{\text{TFD}})$: Weight of Total Passenger Delay

TFD_{RBS} : Total Flight Delay as a result of RBS

TPD_{RBS} : Total Passenger Delay as a result of RBS

EWR Case Study:

RBPax minimizes GDP Dis-utility



- RBS (the current rule) is only acceptable when the system solely focuses on airlines.
- If both airlines and passengers are considered, RBPax minimizes the total GDP disutility.

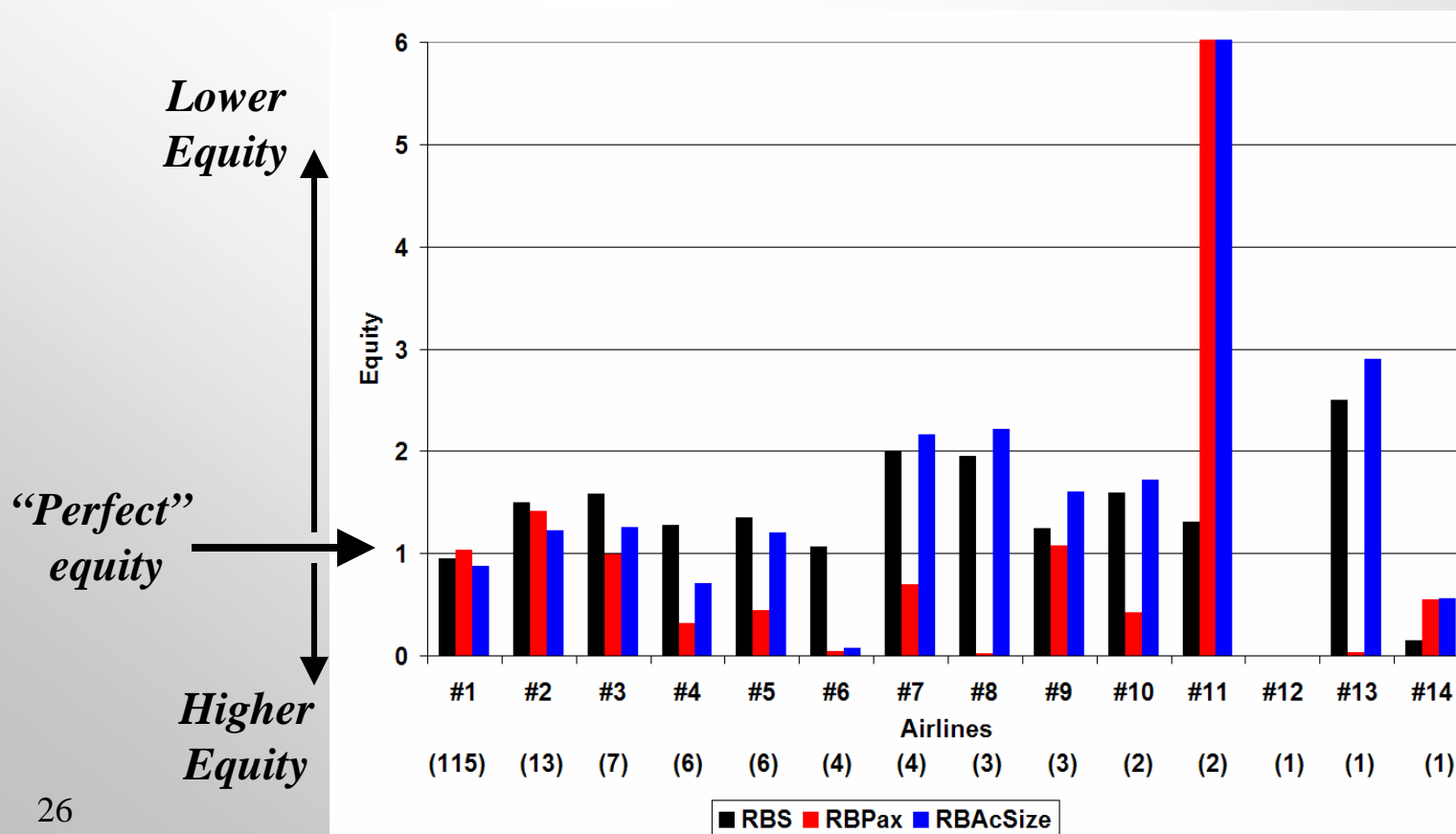
Passenger Delay Only

Flight Delay Only

EWR Case Study: Airline Equity

- The more flights an airline has, the more flight delay it should be assigned.

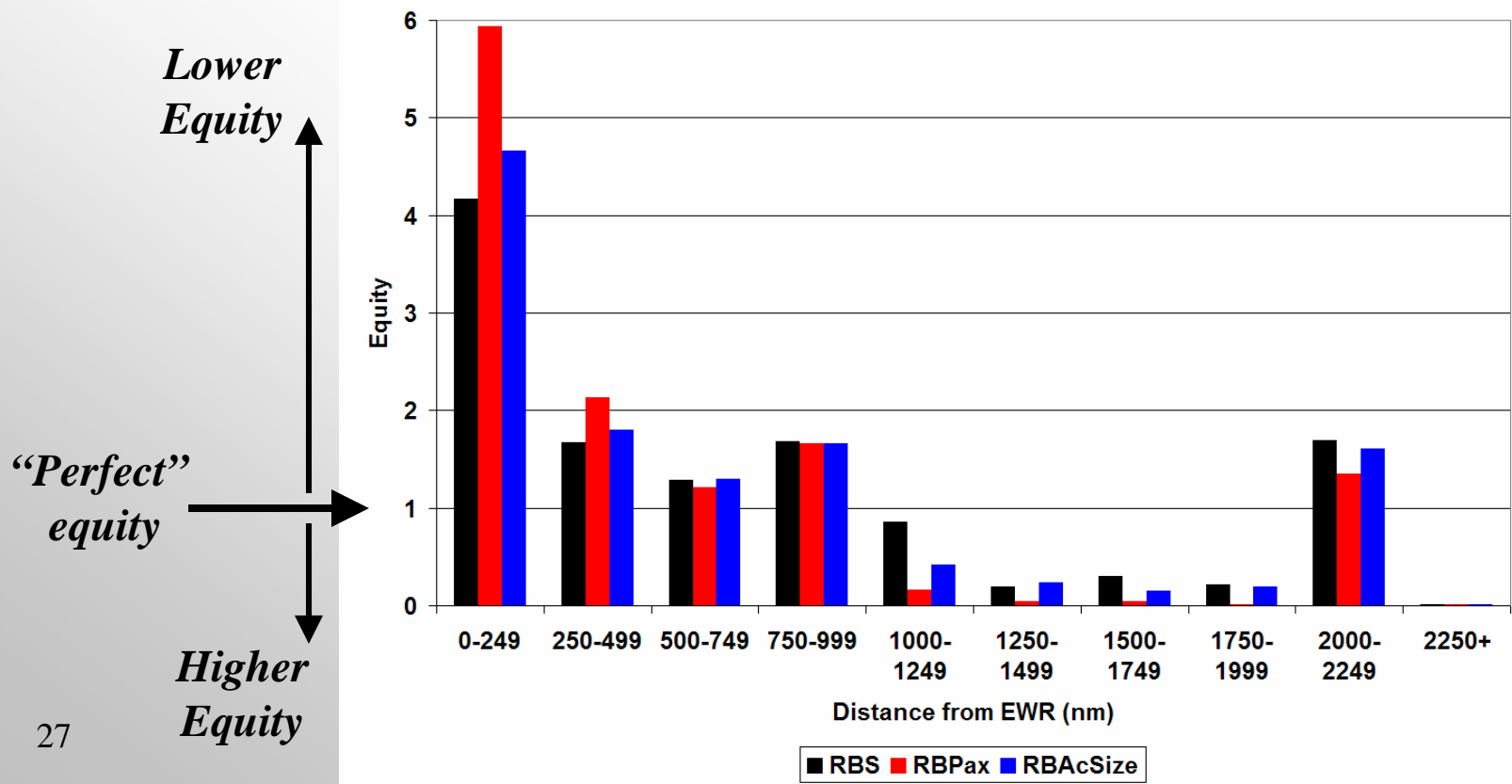
$$\text{Airline Equity} = \frac{(\text{Flight Delay of Airline A} / \text{Total GDP Flight Delay})}{\text{by Operations} \quad (\text{Number of Flights from Airline A} / \text{Total Number of Flights in GDP})}$$



EWR Case Study: Passenger Equity

- The more passengers an airline has, the more total passenger delay it should have.

Equity by Passengers = $\frac{\text{Passenger Delay of Distance A}}{\text{Total GDP Passenger Delay}} \div \frac{\text{Number of Passengers for Distance A}}{\text{Total Number of Passengers in GDP}}$



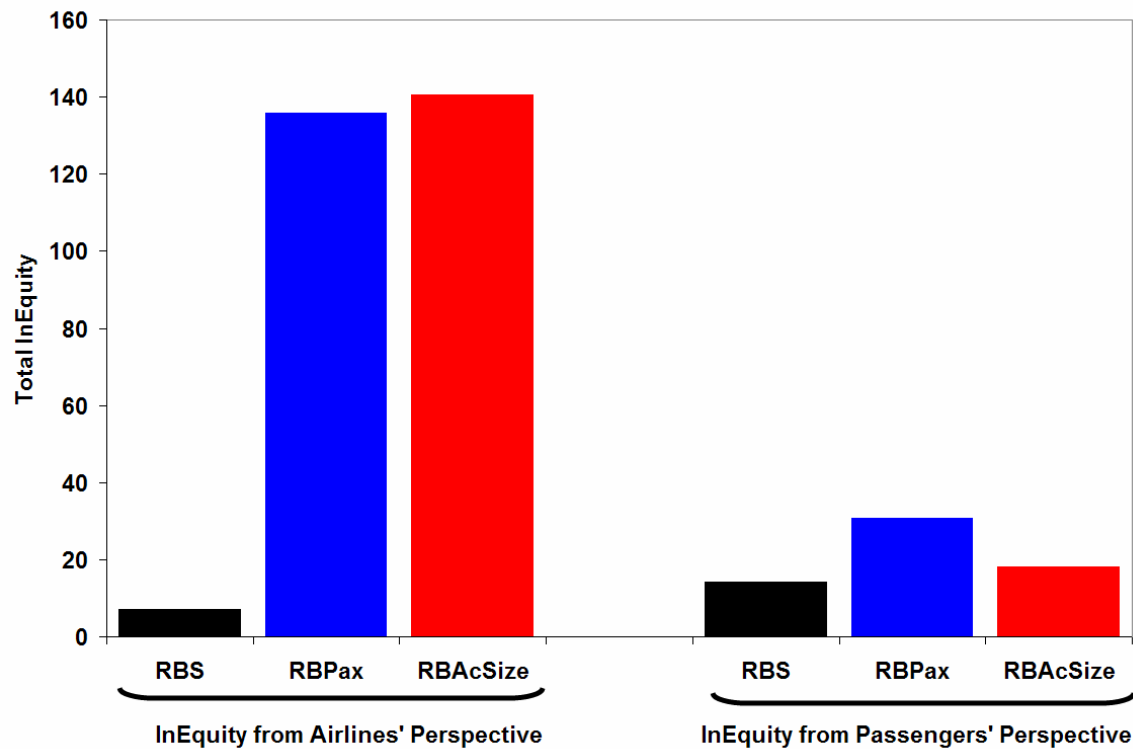
EWR Case Study:



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Comparison of Total GDP Inequity

- Total GDP Inequity is the sum of squared differences between a category's value and the "perfect" equity (1).
- RBS (the current rule) results in least airline and passenger inequity. However, this favorable equity is achieved at the expense of more than 144,000 minutes more of passenger delay.



EWR Case Study: Results



- Three GDP rationing rules are compared for a GDP at EWR airport.
- *Different rules trades flight delays and passenger delays differently.*
 - *Ration-by-Passenger (RBPax)* decreased total passenger delay by **22%** and decreased total fuel burn by **63%** but increased total flight delay by **1.1%** compared to RBS.
 - *Ration-by-Aircraft size (RBAc)* decreased total passenger delay by **10%** and decreased total fuel burn by **25%** but increased total flight delay by **0.4%** compared to RBS.
- *Ration-by-Passenger results in the minimum GDP disutility* when both airlines and passengers are considered in the decision-making.
- *The current rule (Ration-by-Schedule) is only preferred when the system solely focuses on airlines.*
- The current rule (Ration-by-Schedule) results in the least total GDP inequity for both airlines and passengers. However, this is achieved with a great inefficiency loss in passenger delays (144,407 more minutes)



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Observations



- 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, these rationing rules incentivize certain airline behavior.
- Ration-by-Passenger could, in the long run, result in the migration of airline fleets to larger sized aircraft that would increase the passenger flow capacity and improvement of air transportation capacity.
- This incentive does not directly result in reduced frequency, but reduced frequency may be a by-product of upgauging.

Future Work



- Results presented here are only for one GDP day. The impact of different rationing rules over the long-term will be investigated.
- Extend this work to include
 - Different rationing rules (e.g. Ration-by-Environmental impact, Ration-by-Auction)
 - The impact of GDP scope
 - The impact of schedule density
 - The impact of cancellation policy
 - The impact of airline substitution strategy (Substitution strategy 1 vs. strategy 2)
 - Airport efficiency and equity metrics

Back-up Slides

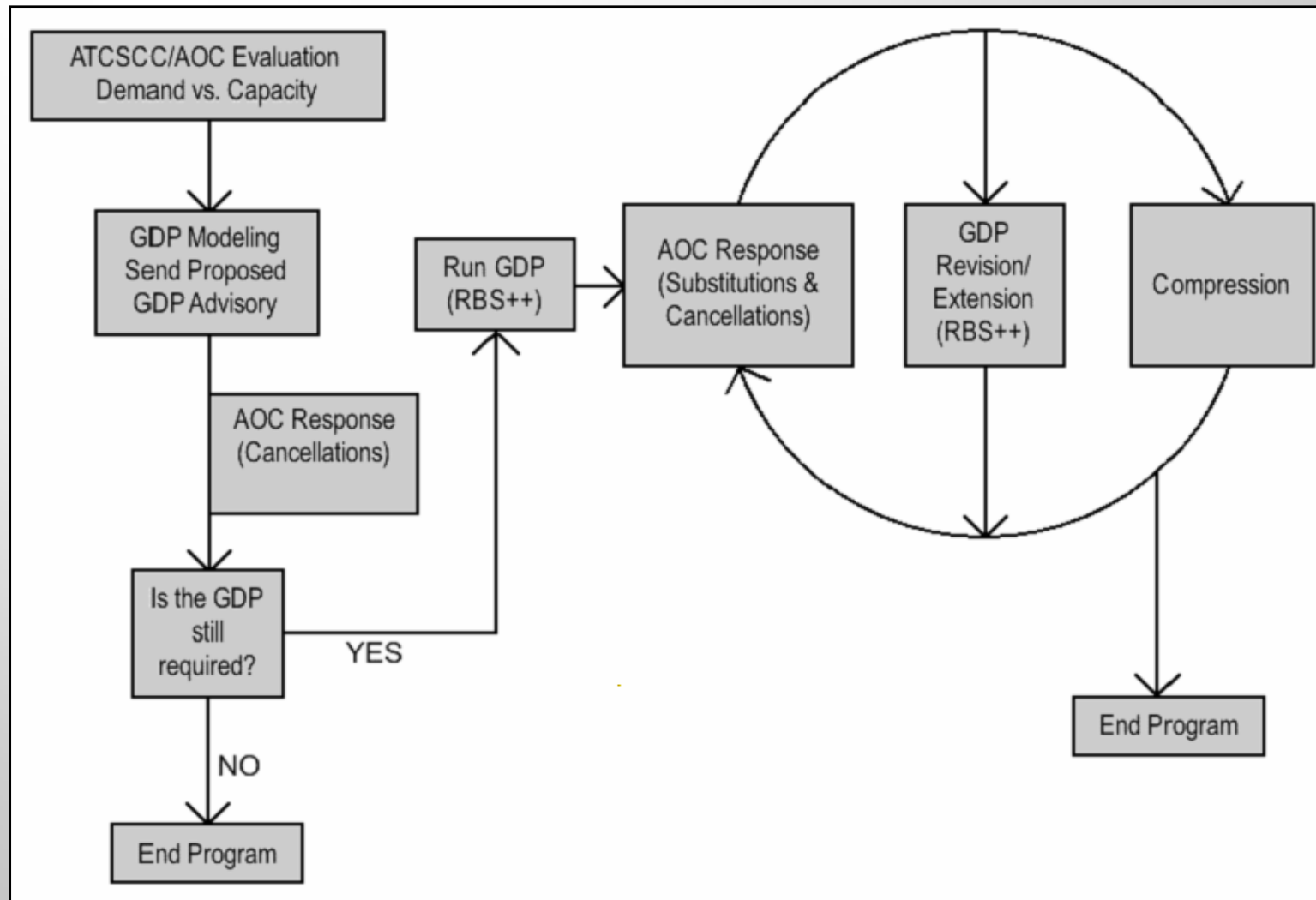


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How does GDP work?



Why is “Equitable Allocation” Important?



1. A primary objective of the FAA's ATM functions is to provide fair and equitable access to the National Air Space.
2. The CDM experience has shown that not only equitable treatment of carriers is advisable, but it may be a necessary condition for efficient use of resource.
3. Equity provides a framework for the allocation process and forces to consider the objective of the allocation process.
 - It is impossible to measure efficient use of a resource without having some understanding of how users value the resource.

Literature Review Summary



No	Article	Rationing Rule	Focus	Subs&Cancel Modeling	Optimization/ Simulation	Problem	Airport
1	Vossen (2002)	<ul style="list-style-type: none"> • Airline-based Delay Allocation • Cost-Sharing (Shapely Value) • Proportional Random Assignment • Total Deviation Model (Compression alternative) • Greedy Procedure (Ideal Shares) (Compression alternative) • Total Deviation Model with Proportional Random Assignment • Greedy Procedure with Proportional Assignment 	Airlines	N	Optimization	<ul style="list-style-type: none"> • Jan-May 2001 with variations 	<ul style="list-style-type: none"> • Not available • Not available • BOS & LGA • Not available • EWR & LAX • BOS • BOS
2	Hoffman (2007)	<ul style="list-style-type: none"> • Ration-by-Distance • Equity-based-Ration-by-Distance 	Airlines	N	Simulation Stochastic	1 day	SFO
3	Hall (1999 & 2002)	<ul style="list-style-type: none"> • Objective-based Allocation Method • Arrival-Departure Capacity Allocation Method (ADCAM) 	Airlines	Y	Simulation Stochastic	July 10, 1997	ORD, MSP
	Manley (2008)	<ul style="list-style-type: none"> • Ration-by-Passenger • Ration-by-Emissions&Noise • Ration-by-Auction 	Airlines Passengers Airport	Y	Simulation Stochastic	summer and winter 1 day with variations	EWR, LGA, JFK

- Young, Peyton H.; “*Equity: In Theory and Practice*”; Princeton University Press, 1984.
- Litman, Todd. Evaluating Transportation Equity: Guidance for Incorporating Distributional Impacts in Transportation Planning. *Victoria Transport Policy Institute, Victoria, Canada.* Mar 8, 2006.

