# NEXTOR CDM Research Contributions

**Michael Ball**
Robert H Smith School of Business and Institute for System Research
University of Maryland

September 2016

# CDM History

- Initial CDM concepts were developed starting in the mid-90's; ***NEXTOR was founded in 1996***.
- CDM-based decision support tool (FSM – the flight schedule monitor) and information exchange network (CDM-net) became operational in 1998 for the planning and control of ground delay programs (GDP's).
- Broad participation by FAA operations personnel and virtually all air carriers and also non-scheduled operators.
- "CDM-Group" meets regularly to develop new computer-based tools and operational procedures, to analyze air traffic data and problem areas and to solve pressing problems.
- Over the years adaptation of CDM tools and philosophy to many other contexts.

# CDM Concepts and Features

- **Philosophical components**:
  - improved information and common situational awareness
  - distributed control and decision making:
    - Decision made by most appropriate party
    - Economic tradeoffs made by appropriate flight operator
  - strong and continuous interaction among airspace system managers and flight operators
    - FAA—airlines
    - airline—airline; peer pressure
- **Technical accomplishments:**
  - new fair allocation principles
  - shared decision support tools
  - shared communications network
- **Reliance on data analysis and objective critique**

# Initial NEXTOR Research

Analysis of CDM Resource Allocation and Information Exchange Mechanisms

New Resource Allocation Methods /

Incorporation of CDM Principles into More Traditional Models and Approaches

Analysis of CDM Benefits Mechanisms

# CDM Benefit Mechanisms

A major tenet of CDM is to allow airlines, whenever possible, to control economic tradeoffs in resource allocation decisions

.....

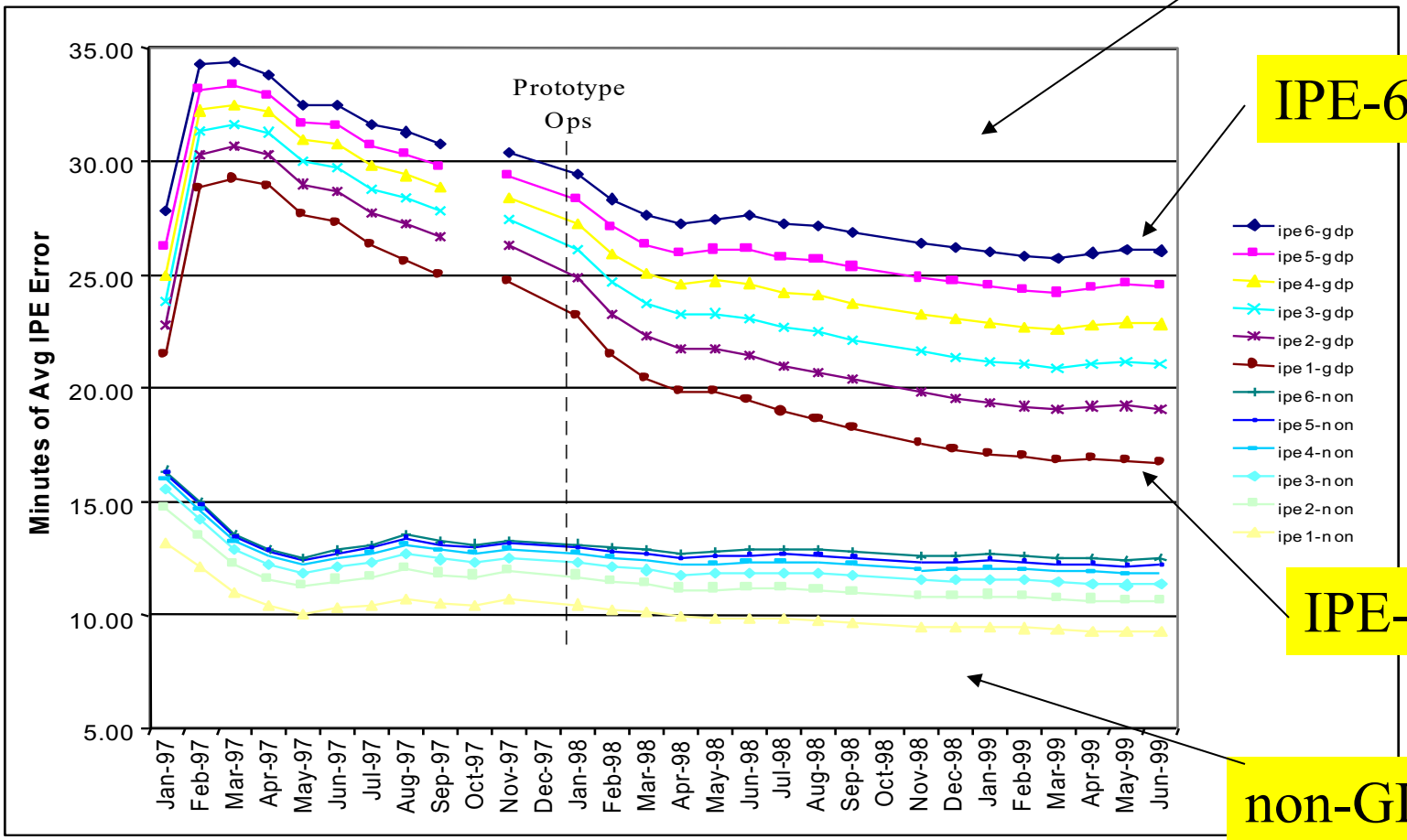
Traditional measures of benefits, e.g. system delay or throughput, may not capture the major impact.

**First CDM Benefits Assessment:**

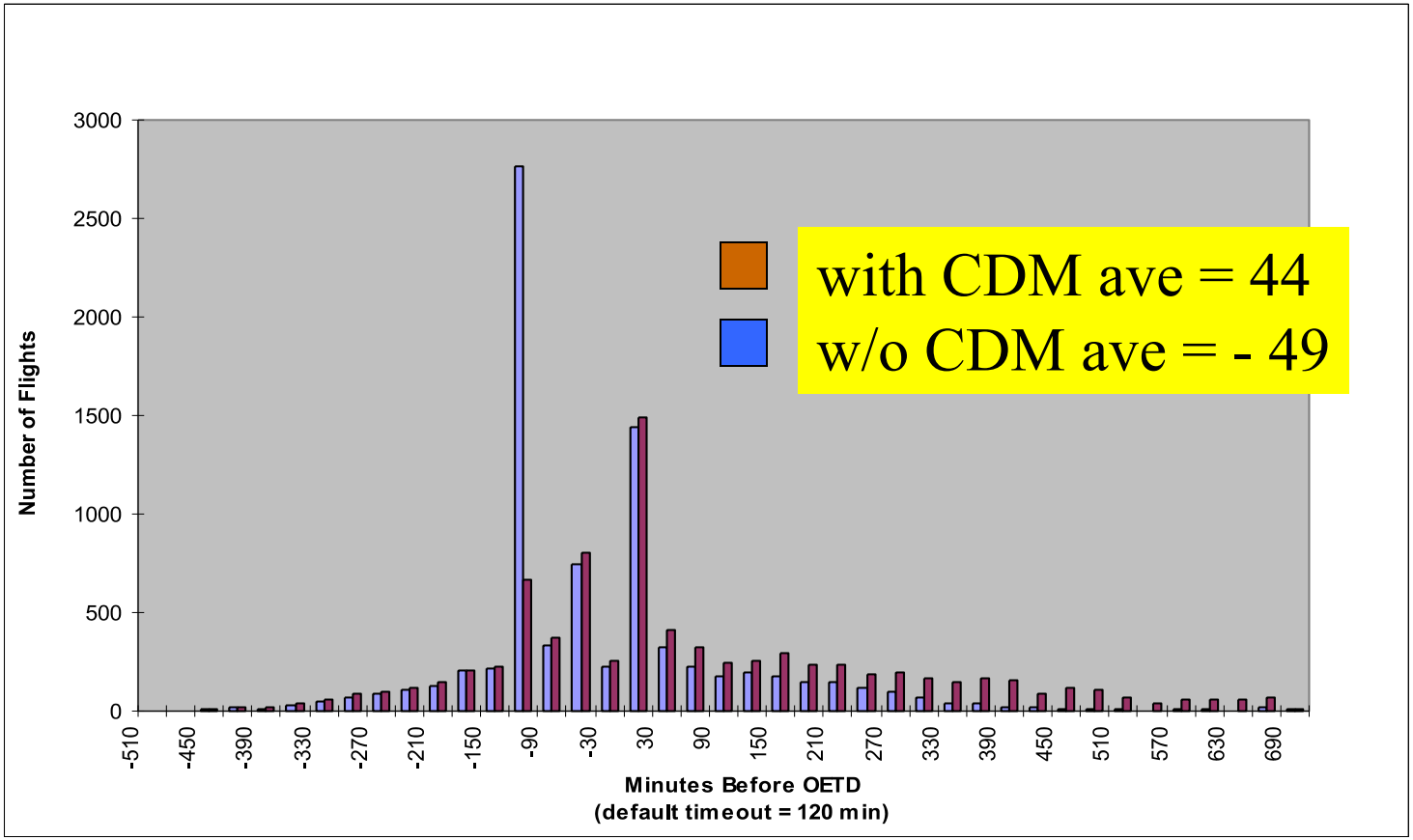
[Ball, Hoffman, Knorr, Wetherly & Wambsganss, 2001]

# Improvement in Departure Time Predictions

Integrated Predictor Error (IPE):

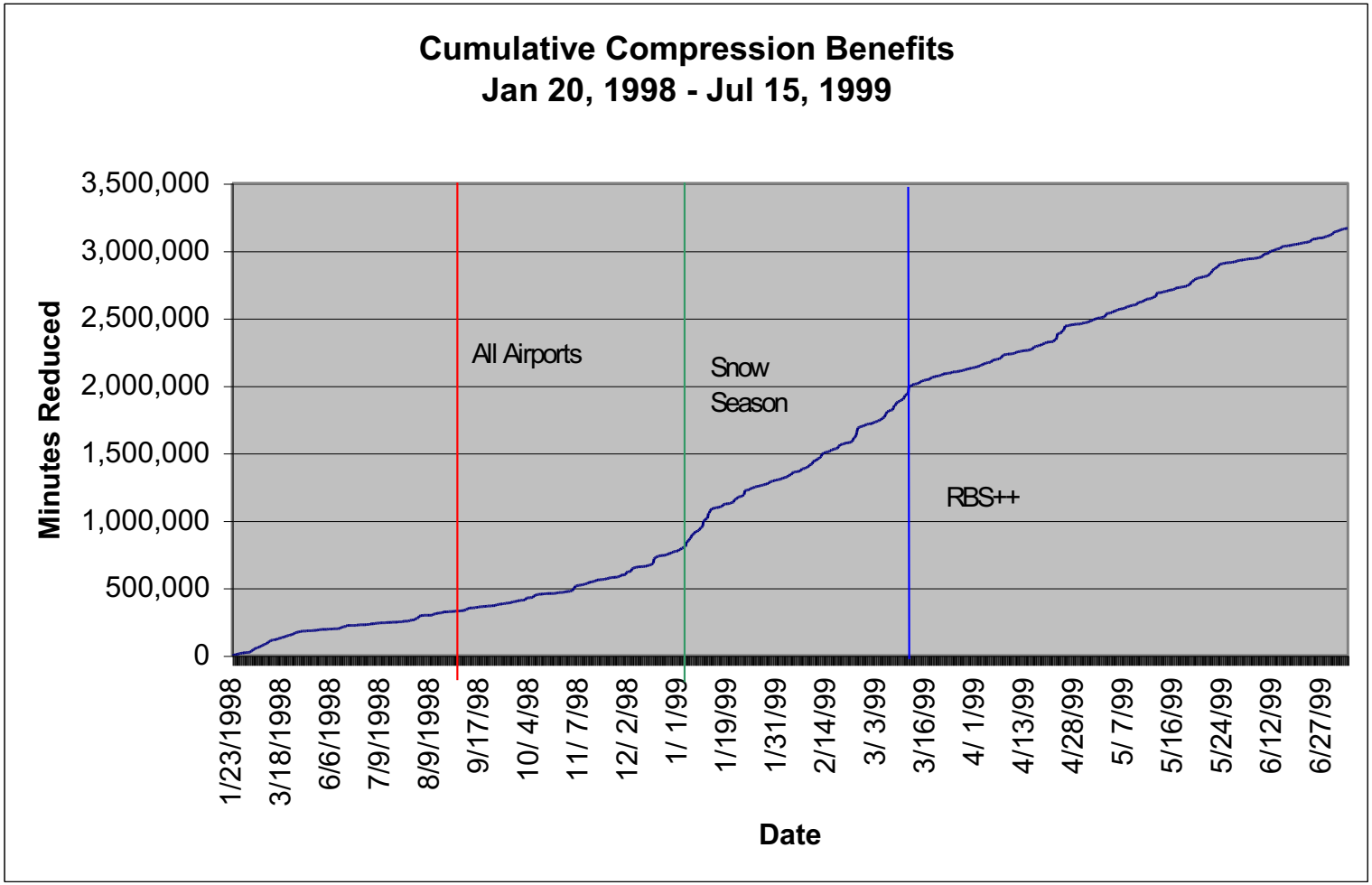


# Shift in Distribution of Cancellation Notification Time




Notification time given in ***minutes before OETD***
(Original Estimated Time of Departure)
Airport = SFO

# Cumulative Compression Savings



# Ground Delay Programs

delayed departures

delayed departures

delayed arrivals/
no airborne holding

delayed departures

control = flight departure time
decision variable = flight arrival time (slot)

# GDPs under CDM

Resource Allocation Process:

- FAA: *initial "fair" slot allocation*
  [Ration-by-schedule]
- Airlines: *flight-slot assignments/reassignments*
  [Cancellations and substitutions]
- FAA: *periodic reallocation to maximize slot utilization*

  [Compression, slot credit substitution, adaptive compression]

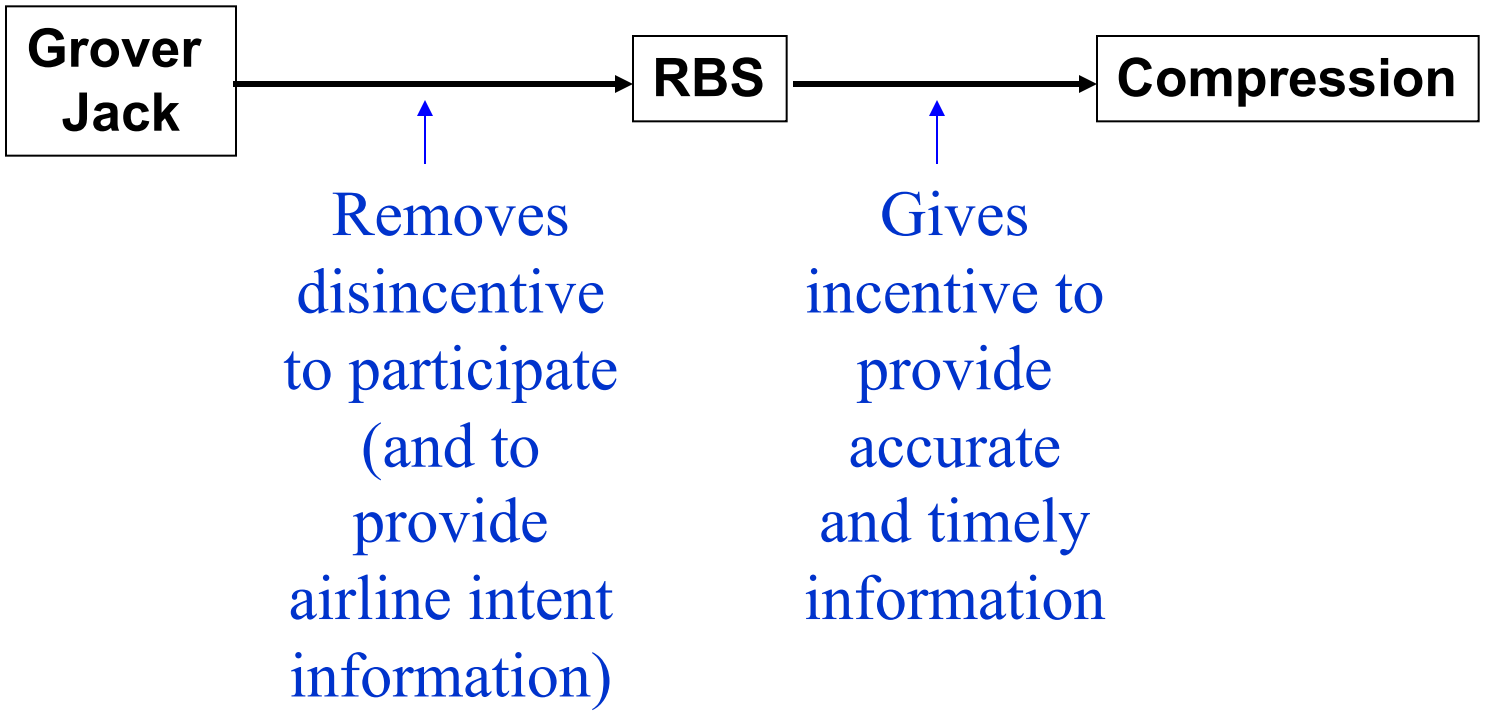
Note:

*- reduced capacity is partitioned into sequence of arrival slots*

*- ground delays are derived from delays in arrival time*

# CDM and Information Sharing

***Research allocation criteria can impact the willingness of flight operators to provide information and the degree to which provided information is accurate and truthful.***



# RBS as equitable slot allocation

**Property 1:** RBS minimizes total delay

**Property 2:** RBS minimizes the maximum delay and minimizes the number of flights that receive the maximum delay – this property holds "recursively", e.g. given that max delay is minimized, it also minimizes the 2nd highest delay value, etc.

**Property 3:** For any flight, the only way to decrease its delay is to increase the delay of a flight with equal or more delay.

***These properties are equivalent to certain well-established fair allocation principles.***

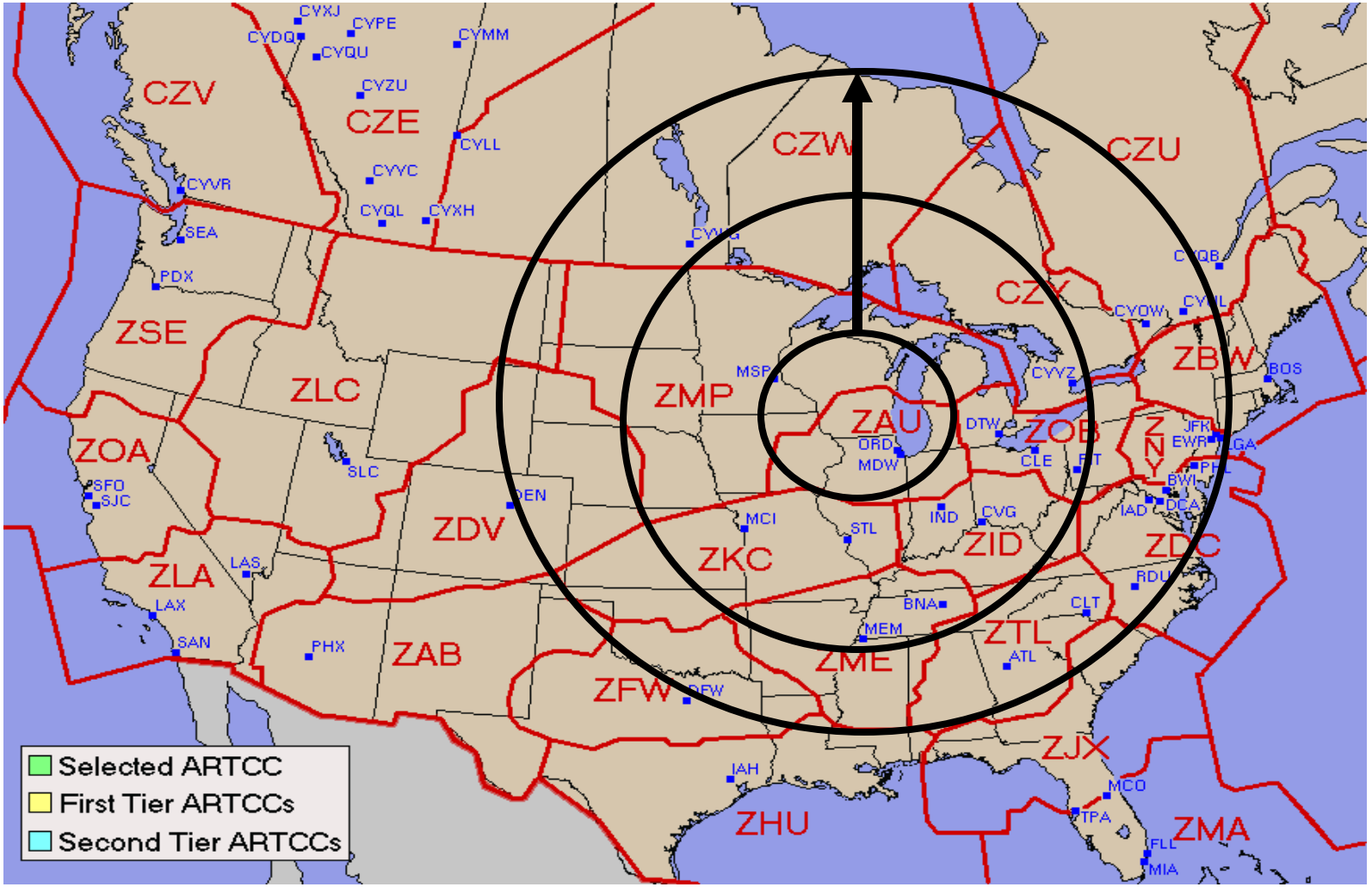
NEXTOR research develop formal models and metrics for fair/equitable resource allocation and then used these to enhance CDM process – an important theme: explicit modeling of equity/efficiency tradeoffs:

[Vossen & Ball, 2006], [Ball & Lulli, 2004], [Vossen, Ball, Hoffman & Wambsganss, 2003], [Ball, Hoffman & Mukherjee, 2010], [Sherali, Staats & Trani, 2004, 2006], [Glover & Ball, 2013]

# Distance Based GDPs

Set radius for GDP plan: flights outside circle are exempt / receive no delay

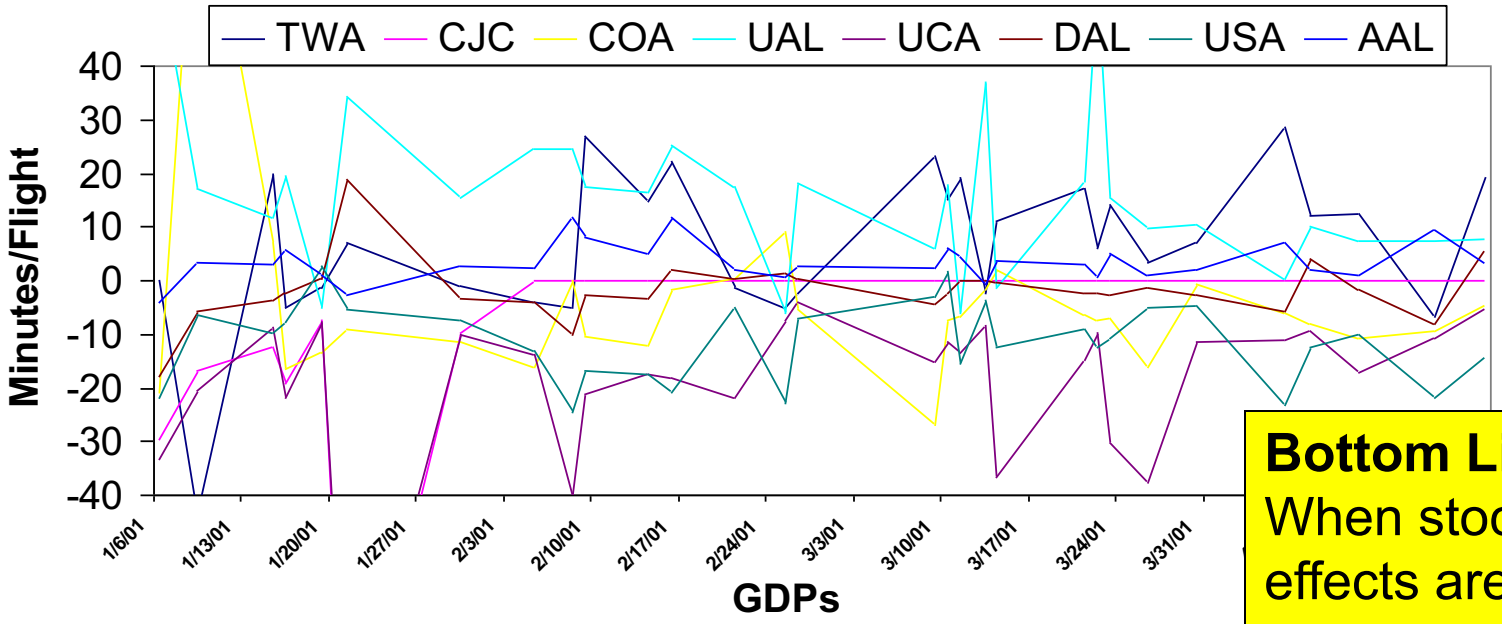
***Modeled as equity efficiency tradeoff***



# Further Question: *Do exemptions induce a systematic bias in the relative treatment of airlines during a GDP??*

## Boston / Logan Airport:

**Deviation RBS (standard) vs RBS (+exemptions), Boston**




Flight exemptions introduce systematic biases:

- USA (11m/flt), UCA (18m/flt) "lose" under exe

**Bottom Line:**
When stochastic effects are considered there is a tradeoff between equity and efficiency

# Optimization-Based Approach to Equity

**Conceptual Approach:** use normal exemption criterion but replace RBS with integer programming model that adjusts allocation to short-haul flights based on imbalance caused by exemptions.

**Multi-objective problem:**

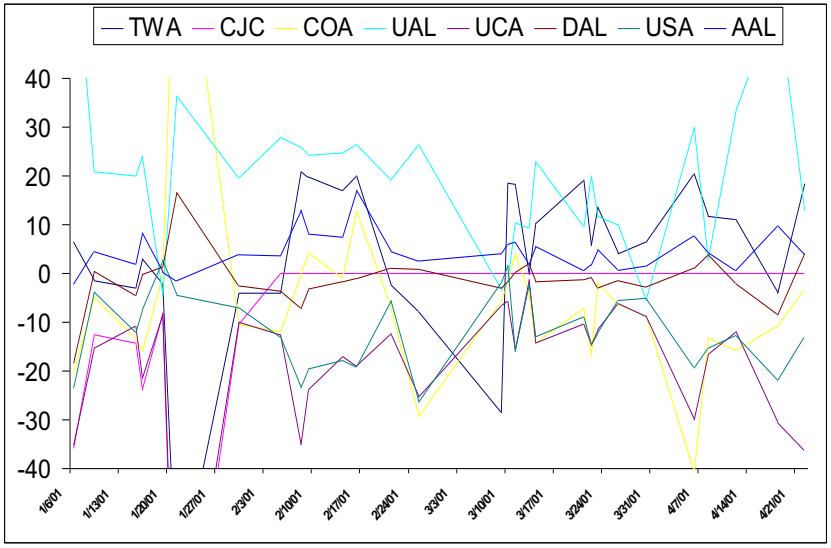
- Obj 1: measure of efficiency
- Obj 2: measure of equity

**Equity measure:**

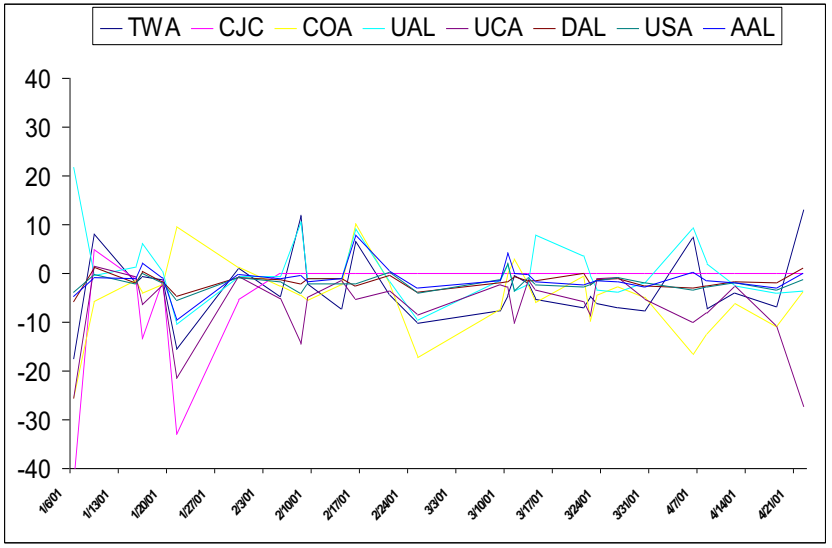
- Define "ideal" allocation (this has "perfect" equity)
- Obj 2: measure of deviation between ideal solution and solution chosen

# Impact of Model: reduction in exemption bias at Logan

Deviation RBS ideal-RBS actual




Deviation RBS ideal-Opt. model




- Minimize deviations using optimization model that incorporates exemptions
- reduces systematic biases, e.g. USA from 11m/flt to 2m/flt, UCA from 18m/flt to 5m/flt

# Adaptation of stochastic optimization models for GDP planning to CDM setting

Earlier models ***allocated flights to slots*** to minimize expected delays by "hedging" against alternate weather scenarios: [Richetta & Odoni, 1993]

The CDM cancellation and substitution process allows each flight operator to reassign its flights to the slots it has been allocated.

Optimization models adapted ***to determine a "Planned Airport Acceptance Rate" (PAAR)*** that hedges against weather scenarios ➔ flight-to-slot allocation can be carried about by CDM tools (RBS-cancellations/substitutions – compression) : [Ball, Hoffman, Odoni & Rifkin, 2003]; [Kotnyek & Richetta, 2006]

# CDM and Slot Exchange

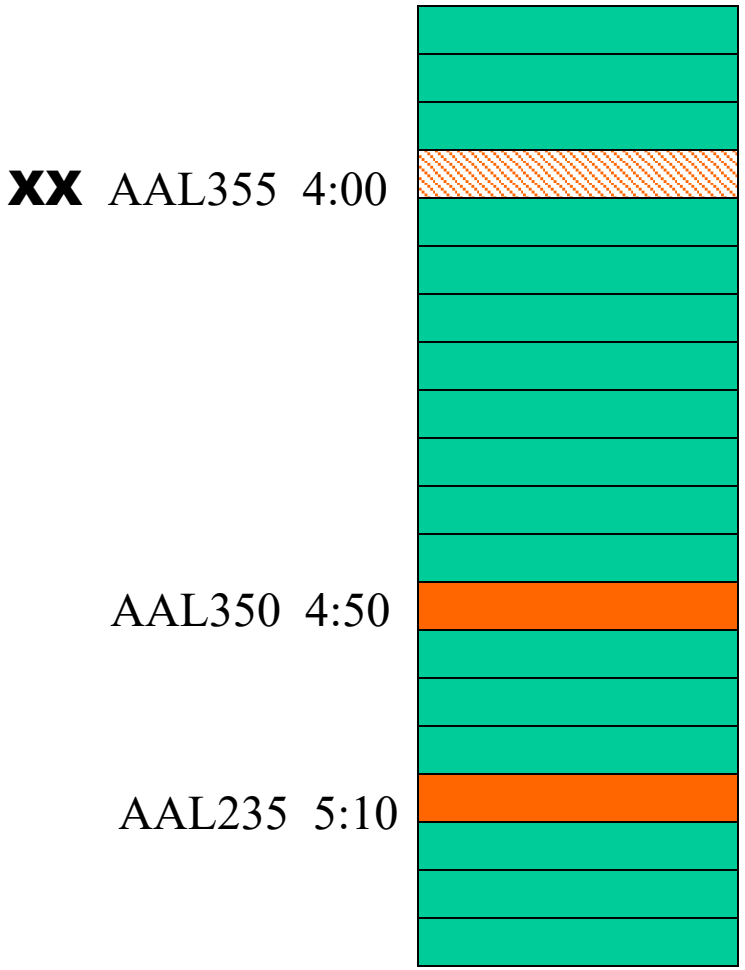
**A fundamental piece of the CDM GDP resource allocation is two types of slot exchange:**

**Intra-Airline Slot Exchange -- Cancellation and Substitution Process:** *slot-to-flight* allocation viewed as *slot-to-airline* allocation; airlines can reassign slots they "own" to their flights in any way possible – as part of process they may cancel certain flights.

**Inter-Airline Slot Exchange -- Compression:** implements a type of inter-airline slot exchange in situation where airlines are assigned slots they are otherwise unable to use.

NEXTOR research viewed slot exchange more broadly as slot trading and investigated multiple generalizations: [Vossen & Ball, 2006], [Ball, Lovell, Hoffman & Mukherjee, 2005 ], [Sherali, Hill, McCrea & Trani, 2011]

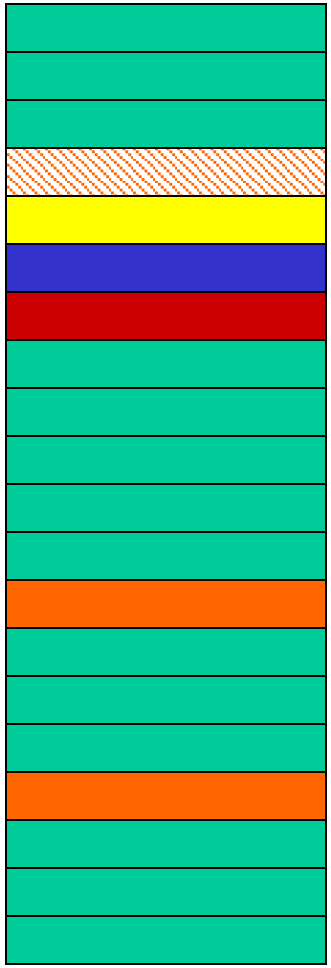
# Why Exchange Slots??




Slot made available by canceled or delayed flight

Earliest time of arrival: 4:15

# Current Procedure: Compression



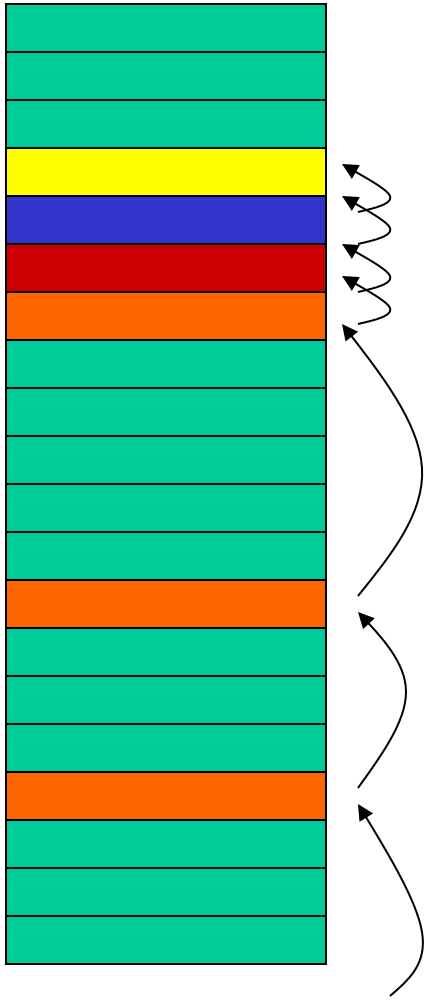
**XX** AAL355 4:00
UAL205 4:05
DAL254 4:10
USA105 4:15

**Earliest time of arrival: 4:15**

AAL350 4:50

AAL235 5:10

# Current Procedure: Compression



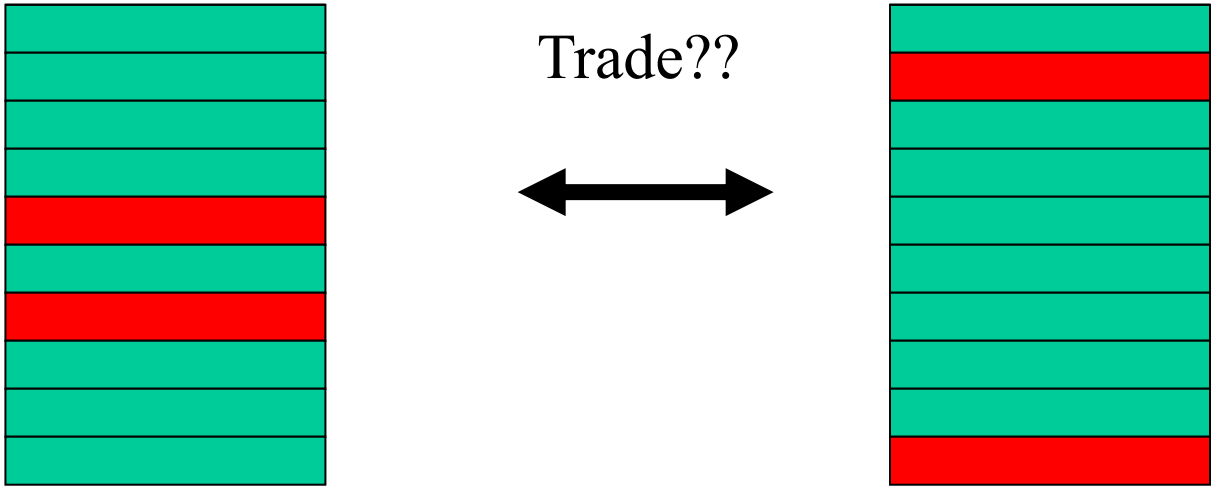

**Earliest time of arrival: 4:15**

# Advanced Slot Trading: From 1-for-1 trades to 2-for-2 trades

Compression

- 1-for-1 trading system, i.e. offers involve giving up one slot and getting one in return (many offers processed simultaneously)

What about k-for-k or k-for-n offers, e.g. 2-for-2:




Research has developed methods for compact (and even implicit) representation of trade offers and optimization models to find "best" set of trades; also embedding trade identification within larger optimization models.

# Batch-oriented vs Transaction-oriented slot trading

Compression is a ***batch-oriented*** slot trading mechanism, i.e. "trade requests" are collected and then periodically executed, e.g. every hour ….
What about a ***transaction-oriented*** system that considers and executes each request as it become available?

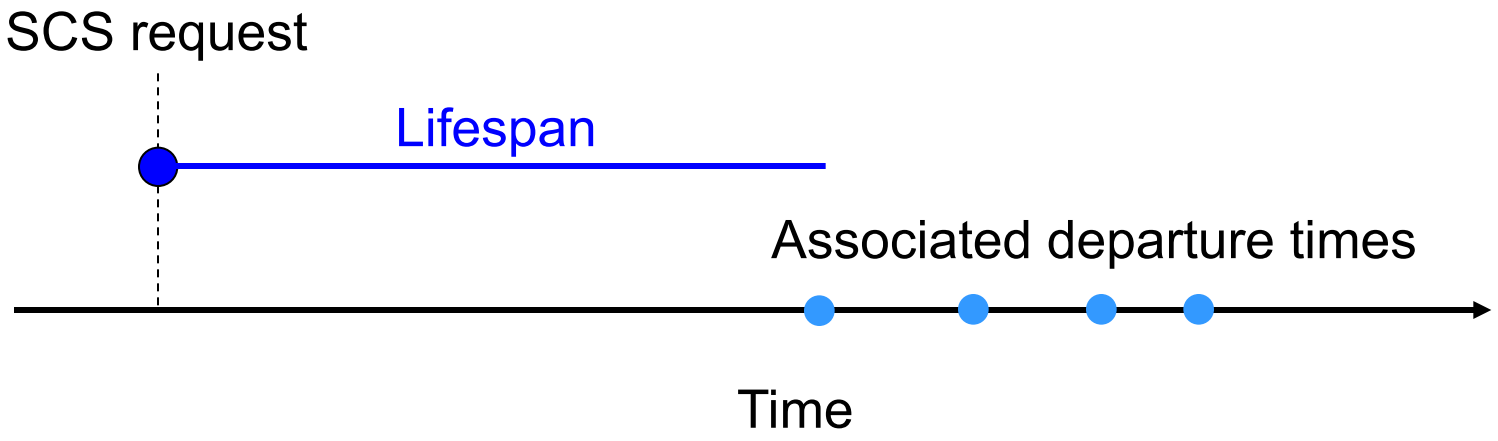
**Tradeoff:** batch oriented allows optimization over a large set of requests; transaction-oriented allows immediate response and no request expiration.

# CDM transaction-oriented slot trading: Slot Credit Substitution (SCS) – later Adaptive Compression

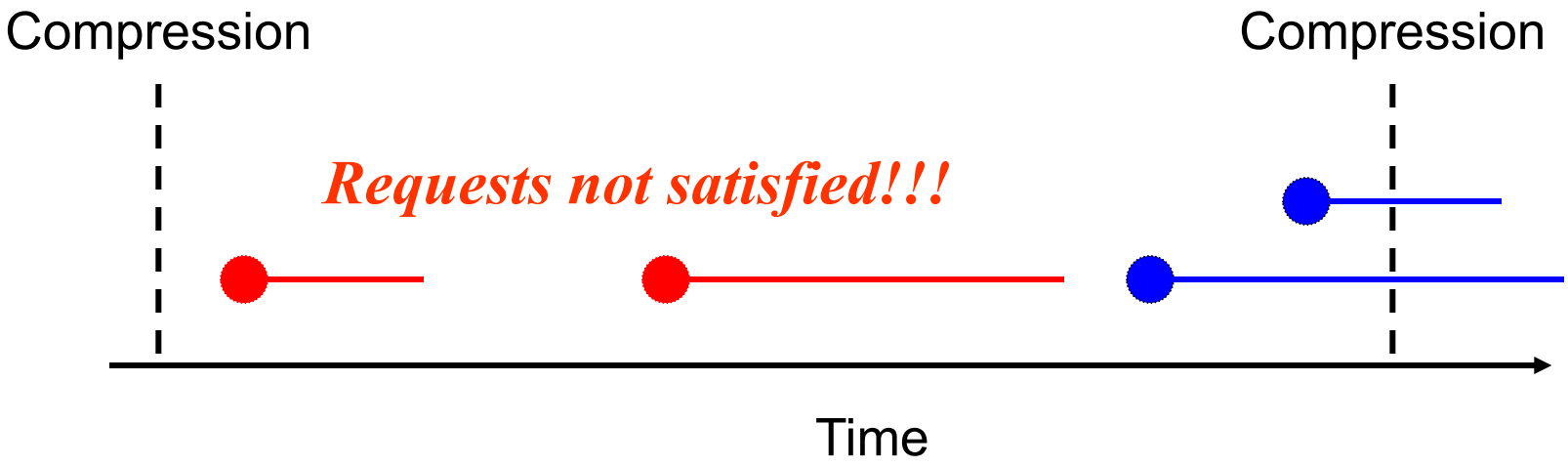
Each SCS request requires a set of ***arrival*** slot exchanges to be executed

Each arrival slot exchange implies a revision of the ***departure time*** of a flight.

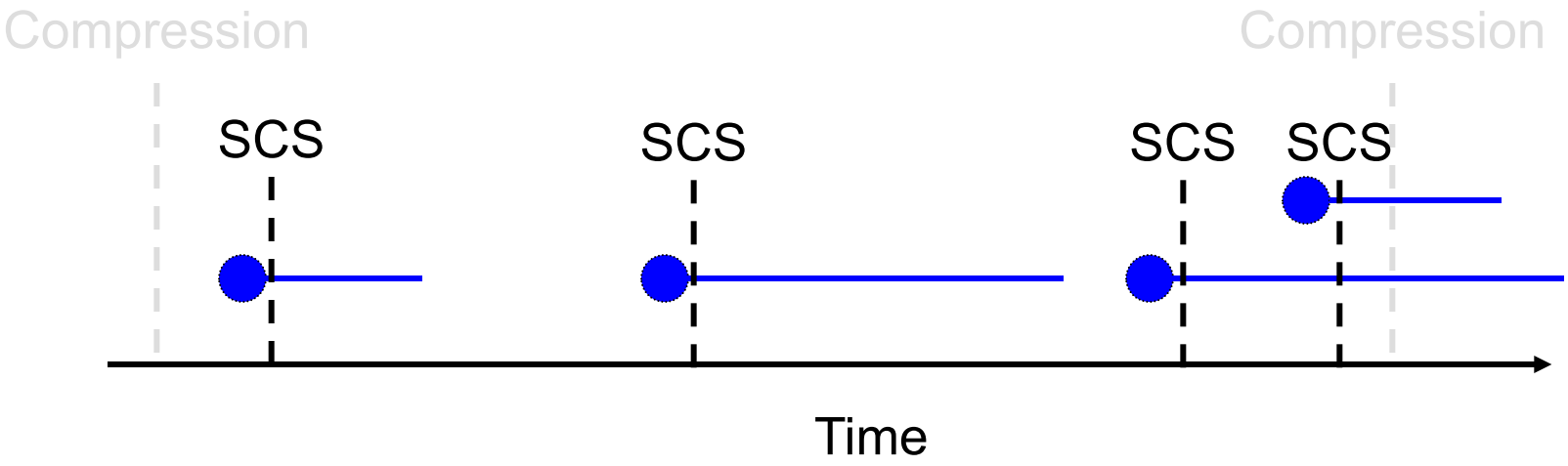
In order to implement the exchange, the transaction must be completed before the earliest revised departure time, i.e. the request has a ***lifespan*** within which it must be executed



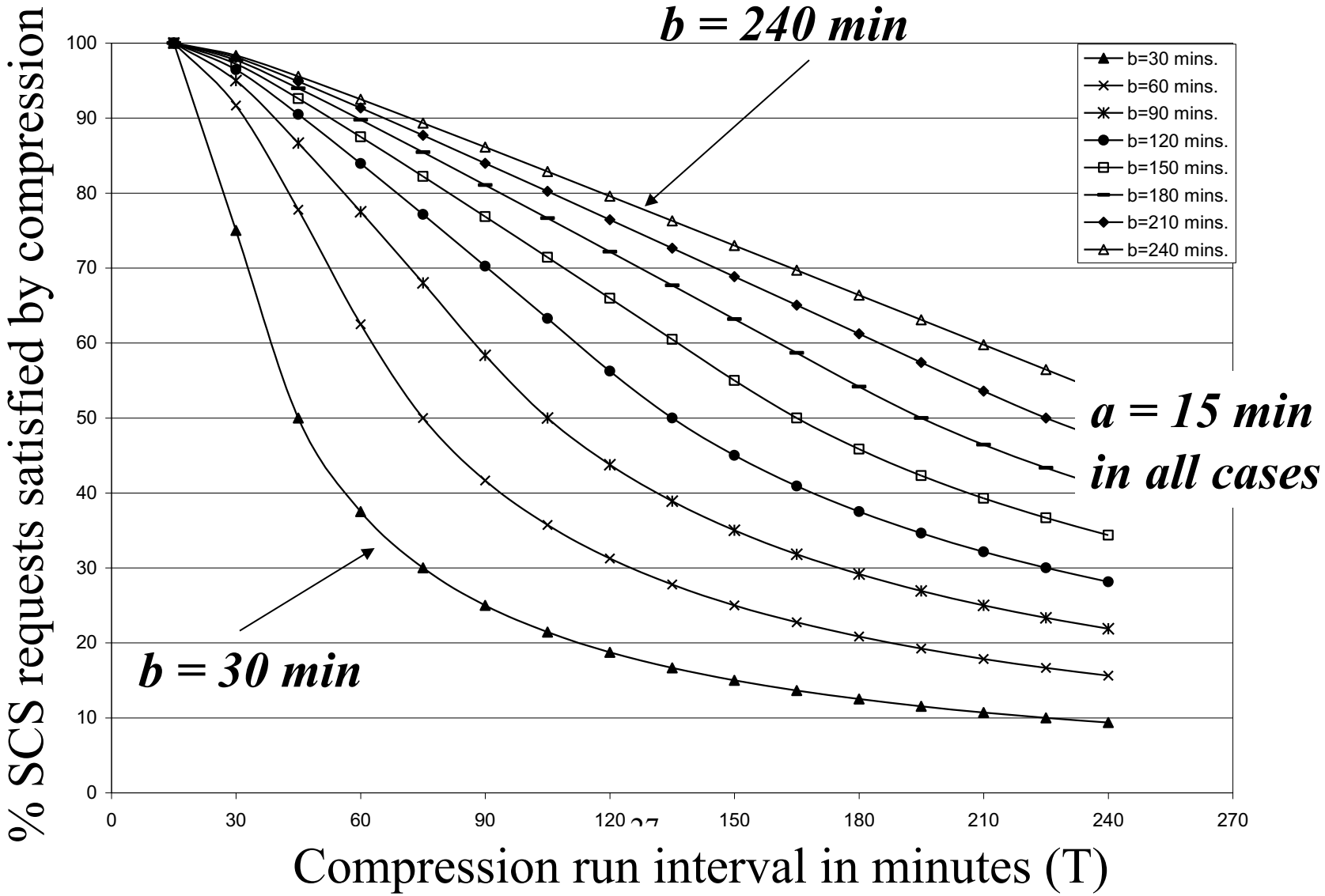
# Not all requests could be captured by Compression



# All requests are captured by SCS



# Model results: compression vs. SCS



# Airspace Flow Programs

In 2006, CDM concepts developed for GDP were adapted to address airspace and metroplex congestion using a new traffic management initiative, the Airspace Flow Program (AFP); a more recent related development is the collaborative trajectory options program (CTOP)'

NEXTOR research addressed a variety of relevant research questions, especially related to flight operator strategies and response: [Vakili & Ball, 2009], [Kim & Hansen, 2013], [Yoon, Hansen & Ball, 2012], [Kim & Hansen, 2015], [Ganji, Ball & Lovell, 2009]

# Other Recent Developments

- Integration of slot trading models into large-scale traffic management optimization models [Sherali, Hill McCrea & Trani 2013]
- Analysis of CDM data to understand airline value/cost function and behavior [Xiong & Hansen, 2013], [Seelhorst & Hansen, 2012][Xiong & Hansen, 2014]
- Consideration of equity / efficiency tradeoffs in broader ATM (and non ATM) contexts [Bertsimas, Farias & Trichakis 2011], [Barnhart, Bertsimas, Caramanis & Fearing 2012]
- Service level expectation setting for collaborative strategic TFM planning [Swaroop & Ball, 2012], [Yan, Swaroop, Ball, Barnhart & Vaze, 2016]

**… and a NASA funded project that had its kickoff meeting this past Wednesday:**

Decision Support Capabilities for Effective Application of Collaborative Trajectory Options Program (CTOP): Hoffman, Ball, Hansen & Smith.

# Final Thoughts

- CDM has had a very substantial impact on air traffic management in the US
- In a different form (airport / A-CDM) it has been widely used in Europe
- It represents a philosophical approach to attacking problems that is broadly accepted both in the US and Europe (and throughout the world).

***….. from a research standpoint it provides a new perspective on problems that makes them both more interesting and more challenging … and leads to many new innovations***

# Final Final Thought

***NEXTOR and CDM grew up together:***

***Let's celebrate both!!!***