Results of a Congestion Management Study for Day-of-Flight

GRA, Incorporated:
Frank Berardino, Richard Golaszewski
George Mason University:
Karla Hoffman, Lance Sherry, Kara Aqbal
Sensis, Incorporated
George Hunter, Diego Escala, Huina Gao

CONTRACT SPONSOR: NASA (Michael Bloem)

Outline of Talk

- Project introduction & problem overview
- Overview of congestion pricing and auctions and relationship to airspace problem
- Market based TFM concept development
- Down-select and fast time simulation results
- HITL simulation and survey results
- Conclusions and future research

Research Scope

- Ground Delay Programs are based on a FIFO (Ration-by-schedule) approach (i.e. “Ration by Schedule”)
- Ration by Schedule does not consider the consequences to the ***passengers***
- Even with Cooperative Decision Making that allows swapping of slots, the bias is towards the airline with many slots at a given airport.
- This research is designed to evaluate whether there are ***economic concepts*** that can be incorporated into the Traffic Flow Management (TFM) concepts
  - Economic Efficiency = slot (permission to depart) goes to those that value it the most)
- Model should consider needs of “players”
  - **TFM** wants to push as many planes through system as possible
  - **Airlines** argue that they need a mechanism that allows them to accommodate their most valuable flights.
  - **Passengers** want on-time performance
- **Economics** argues that users be charged the cost that they impose on other

Research Agenda

1. Provide NASA with a literature search that details market-based concepts applied in other government applications and consider their applicability to the current airspace congestion problem.
2. Develop and evaluate different market-based Traffic Flow Mgt. (TFM) concepts through fast-time NAS-wide simulation to quantify the possible impact of various concepts.
3. Create a down-select process for evaluating alternatives and choosing the most viable
   - Simulation results
   - Discussion with airlines
4. Design a Human-in-the-Loop simulation that gives feedback on our design choices.

Ground Delay Programs

The current *short-term strategy (day of flight)* for reducing air traffic congestion delay is Ground Delay Programs (GDP) and Air Flow Management (AFM).

These processes are mechanisms to decrease the rate of incoming flights into an airport when the supply exceeds capacity.

- Under GDP, flights to affected airports are held at their departure airport for later takeoff
- Similarly, AFM keeps airplanes on the ground, where possible, and reroutes to avoid congested areas
- The ordering of flights is a first-come first-served system whereby departures are rationed to the arrival airport based on scheduled time of arrival
- Once schedule collapsed, airlines can swap locations in the queue among their flights and can give back a location in the queue for a later location– called **Collaborative Decision Making (CDM)**

The motivation behind GDPs and AFMs is to **convert** the foreseen **airborne delays into** *safer and cheaper* **ground delays**. [Ball, Lulli 2003]

Need for Demand Management

- Delays have continued to increase in National Air Space
- New York airports are a major source of delays throughout the NAS but congestion at other airports increasing
- At a few airports in the US, “Slot controls” are enforced to avoid over-scheduling.
  - Caps at Kennedy, LaGuardia, Newark, Reagan-National
- Slots are allocated based on historical presence (newer carriers are barred entrance unless Congress steps in).
- Even with slot controls, inclement weather and variable runway configurations creates congestion resulting in significant delays.
- A much larger set of airports is impacted by weather than just the slot-controlled airports.

Issues with Current System

- Capacity Issues
  - Caps set at NY airports are based on perfect weather days and don't consider variability due to different runway configurations, wind conditions, or other weather influences – all other airports impacted by weather and schedules have little regulatory control
- TFM Issues
  - Flight operators can only be assigned capacity based on their proportion in the scheduled flights
  - May not be economically efficient
    - Airline with many flights have many ways to choose when their flights depart
    - However, there is no mechanism for trades among airlines or trades among locations
    - Carrier with few valuable flights cannot control cancellation
  - Viable to gaming among mainline airlines
    - Low cost carriers and/or regional carriers might be forced to incur undue hardships

Overall conclusions when comparing auctions and congestion pricing:

- Auctions are mostly used for long-term rights:
  - Oil Drilling
  - Spectrum Use
  - Logging and Mining

  For the airline situation, an auction is most appropriate for the allocation of slots (rights to announce a departure or landing). These decisions are for airport access for periods of at least six months but could be for multiple years

- Congestion pricing approaches are mostly used for stochastic/dynamic situations
  - road and port pricing, revenue management and electricity
  - All have a highly *stochastic* component

  For the airline situation, congestion management approach is most likely to be used when weather reduces capacity below stated slot capacity.

Literature Review and Conclusions

- What can we learn from congestion pricing and/or auction uses in other government settings?
- Objectives in evaluating day of flight markets
  - Do they make sense?
  - Can they work in the real world?
  - Would they result in a "better" allocation of capacity?
- We reviewed applications in other venues
  - Huge literature review resulting in 2 papers to journals and three technical papers.
  - Conclusion:
    - Congestion pricing – very useful for dynamic (weather) issues
    - Auctions – allows the flexibility for long-term planning but difficult to implement for many unique interrelated objects

Probably best to have a **hybrid approach**

- Long term leases by auction
- Short Term stochastic changes handled by congestion pricing

What is airline(s) perspective?

- Airlines want to know "Where does the money go?"
  - Airlines do not trust either ATC or Airport Authorities and do not want to consider any scheme that adds additional tolls to the system
  - Airlines claim that the current process works well for most but not all of their flights.
  - Current problem: Some high-valued flights at airports that airline does not control are delayed excessively

- Airlines would like a trading mechanism incorporated into current CDM so that airlines could swap with each other to improve the schedule. It would be good if swaps could be across airports

- Only a small percentage of flights need more flexibility than already exists in Cooperative Decision-making Process

- For economic efficiency:
  - One should consider the amount of congestion caused by the given flight
  - One would like to insure that buy/sell/trades are available to all (i.e. airline cannot choose its trading partners)

Conclusions

The “day of flight” are constrained by the number of decisions that need to be made in a very short period of time

- Need time to close complex markets (multi-round auctions may be difficult for decision makers)
- Decisions are interrelated (various flights, airspace sectors)
- Ideally markets should trade using some price mechanism so that all decisions are on a common metric
- All players should have equal access to the resources if they are willing to pay for such access
- The current CDM mechanism has only very limited trading… can only “trade in” a slot to get a later slot.

We want to consider how to incorporate trading both among airlines and between airports for access when needed.

Conclusions

- Markets might improve the allocation of airspace
- Today, some operators may be willing to pay more for access to the NAS than others but can't
- Any time there are terms for trading assets a market can improve the allocation
  - Barter – one for one exchange is good
  - Price – trade for cash is much better –permits trades of assets not of equal value
- 3400 alternative market-based alternatives
- Four concepts had resonance

Concepts with most resonance: Free-pass permits

- Free-pass permits
  - "Free-pass" permits are provided to airlines whereby airline when using the permit can go to the front of the line.
  - <u>All permits are alike</u>
  - Permits are arrival airport-time bin specific (allowed to arrive within the 15 minute time period)
  - Airlines receive limited number of permits (e.g. 10-15% of IMR arrivals)
    - Quantity a percentage of airport capacity
    - Ration by schedule (RBS)
  - Flights with permits likely to have on-time departures even during bad weather
  - On day of flight, carriers can assign permits to any feasible flight, or sell it
    - Sales via Traffic Flow Management provider
    - Owner of permit posts an asking price
    - First buyer that meets the asking price wins it
  - Facilitates exchange of access rights on day of flight to higher uses

Concepts with most resonance: Priority Permits

- Priority permits
  - High, medium, low priority permits
  - <u>All flights have a permit</u>
  - Permits are arrival airport-time bin specific
  - Participating AOCs receive limited number of high and medium priority permits
    - Quantity a percentage of airport capacity
    - Ration by schedule (RBS)
  - Non participating users have low priority permits by default
  - Permits determine Traffic Flow Management flight priorities
    - High priority does not guarantee exemption from delays

Concepts with most resonance: Day of flight tolling

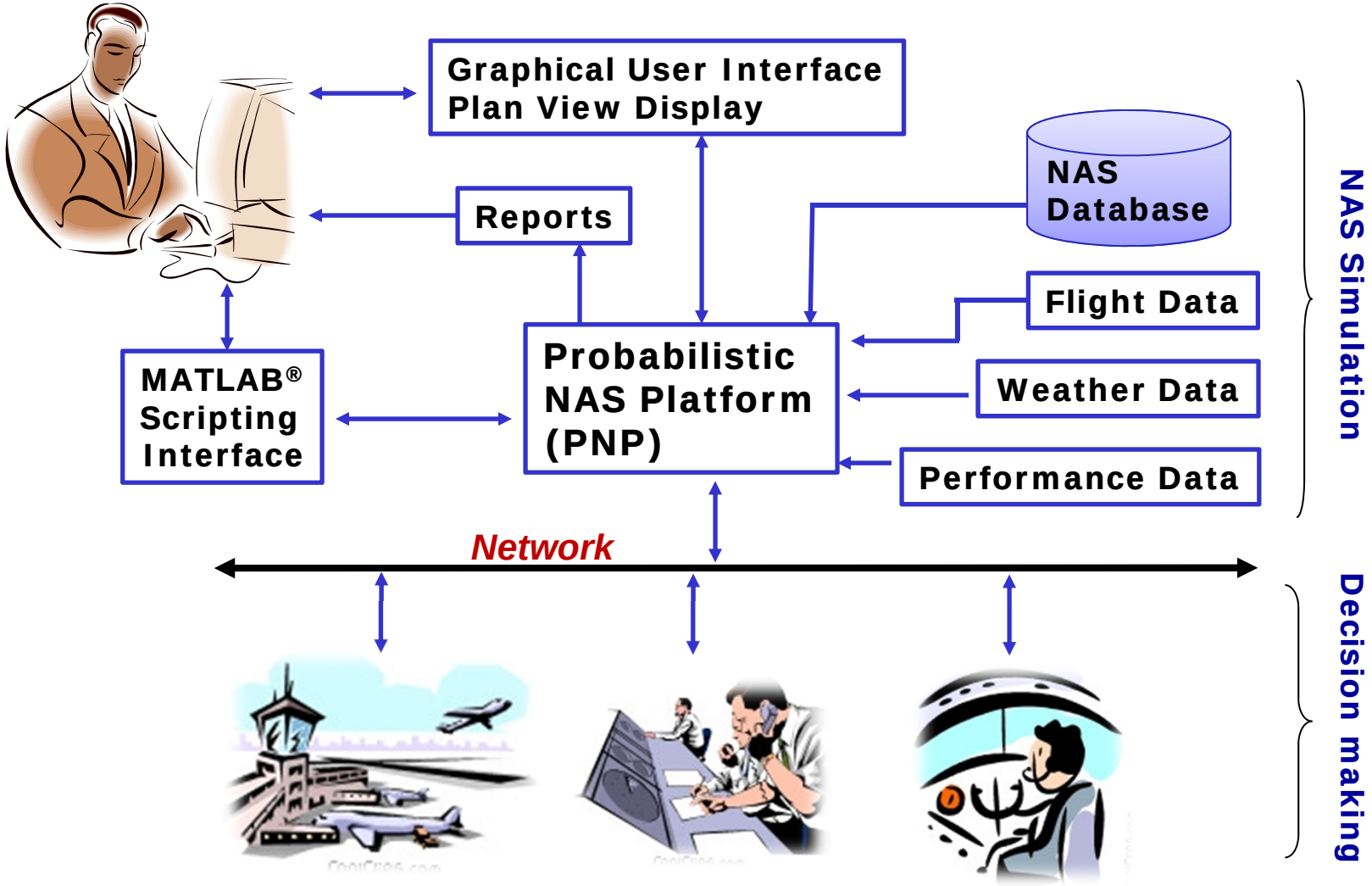
- Day-of-flight tolling
  - Flights imposing significant congestion are assessed a toll
  - Toll is computed based on Flight Congestion Cost, i.e. cost that a given flight imposes on all other flights in network (both airspace and runway use)

Concepts with most resonance: Willingness to Pay

- Willingness to pay
  - Airline provides Traffic Flow Managment (TFM) with a price at which they are willing to fly with no delay
  - TFM considers both amount of delay caused by flight and willingness to pay and ranks flights based on weighted average of these two issues

  - Hardest to get the metrics correct
  - Would like a “second price” approach… all players get to pay the same second price based on lowest price paid … but then cannot incorporate the amount that flight imposed on system.

PNP Architecture



Key Finding: Substantial Flight Delay Cost Savings

Free-pass permits:	$1.11M - $1.87M /day
Priority permits:	$0.74M - $3.0M /day
Day-of-flight tolling:	$2.64M - $6.58M /day

Annualized saving: 365 M – 2,190 M

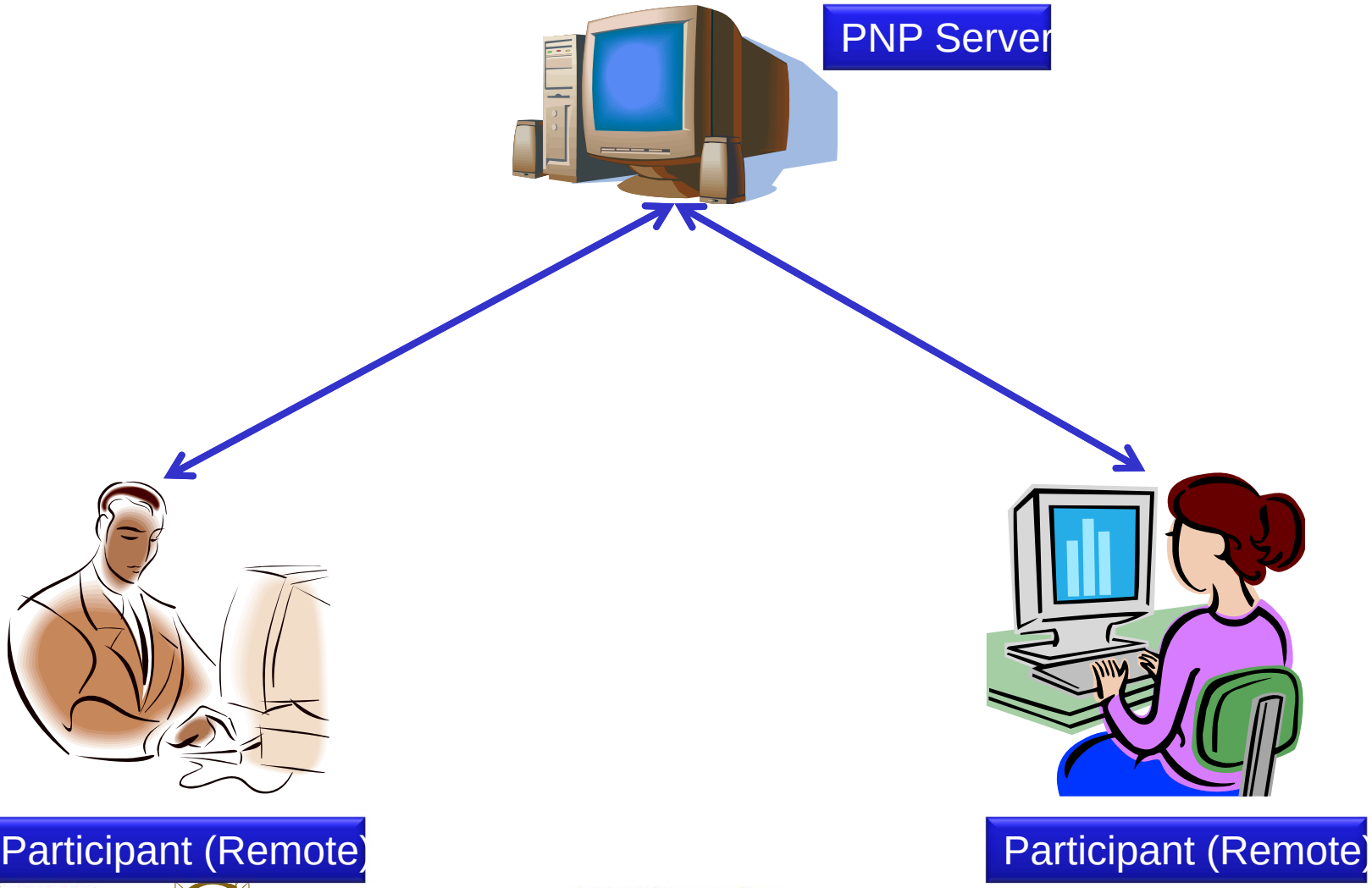
Concepts for HITL Simulation

- Collect people with direct experience in handling GDPs and AFPs for airlines
- Use the free-pass permit because it was most likely to be accepted and reduces complexity (only need to decide how to use 10-12% of total flights)
- An airline can apply a free-pass permit to *any flight capable of arriving at the given airport during the time-specific period that the free-pass permit specifies.* "Capable of arriving" means that the airplane can depart and fly a flight-plan that allows for a safe arrival at the designated airport in that time period.
- Two phases to experiment
  - Case I: Airlines may use its allocated permits on its own flights but trades among airlines are not allowed
  - Case 2: The airline may use its allocated permits on its own flights or they may choose to sell these permits to another airline at an amount specified.
    - Thus, airlines can provide "bids" to the system that state that they are willing to sell this permit to another airline for $X.
    - In this second experiment, airlines will be provided with a lump sum of cash at the beginning of the day to buy and sell permits.

Human in the Loop (HITL) Simulation

- Results should benefit from human decision-making
  - If humans offer no benefit over automated system, no need for humans
- Decision making process should be simple
  - Potentially high workload for participants (lots of flights)
- Behavior should support incentives
- Simulation should provide feedback on performance
  - These flights escaped delay -> now they can make their connections
  - You saved the airline this much $$$

HITL System



Simulation

- Each of the participants receives information of the following:
  - A description of the weather conditions expected for the day studied
  - A list of all flights that the airline has scheduled that day
  - A list of the permits available to that airline for that day
  - A description of each of the screens that will be available to the participants during the day.

Measurement concepts:

Costs are calculated in two ways:

- The calculation of Flight Congestion Cost: This is the cost that determines the congestion that this flight causes to the system.
- The calculation of Flight Delay Cost: This is the cost that the airline incurs (internally) based on the congestion the flight incurs.

What would constitute an improvement in the system:

- If the mechanism facilitates an outcome where users who are most willing to pay are given priority;

- A market may facilitate greater use of available scarce capacity; if some capacity is not used today and a market can either facilitate its use or, at a minimum, not prevent its use, then that also would be desirable.
- Throughput is either improved or not degraded
- Delays are shortened; Less average delay per passenter

Using own permits or buying permits of others

My Flights

Current time: 11:00 GMT

Current at-risk departures

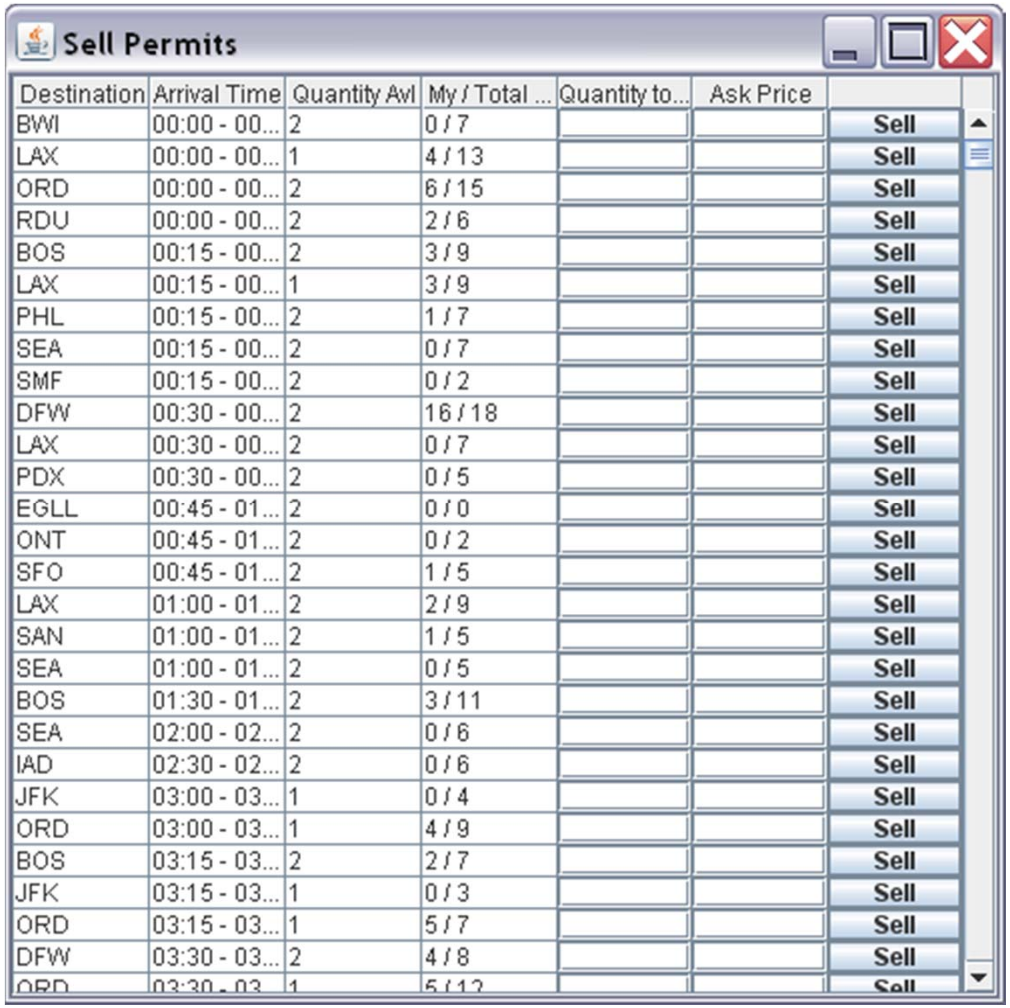
Aircraft ID	Equip	Orig	Dest	Sched Dep	Sched Arr	FDC	Delay So Far	Next Dest	Turn Time	Prob Delay	My / Total Fli...	My Permits	Permits Avl	Price		Use Permit
EGF629	E135	RDU	DCA	11:09	11:55	$3,173	00:00	N/A	N/A	00:35	1 / 1	0	0	N/A	Buy	
AAL1767	B738	BDL	DFW	11:15	14:39	$1,808	00:00	SNA	00:44	00:17	9 / 10	2	0	N/A	Buy	

Future departures to above airports / time bins

Aircraft ID	Equip	Dep Apt	Arr Apt	Dep Time	Arr Time	Total Est Delay	Pred FDC
AAL318	B738	DFW	DCA	08:44	11:50	01:40	$36,891
EGF780	E145	FWA	DFW	12:30	14:33	00:00	$1
AAL1895	MD82	BNA	DFW	13:04	14:37	00:00	$1
AAL1430	MD83	ELP	DFW	13:20	14:32	00:00	$1
AAL1115	MD82	MEM	DFW	13:27	14:41	00:00	$1
EGF264	SF34	MLU	DFW	13:36	14:37	00:00	$1

Please make your selections and click "Submit" to continue Submit

Selling permits



Sell Permits

Destination	Arrival Time	Quantity Avl	My / Total ...	Quantity to...	Ask Price	
BWI	00:00 - 00...	2	0 / 7			Sell
LAX	00:00 - 00...	1	4 / 13			Sell
ORD	00:00 - 00...	2	6 / 15			Sell
RDU	00:00 - 00...	2	2 / 6			Sell
BOS	00:15 - 00...	2	3 / 9			Sell
LAX	00:15 - 00...	1	3 / 9			Sell
PHL	00:15 - 00...	2	1 / 7			Sell
SEA	00:15 - 00...	2	0 / 7			Sell
SMF	00:15 - 00...	2	0 / 2			Sell
DFW	00:30 - 00...	2	16 / 18			Sell
LAX	00:30 - 00...	2	0 / 7			Sell
PDX	00:30 - 00...	2	0 / 5			Sell
EGLL	00:45 - 01...	2	0 / 0			Sell
ONT	00:45 - 01...	2	0 / 2			Sell
SFO	00:45 - 01...	2	1 / 5			Sell
LAX	01:00 - 01...	2	2 / 9			Sell
SAN	01:00 - 01...	2	1 / 5			Sell
SEA	01:00 - 01...	2	0 / 5			Sell
BOS	01:30 - 01...	2	3 / 11			Sell
SEA	02:00 - 02...	2	0 / 6			Sell
IAD	02:30 - 02...	2	0 / 6			Sell
JFK	03:00 - 03...	1	0 / 4			Sell
ORD	03:00 - 03...	1	4 / 9			Sell
BOS	03:15 - 03...	2	2 / 7			Sell
JFK	03:15 - 03...	1	0 / 3			Sell
ORD	03:15 - 03...	1	5 / 7			Sell
DFW	03:30 - 03...	2	4 / 8			Sell
ORD	03:30 - 03...	1	5 / 12			Sell

Participants

- Roger Beatty
  - Airline Operations Coordinator at American Airlines
  - FAA Examiner for Aircraft Dispatcher Certificate
- Mike Wamsganss
  - Senior Associate, Booz Allen Hamilton
  - Previous Chief Executive Officer at Metron Aviation
  - Originator of much of the FAA Collaborative Decision Making (CDM) tools
- Giles O'Keeffe
  - Principal Subject Matter Expert, Airline Operational Control, Metron Aviation
  - Past President of Airline Dispatcher Federation
  - Aircraft Dispatcher, Chief Dispatcher, Air Traffic Coordinator at Northwest Airlines
- Ira Gershkoff
  - President and CEO of SlipStream Aviation Software, Inc.
  - 25+ years, strategic and operational information systems in the airline industry.
- Ben Rich
  - Principal Subject Matter Expert, Cockpit Procedures, Metron Aviation
  - Former Captain, Boeing 777, Emirates Airline
  - Chairman, APA Accident Investigation Committee
  - FAA licensed Dispatcher
- Lance Sherry
  - Associate Professor, Systems Engineering and Operations Research, GMU
  - Executive director for the Center for Air Transportation Systems Research (CATSR)
  - Previous experience in development of dispatcher-assisted software

Transactions

- Offers
  - 1,271 permits offered
- Transactions
  - 27 original transactions
- Results
  - 1.6% of offered permits purchased

Buyer \ Seller	AAL	COA	DAL	NWA	SWA	UAL	USA	Total
AAL		2				1	1	4
COA								
DAL		2		1		1		4
NWA	1	1						2
SWA	2			1		1	1	5
UAL								
USA	4	1						5
Total	7	6		2		3	2	20

- $1398K savings by use of permits
- $256K extra savings in Delay costs because of transactions.
  - BUT LEARNING PROCESS WAS SLOW, i.e. most premits offered at prices much higher than accepted.

Participant Comments

- "I think you have something worth pursuing here"
- "Benefits analysis performed by Nextor some years back showed that expanding our present, limited trading capability, is the surest way to generating discernable benefits to the operators."
- "It would improve the CDM system …"
- "I really enjoyed the exercise and I think the concept has some promise. But it needs to incorporate essential characteristics of today's system (rapidly changing, lots of uncertainty, slot swapping as an essential network management tool) or it probably won't go very far."
- "I would recommend that the air carriers create a new job position that combines business acumen with airline operational control expertise and have that person parked next to whoever is doing the air traffic coordination for the company. A sort of 'day-trader' in permits."

Executive Summary

- Experienced, insightful HITL participants
- Trading resulted in additional Airline flight cost savings
- Trading scheme had greater passenger throughout but consistent with current equity issues (regional carriers, small load factor and smaller spoke locations impacted negatively)
- User performance has several components that interact, sometimes in subtle ways
- Participants liked the permit idea and were willing to participate again!
- The fast-time and HITL simulations complement each other well and tell us much, but many questions remain
  - Need to experiment with different concepts and parameter settings
  - Different weather/schedule days
  - Enhance software display and capabilities
  - User learning and evolution of performance

Reflections on Project:

- We went into project with the idea of using either congestion pricing, auctions or some hybrid of the two to manage congestion
- We learned from industry and research that there was a simpler and more acceptable (to the industry) solution → PERMITS
- We were surprised by how much resonance it had with the airline dispatcher community
- Idea has "legs"
  - Total passenger throughput increased because larger planes used permits
  - Fits well within current GDP system

WHAT WE LEARNED

- Airport need "service standards" that set capacity limits and have mechanism for altering scheduling rules when service standards exceeded
- The topic of this research was only how to handle congestion on "Day of Flight"… but such schemes should be limited *exclusively* to the dynamic component of congestion (i.e. weather issues not scheduling issues).
- Still unresolved: how does one measure amount of delay a flight imposes on system
- One must not overlook the both the complexity of implementation and the likely acceptance of any plan suggested
  - May be able to slightly change the current system since only a small fraction of flights are harmed
  - Needs to be simple enough to not impose added burden on TFM
  - Want a system that is "incentive compatible" (improves the system) and does not encourage gaming
- Surprising to us: There may be a simple approaches that improves the system without much change
- Players ask to have both "bid" and "ask" prices (our simulation had "ask" prices)
- Approach is compatible with new NEXT-GEN technologies

Questions?

Thank You

Publications associated with project

Proceedings:

"Estimating Domestic U.S. Airline Cost of Delays based on EuroControl Model."
A. Q. Kara, J. Ferguson, K. Hoffman, L. Sherry, Proceedings 4th International Conference on Research in Air Transportation –ICRAT 2010, Budapest Hungary June 2010

"Sensitivity Analysis to the Cost of Delay Model for NextGen Benefits Analysis"
Abdul Qadar Kara (Ph.D. Candidate), John Ferguson (Ph.D. Candidate), Karla Hoffman (Ph.D.), Lance Sherry(Ph.D.)
2010 Integrated Communications Navigation and Surveillance (ICNS) Conference May 11-13, 2010

"Performance of Market-Based Traffic Flow Management Concepts," (in press) George Hunter, Diego Escala, Frank Berardino, Karla Hoffman AIAA Modeling and Simulation Conference, Portland, OR, August, 2011.

"Human in the Loop Simulation of Market-Based Traffic Flow Management," Diego Escala INFORMS, Reston, VA, May 2011.

"Development and Evaluation of Market-Based Traffic Flow Management Concepts,"Huina Gao, George Hunter, Frank Berardino, Karla Hoffman, AIAA Aviation Technology, Integration and Operations (ATIO) Forum, Dallas, TX, September 2010

Book Article:

"Spectrum Auctions" Karla Hoffman, *Wireless Network Design: Optimization Models and Solution Procedures* (International Series in Operations Research & Management Science), J. Kennington, E. Olinick and D. Rajan 2010.

Journal publications:

"A Practical Combinatorial Clock Exchange for Spectrum Licenses Karla Hoffman, Dinesh Menon Decision Sciences Vol. 7, No. 1, March 2010, pp. 58–77

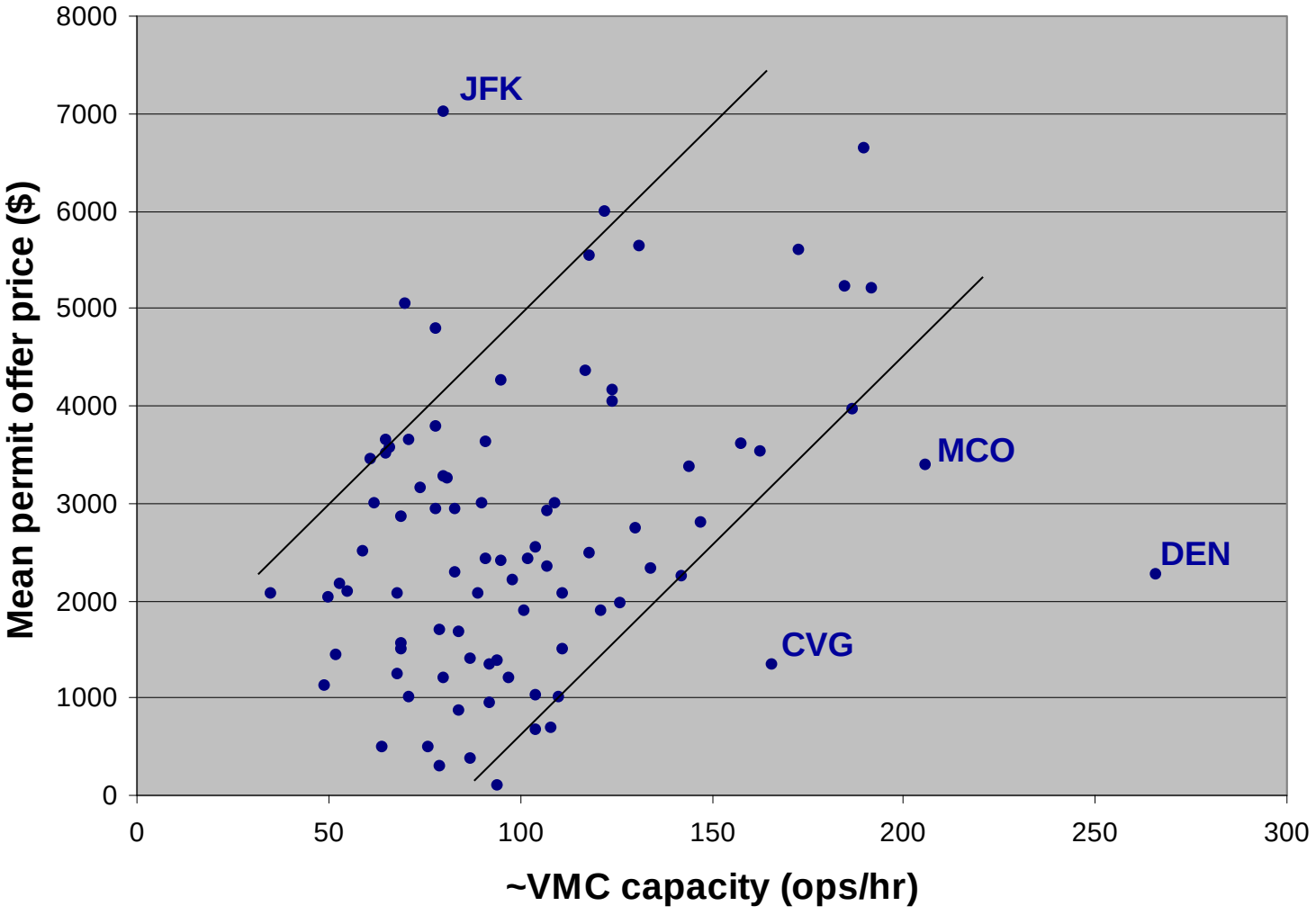
Journal submissions:

"Congestion Pricing Applications to Manage High Temporal Demand for Public Services and Their Relevance to Air Space Management" Submitted to Transport Policy

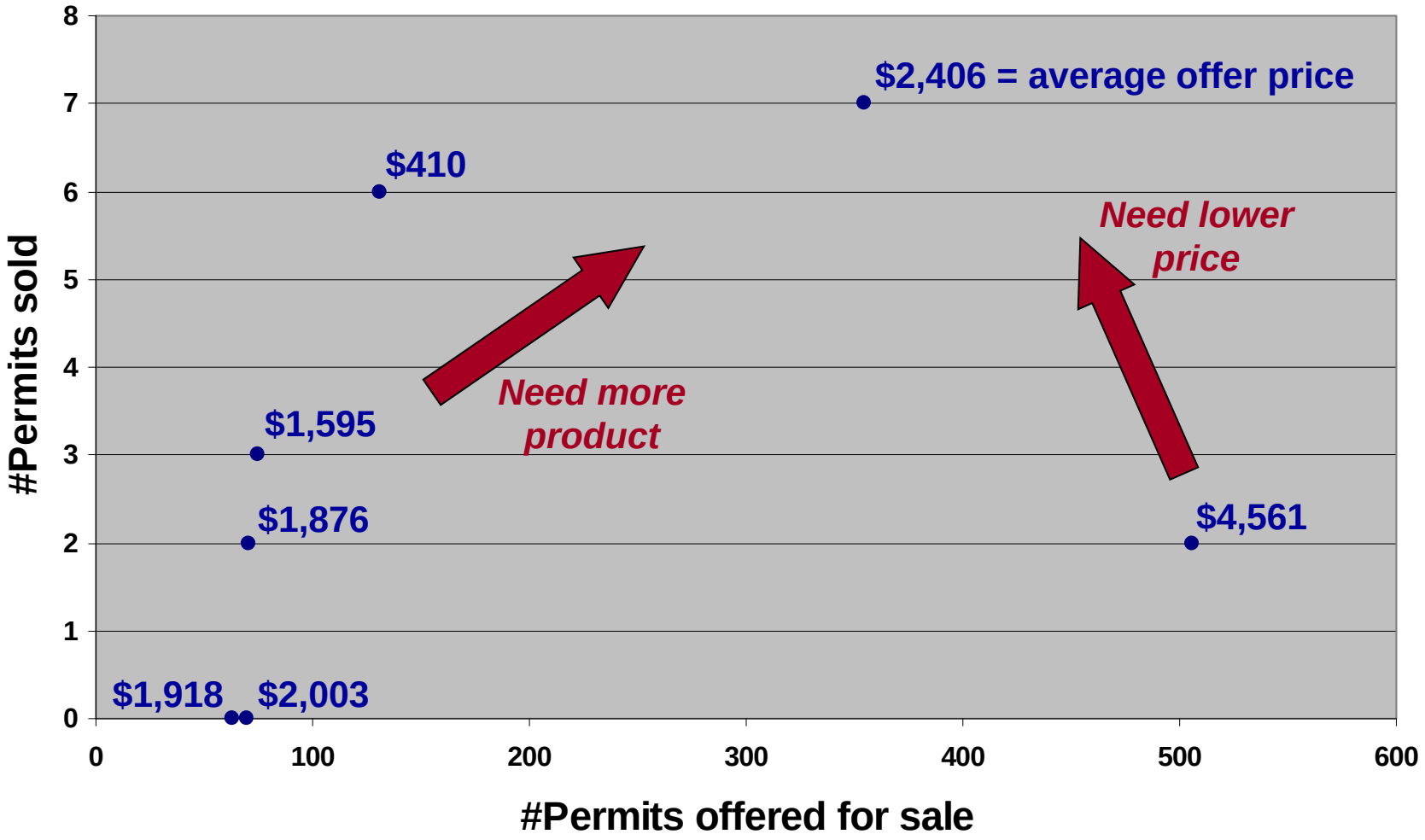
"Auction Applications in Government and their relevance to Air Space Mangement" K. Hoffman, F. Barardino, and G. Hunter submitted to Network and Spatial Economics

"Estimating Domestic U.S. Airline Cost of Delay based on European Model: J. Ferguson, A. Q. Kara, and K.L. Hoffman Transportation Research (invited submission)

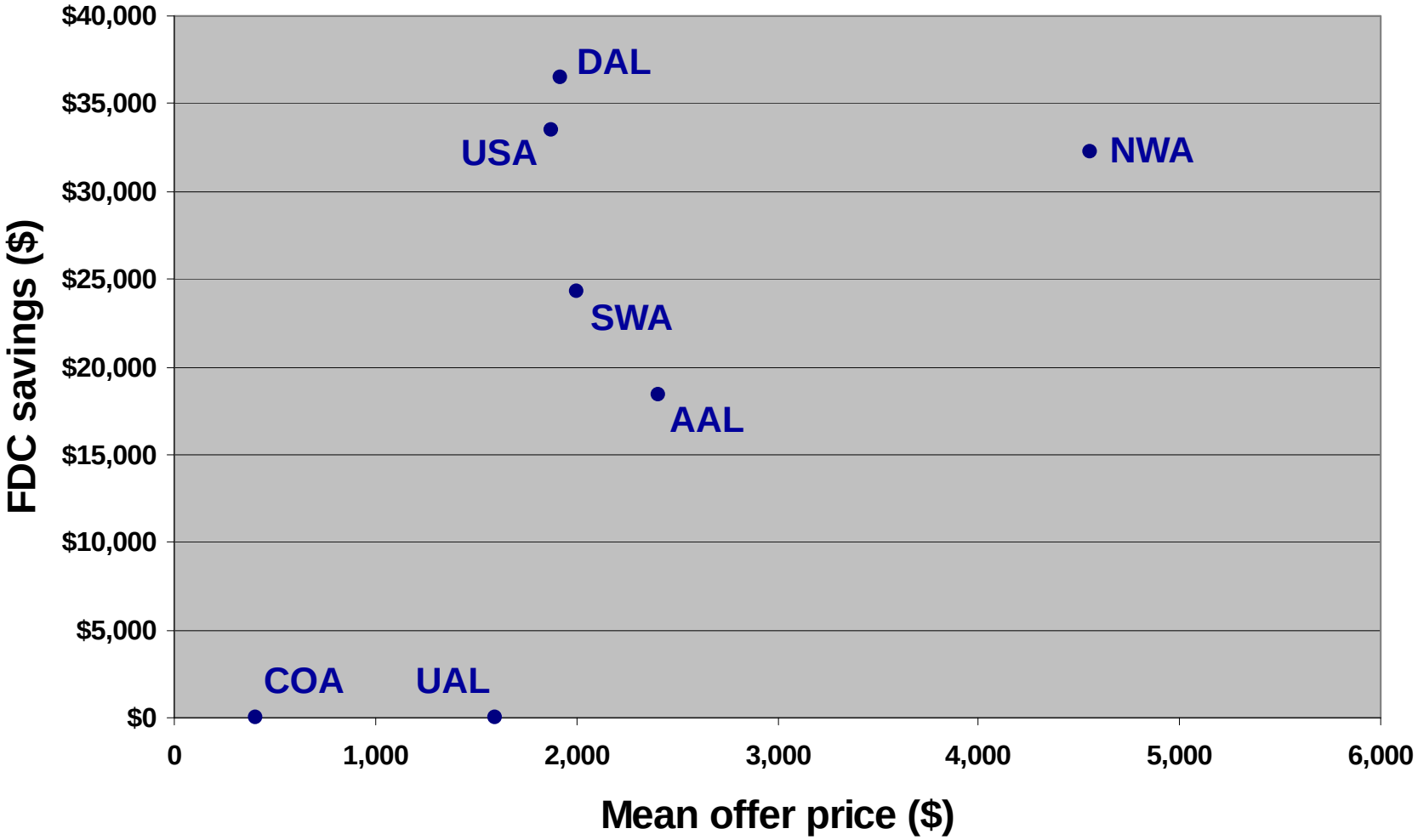
Offer Price Versus Arrival Airport Capacity



Transactions Require Product and Price



FDC Savings From Purchased Permits



Participant Comments: Concept Design

- "Today's TFM system [allows] some limited trading through a mechanism known as "slot credit substitutions (SCS)." Any new process, such as the permit concept, would have to support enough trading to perceive as not resulting in less capability."
- "And I will absolutely attempt to harm my competitors under this type of system, whereas under the current GDP system, I concentrate on helping myself, and am not as concerned with trying to harm the competitors."
- "Priority permits would help considerably once the airlines get faster on their feet. Until that time, they will still help, but mostly on a tactical, one-at-a-time basis."
- "You need to allow players to offer a bid (buy) price, instead of simply relying on the ask (sell) price."

Participant Comments: Software Interface

- "The HF issues will work themselves out. A decent air traffic coordinator would morph into a day-trader of permits within a matter of hours, if not minutes."
- "Full day access is a requirement"
- "I would like to have the entire day set up in front of me, refreshing on a once-a-minute basis, if possible. I would also like the ability to 'manipulate' permits for active flights (including airborne)."
- "need to provide more comprehensive information"
- "there should be more autonomous ability to manipulate within one's own carrier. I should be able to really play around with my 'stuff' all the time – adjusting, changing, re-instating, canceling, etc etc."

Participant Comments: General

- "It would improve CDM, because it creates other options that weren't there before. How could it make the system worse off? Yes, I think a trading system is a good idea."
- "Yes!" [there is value to the priority permit concept]
- "As we saw in the tests, the learning curve and proficiency in the process were important."

Participant Comments: General

- "It would improve CDM, because it creates other options that weren't there before. How could it make the system worse off? Yes, I think a trading system is a good idea."
- "Yes!" [there is value to the priority permit concept]
- "As we saw in the tests, the learning curve and proficiency in the process were important."

Introduction to Problem:

- National Aviation System (NAS) is an important factor of US economy – most travel that is longer than 200 mi. is done using the air transportation system
- Millions of people and tons of cargo are transported annually (both domestically and internationally)
- This is a Complex Adaptive System with Multiple players with differing goals
  - Congress, Airlines, Airports, Air Traffic Control, Passengers
- Cost of air delay is estimated at over $41B/year (CBO) – Cost to airlines estimated at $16-18B/year

Key Sources of Misallocation

- **User Taxes**: Do not correlate with the cost of producing ATC services and contribute to overuse (by GA) and under-use (by larger aircraft)

- **User Taxes**: Do not include costs of delay imposed on others and so under-state the actual resource costs imposed on the NAS by some flights

- **No Service Standard**: NAS is operated like a congested freeway vs. toll road with time of day pricing designed to produce 60mph traffic

- **No Exchange:** The initial allocation via RBS is independent of the net value of a flight to society (vs. just to the carrier); but this would matter less if there was an efficient secondary market

Conclusions

- Markets might improve the allocation of airspace
- Today, some operators may be willing to pay more for access to the NAS than others but can't
- Any time there are terms for trading assets a market can improve the allocation
  - Barter – one for one exchange is good
  - Price – trade for cash is much better –permits trades of assets not of equal value
- 3400 alternative market-based alternatives
  - Variation in allocation among alternatives

Measurement concepts:

Costs are calculated in two ways:

- The calculation of Flight Congestion Cost: This is the cost that determines the congestion that this flight causes to the system.
- The calculation of Flight Delay Cost: This is the cost that the airline incurs (internally) based on the congestion the flight incurs.

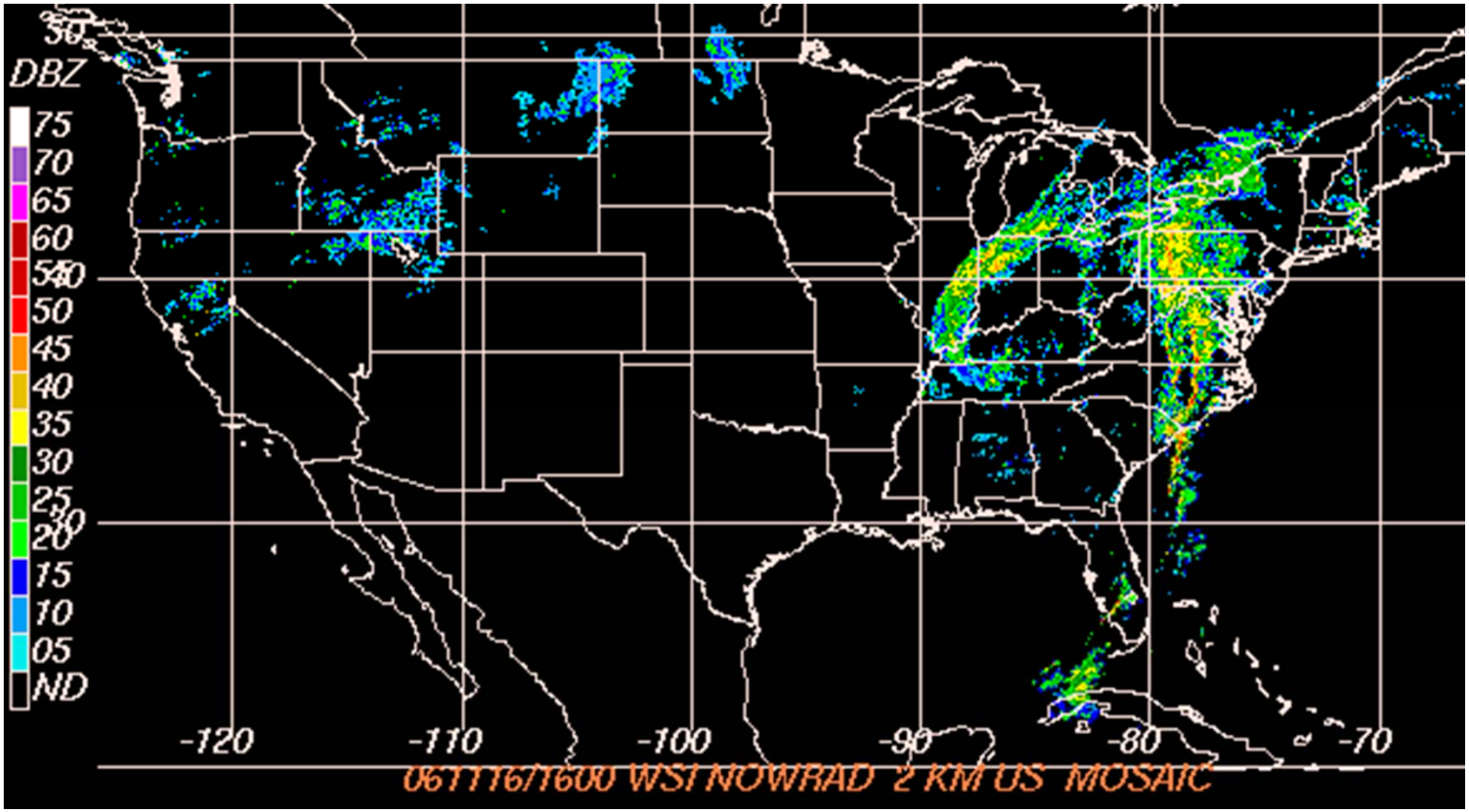
What would constitute an improvement in the system:

- IF it facilitates an outcome where users who are most willing to pay are given priority; the current allocation system is based on flight plans and so does not take into account how users value access directly.

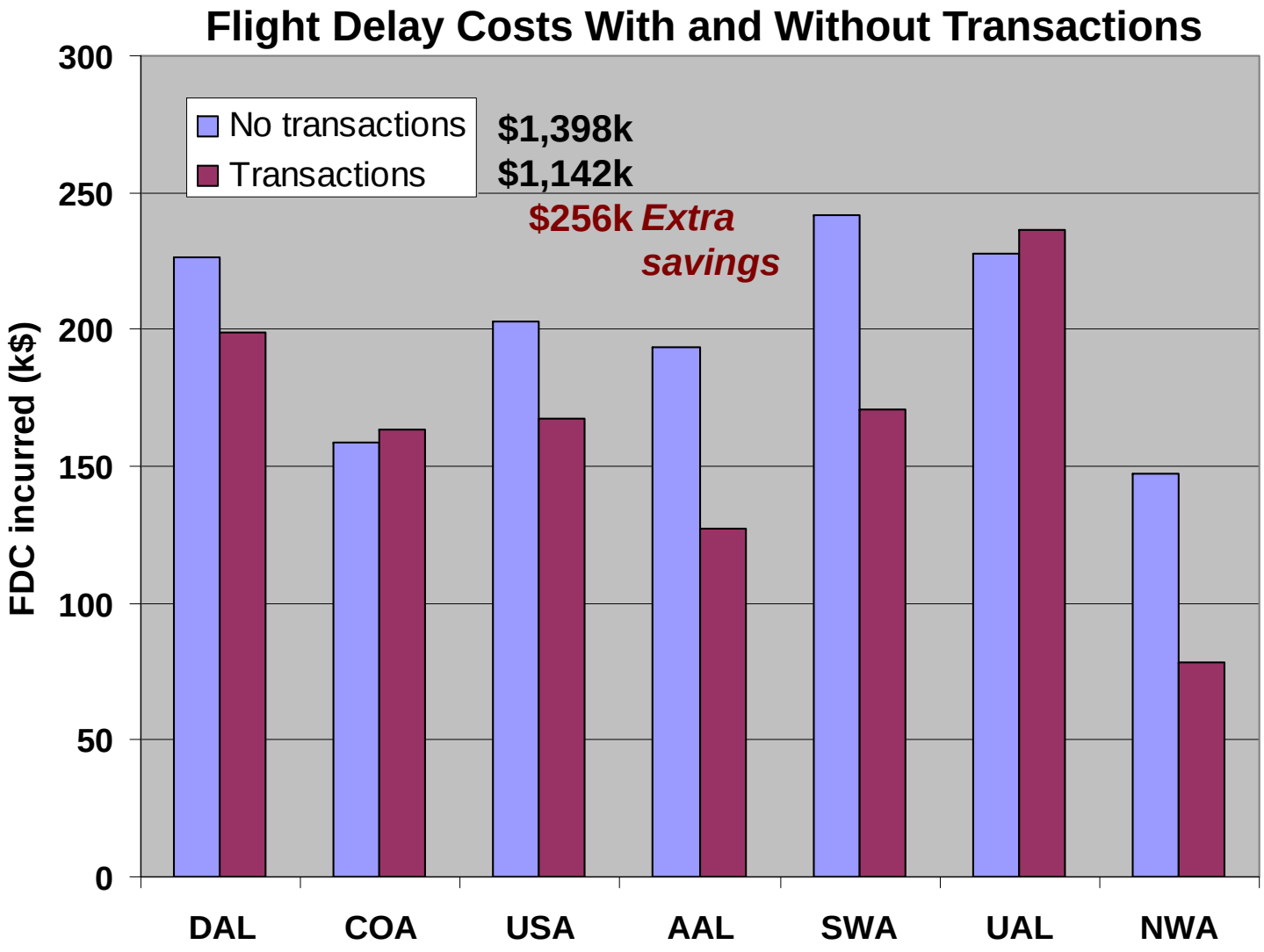
- A market may facilitate greater use of available scarce capacity; if some capacity is not used today and a market can either facilitate its use or, at a minimum, not prevent its use, then that also would be desirable.

November 16, 2006: NexRad Reflectivity

- Heavy weather, heavy traffic day (Thursday)



Transactions Provide Additional Savings



Participating users: 4,904 flights **Non participating users: 11,215 flights**

Participants:

- GRA, Incorporated:

  Frank Berardino, Richard Golaszewski
- George Mason University:

  Karla Hoffman, Lance Sherry, Kara Aqbal
- Sensis, Incorporated

  George Hunter, Diego Escala, Huina Gao

Contract Sponsor: Michael Bloem, NASA Ames

Special thanks to: Dr. Kapil Sheth, NASA Ames

And to our simulation participants