Airport Departure Flow Management System

Final Presentation

SYST 798 / OR 680

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Agenda

- Introduction
- Technical Approach
- Architecture
- Modeling & Simulation
- Evaluation & Recommendations
- Future Work & Acknowledgements

Introduction

Problem Definition (1/2)

- Problem Statement
  - All major U.S. airports are scheduled with departures at peak travel periods in excess of the runway departure capacity.
  - As a consequence of over-scheduling, and the procedures for push-back, a free-for-all occurs amongst the airlines to secure a slot in the long taxiway departure queues that occur every day.
  - These queues result in excess fuel burn and emissions, and create unnecessary taxiway congestion.
  - Airlines are also unable to rearrange queue positions / slots in the event of delay or disruption.

Introduction
Problem Definition (2/2)

- Proposed Solution
  - Automated system with supporting operational procedures for a virtual queue model implementation that reduces excess taxi time for departing flights by alleviating taxiway congestion, thereby reducing fuel burn and emissions.

- Project Definition
  - Define, develop, and analyze a preliminary concept for an Airport Departure Flow Management System (ADFMS) for the Philadelphia International Airport (PHL) in which
    - Airlines reserve departure slots
    - Airlines are able to trade slots in the event of delay or disruption.
  - Perform cost benefit analysis to justify capital investment in automated system

Introduction

Background and Need

- 11th busiest airport in the world
- 7 Terminals / 120 gates / 14 major airlines

Airport Graphic by "Philadelphia PHL Services --> Main Terminal / Concourses." iFly.com The Web's Best Guide to Airports. <http://www.ifly.com/resources/img/airports/terminal-maps/Philadelphia-PHL-terminal-map.jpg>

"Philadelphia International Airport - Google Maps." Google Maps. Google, n.d. Web. 13 Feb. 2010

Introduction

Objectives, Deliverables and Scope

- Project Objectives
  - Preliminary design and requirements
  - Develop a model
  - Perform simulation
  - Conduct cost-benefit analysis

- Project Deliverables – accepted by Sponsor (Dr. Sherry)
  - ☑ System Requirements Document – 25 February 2010
  - ☑ Concept of Operations (CONOPS) Document – 25 February 2010
  - ☑ Scenario Analysis Models and Document – 28 April 2010
  - ☑ Business Case Analysis (Cost-Benefit) – 28 April 2010

- Scope
  - Philadelphia International Airport (PHL)
  - Ground operations and queuing procedures from push-back to departure

- Out of Scope
  - Impact of Arrivals, Ground Delay Programs, Weather, Volcanoes, General Aviation Aircraft

Introduction
Stakeholders

- Stakeholders
  - Airlines
    - Airline Operating Centers (AOCs)
    - Station Managers
    - Pilots
  - PHL Airport Authority
    - PHL Ramp Control
    - Information Technology (IT) Staff
  - Federal Aviation Administration (FAA)
    - PHL Air Traffic Control Tower (ATCT)
    - PHL Terminal Radar Approach Control (TRACON)
  - Passengers

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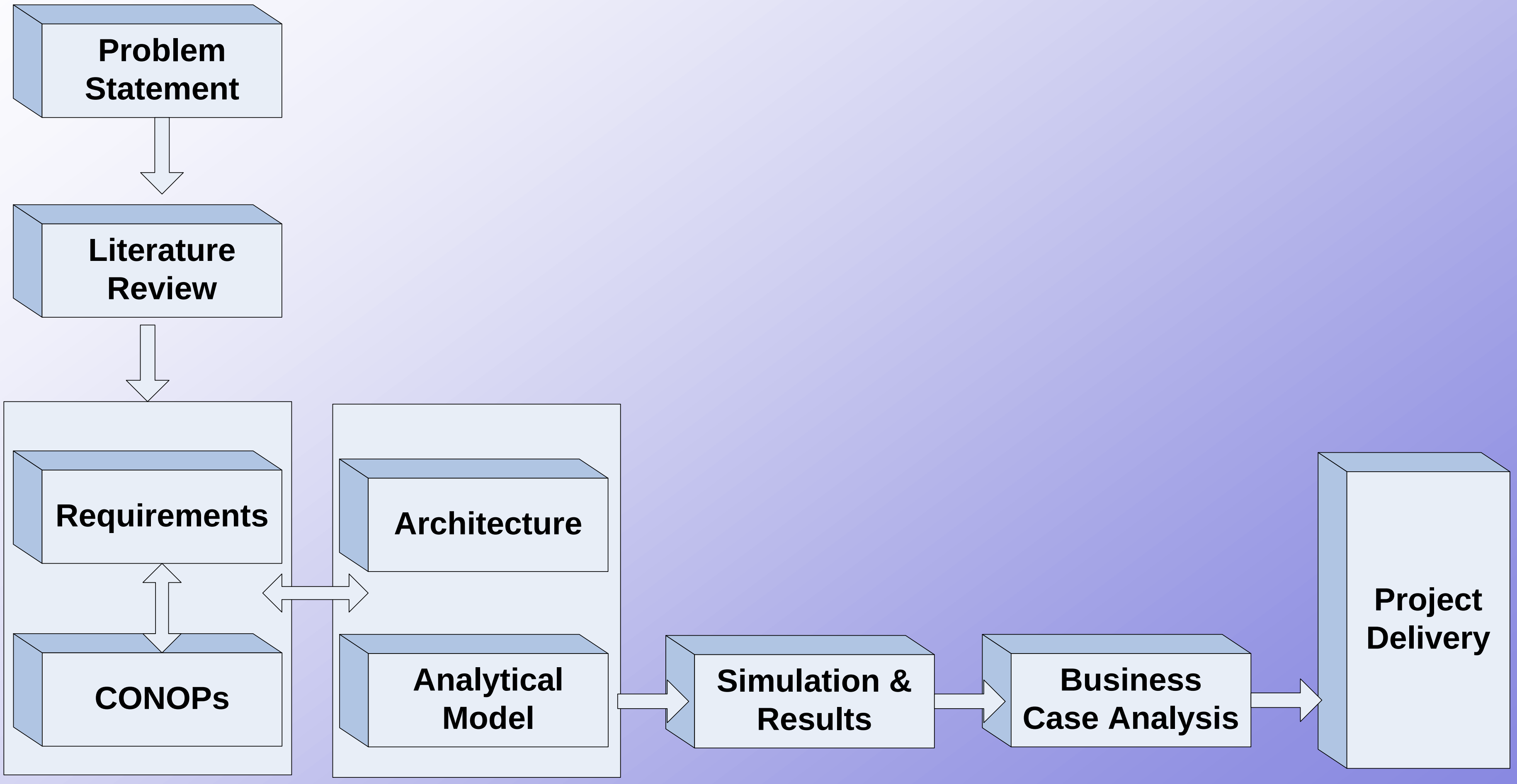
Technical Approach



Technical Approach

Assumptions & Limitations

- Project Assumptions
  - Primary cause of departure delays is over-scheduling
  - Airlines will accept a slot controlled departure system which limits the number of flights that are scheduled for departure each hour
  - Fair weather conditions will give a reasonable approximation for cost-benefits

- Model & Simulation Limitations
  - Data sources do not show the cause of delay (e.g. mechanical, congestion, weather etc.)
  - Data sources do not show the departure gate
  - Model uses one runway for departure (no runway reconfiguration)
  - Model does not de-conflict taxiing aircraft within departure queue (e.g. no assignment of expected push-back times)
  - De-conflicted departures are manually created, become inputs to the simulation

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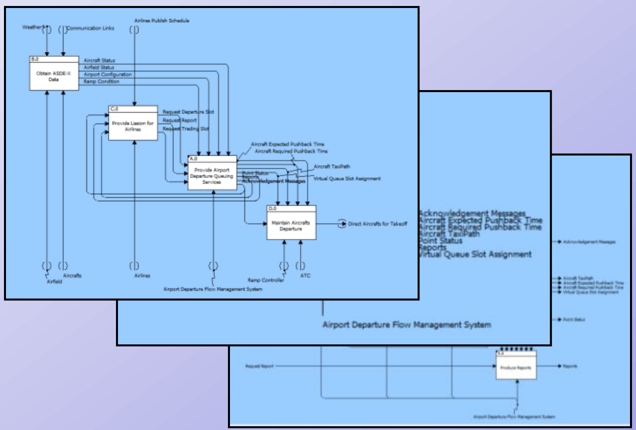
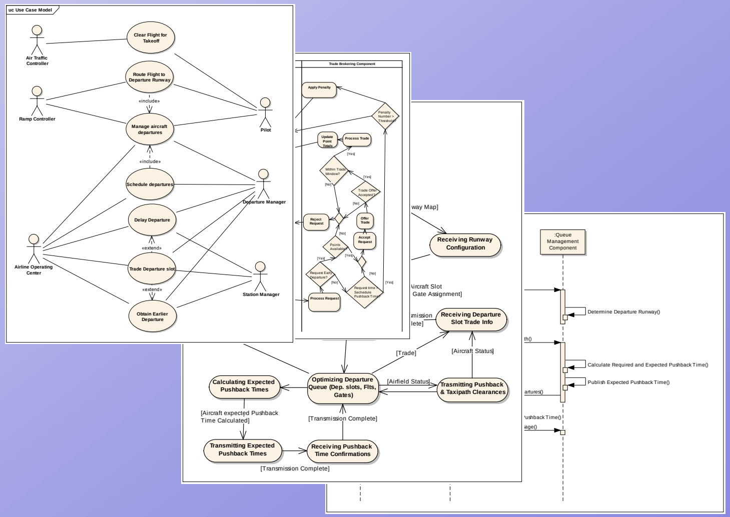
Architecture

Architecture Approach

- Operational Concept
- Use Cases
- Structured Analysis (CORE)
  - Functional Decomposition (2 levels)
  - IDEF0
- Object Oriented (Enterprise Architect)
  - Activity Diagrams
  - Sequence Diagrams
  - Communications Diagrams
  - State Diagrams
  - Behavior rules
  - Class Diagrams
  - Organization Diagrams



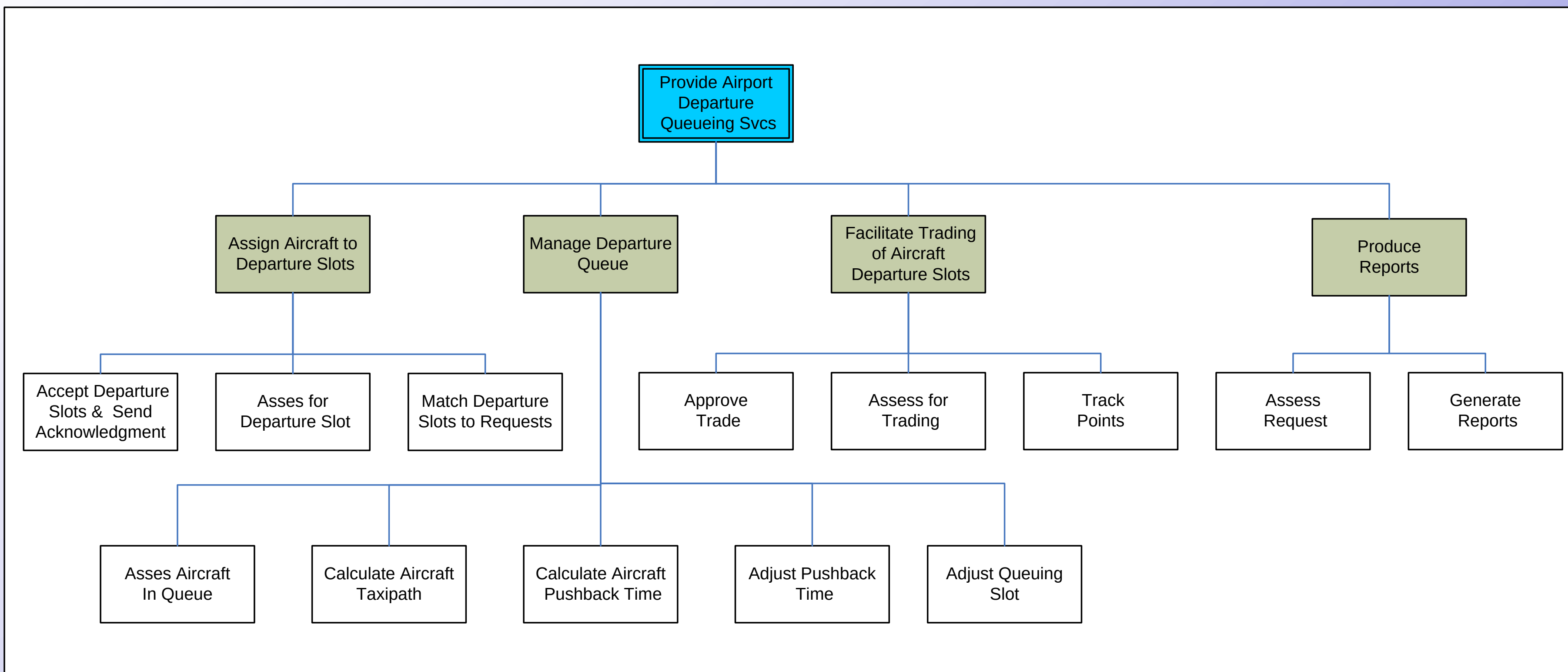


Developing the architecture allowed us to take a general concept and define operational /system structure and behavior to support that concept.

Architecture
Operational Concept

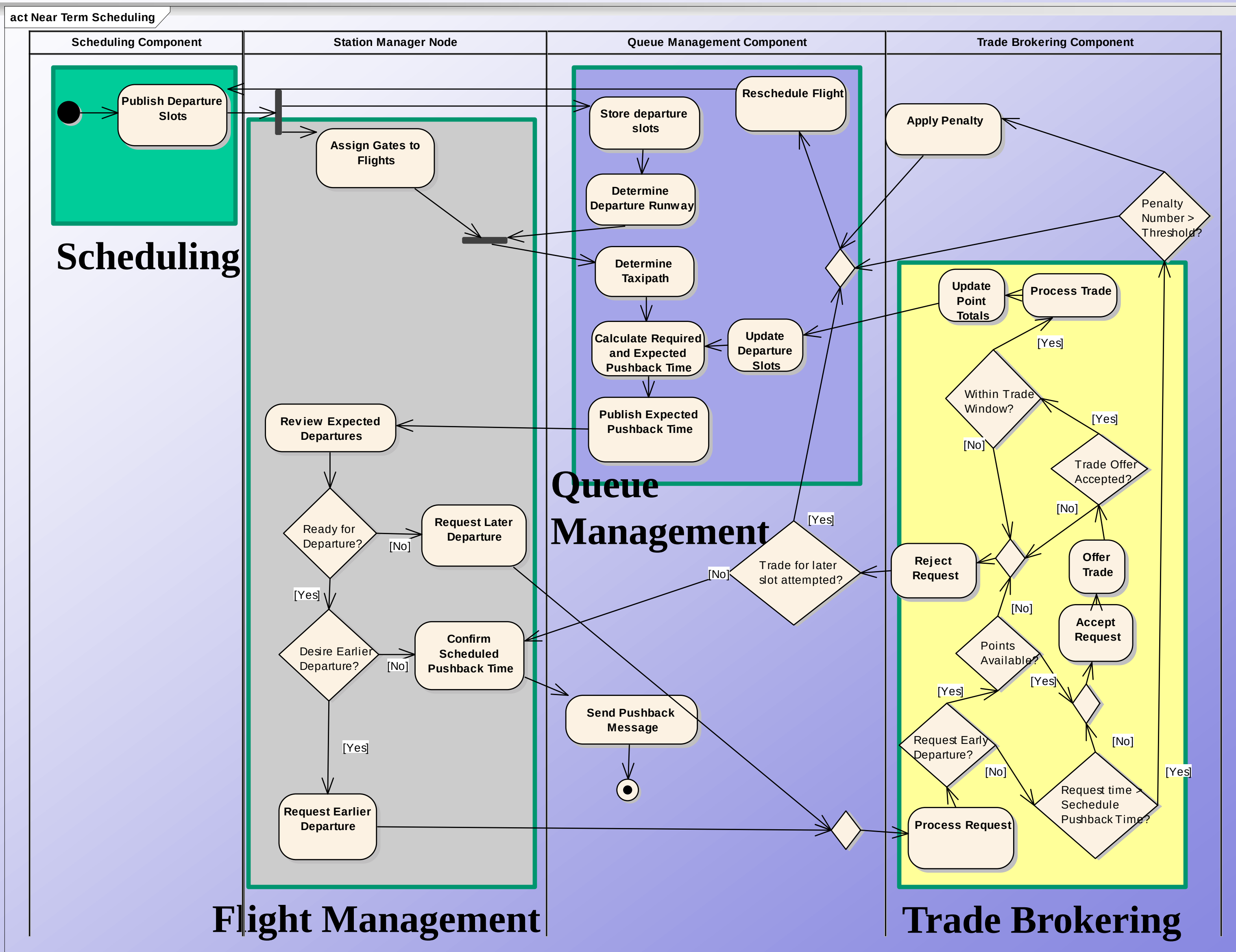
Architecture

Structured Analysis (Functional Decomposition)



Architecture

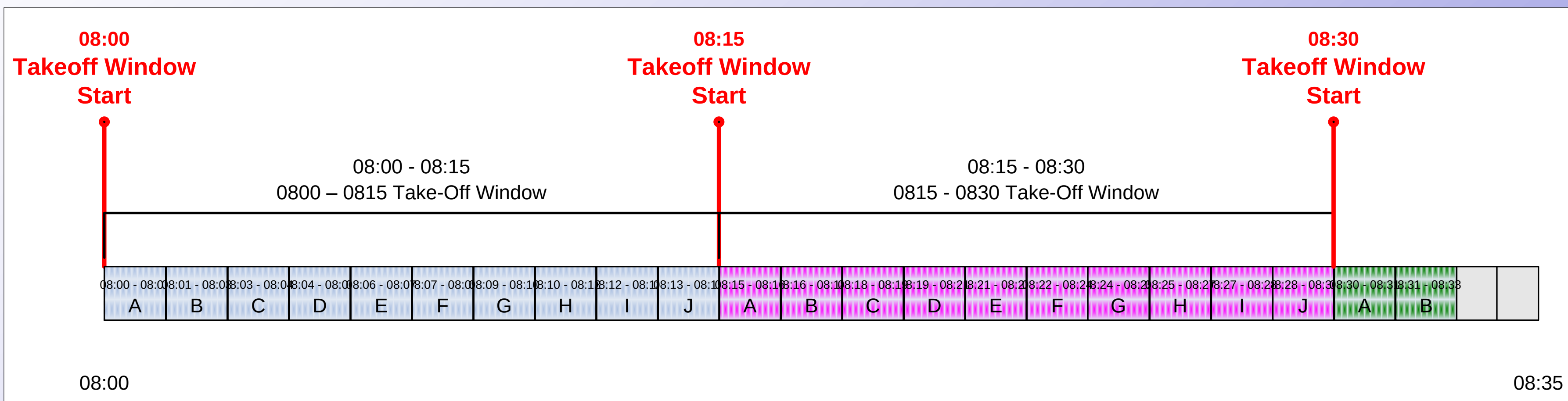
Object-Oriented (System Activity Diagram)



Architecture

System Components (1 of 3)

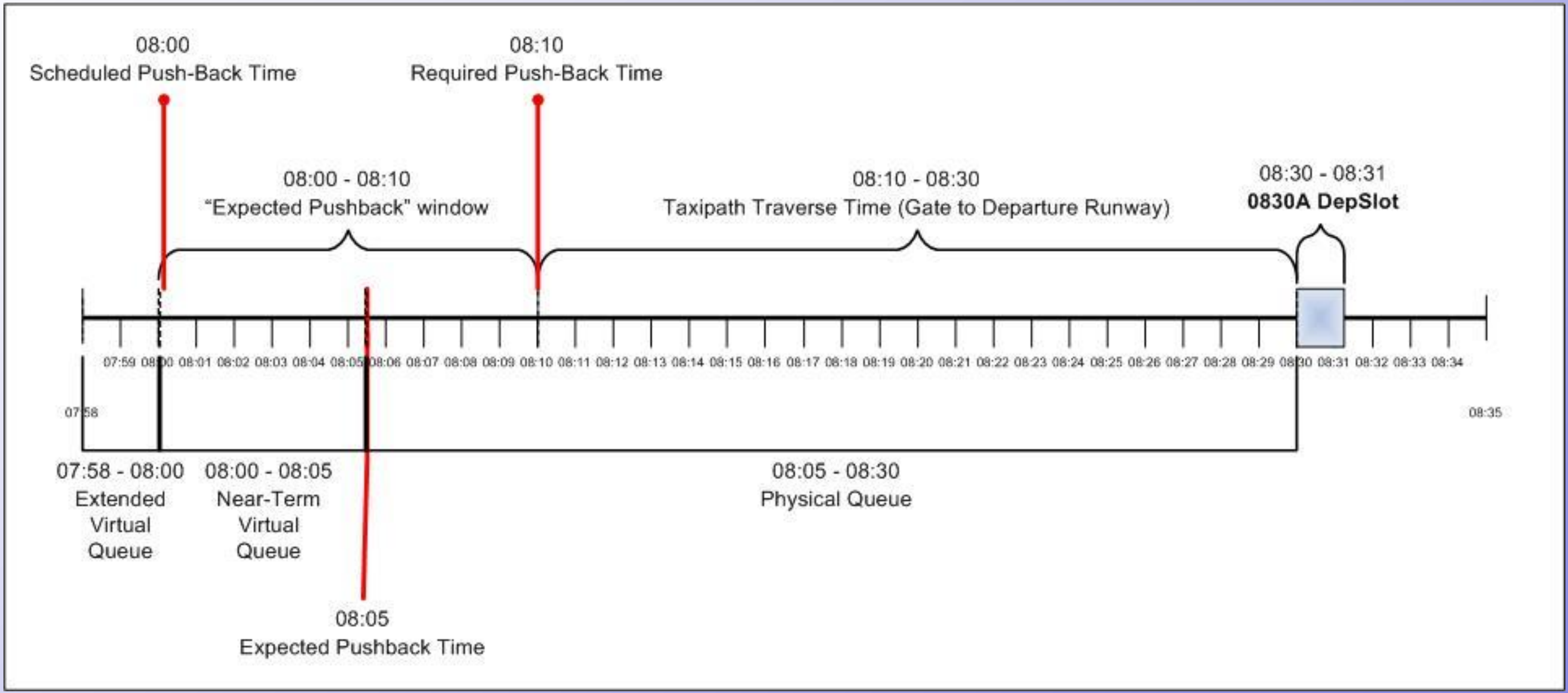
Scheduling Module: levels demand across capacity (10 departures per 15-minute window)



Architecture

System Components (2 of 3)

Queuing Module: divides departure queue into virtual and physical components; minimizes excess taxi time by reducing conflicts on PHL surface



Architecture

System Components (3 of 3)

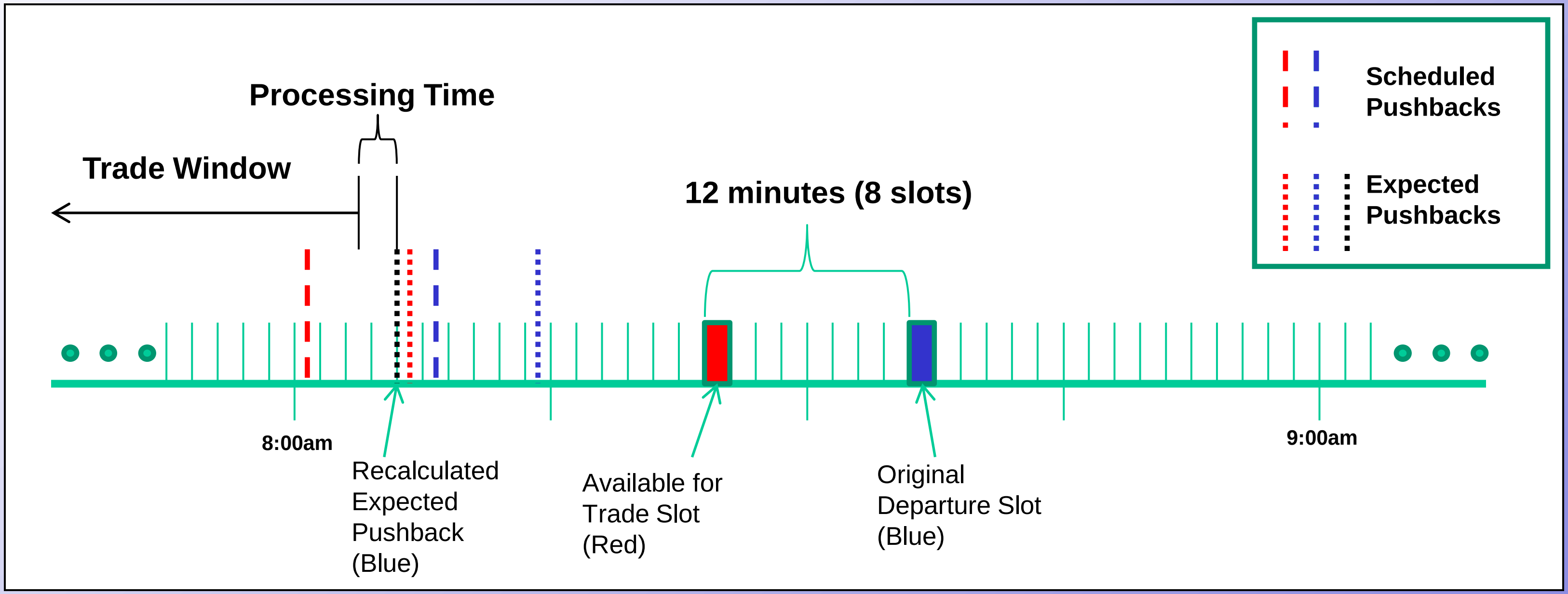
Trade Brokering Module: uses a point system to facilitate departure slot trading amongst airlines within virtual queue

Point system concepts

- An earlier slot is an asset (more valuable than a later slot) – buy/sell earlier slot
- Number of points required = Number of slots earlier
- If I want to take off later, I sell my earlier slot
- Airline departure slots “missed” are assessed penalty if ADFMS not notified early enough
- ADFMS allows ‘falling back’ to later departure slot due to an unforeseen circumstances
- Points awarded periodically / unused points expire periodically
- Point exchange first-in first out (FIFO)
- Unfilled departure slots can be acquired without exchanging points
- No buying when points ≤ 0

Trading for an earlier departure slot:

the processing for the change needs to occur prior to the recalculated expected pushback to facilitate the trade and maximize capacity (maintain the aircraft departure rate) while continuing to reduce conflicts on the PHL surface areas



Architecture

Trade Demonstration

Airline 1

Age	Pts
0 wk	10
1 wk	10
2 wk	10
3 wk	5

Broker

Airline 1	Airline 2	Airline 3
B-5	S-5	

Airline 3

Age	Pts
0 wk	10
1 wk	10
2 wk	10
3 wk	10

Airline 2

Age	Pts
0 wk	15
1 wk	10
2 wk	10
3 wk	10

S-5	Sell 5 slots
S-10	Sell 10 slots
B-5	Buy 5 slots
B-10	Buy 10 slots

- Airline 1 has a flight ready to leave early.
- Airline 2 owns an earlier slot and decides to sell it to Airline 1
- Points are updated

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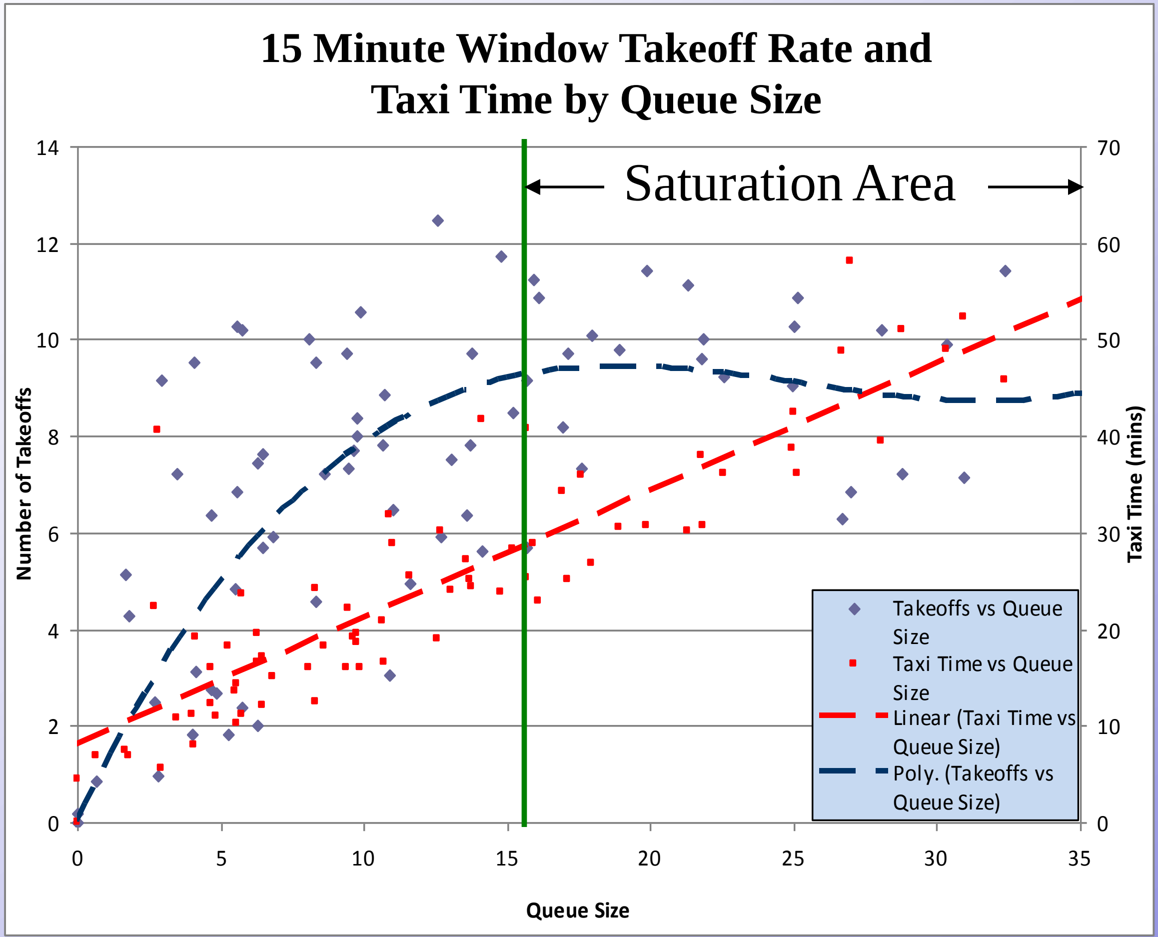
Modeling & Simulation
Observations from Dataset

Takeoff rate stagnates but taxi time grows in saturation area



July 2007	Average Queue Size	Average Taxi Time (mins)
Overall	16	27.73
Peak Time	20	32.83
Non-Peak Time	10	20.92

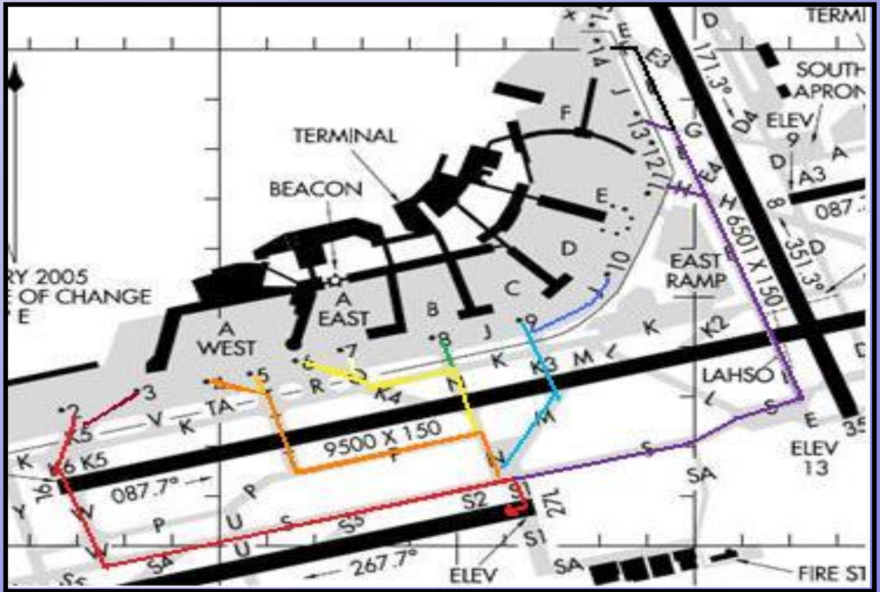
Modeling & Simulation

Apply Queue Management to Avoid Congestion

- Example for Ramp Control Spot 2:

Time	T=0	T=1	T=2	T=3	T=4	T=5	……	T=24	T=25	T=26
Step	**Step 1**	**Step 2**	**Step 3**	**Step 4**	**Step 5**	**Step 6**	**……**	**Step 25**	**Step 26**	**Step 27**
Flight 1			**CS 2**	K5	K6	Cross Runway	……	S1	S1-27L turn	27L
Flight 2	**CS 3**	Apron	Apron-K5 turn	K5	K6	Cross Runway	……	S1	S1-27L turn	27L
Flight 3			**CS 11**	H	H-E turn	Eg	……	S1	S1-s7L turn	27L

- Rules:
  - A flight from Control Spot 2 should not pushback exactly two minutes after a flight from Control Spot 3.
  - A flight from Control Spot 2 should not pushback at the same time as a flight from Control Spot 11.



Simulation Flow Diagram

Read Input File

Initialize Input Attributes

Route to Terminal

Hold at Gate and Scan for Condition

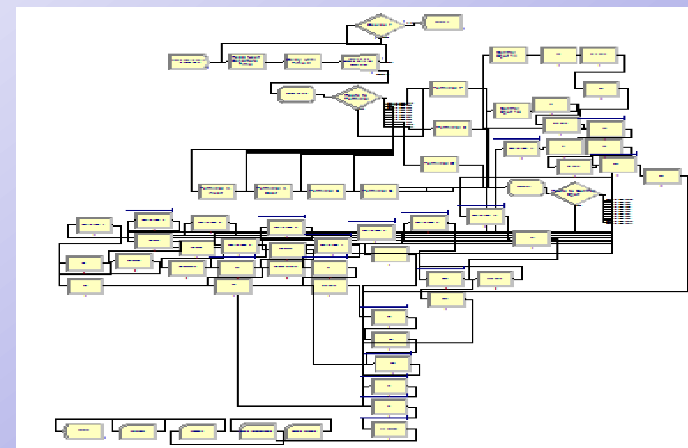
Pushback and Record Start of Taxi Time

Route to Control Spot

Taxi to Runway

Calculate Performance Metrics

Attributes	Decription
AirCarrier	Air Carrier
TimeIn	Time at Gate
ReqPB	Time Request Pushback
SchedTO	Scheduled Takeoff Time
FuelBurn	Kg Fuel Burned per Second of Operation
CO_EM	G CO Emission per KG Fuel Burned
HC_EM	G HC Emission per KG Fuel Burned
NOX_EM	G NOx Emission per KG Fuel Burned
SOX_EM	G SOx Emission per KG Fuel Burned



Calculations
TaxiTime=TNOW-StartTaxi
FuelBurn * (TaxiTime)
CO_EM * FuelBurn * (TaxiTime)
HC_EM * FuelBurn * (TaxiTime)
NOX_EM * FuelBurn * (TaxiTime)
SOX_EM * FuelBurn * (TaxiTime)

Modeling & Simulation

Parameters / Taxi Times

- At demand = capacity [Airport Departure Rate (ADR) of one (1) take-off every 1.5 minutes]
  - A: FCFS Baseline – 10 aircraft pushback each 15 minute increment
    - Most closely models actual taxi-times
  - B: FCFS Improvement – 5 aircraft pushback per 7.5 minute increment
  - C: ADFMS – 1 aircraft departure per 1.5 minute increment
    - Effective pushback is 1 aircraft pushback per 1.5 minute increment
  - X: FCFS Worst case – 20 aircraft pushback each 30 minute increment

- At demand > capacity [ADR of one (1) take-off every 1.5 minutes]
  - Y: Simulate 42 aircraft pushback each 60 minute increment
  - Z: Simulate 44 aircraft pushback each 60 minute increment
    - Maximum for Arena prior to exceeding maximum of 150 concurrent events

Modeling & Simulation

Conflict Reduction

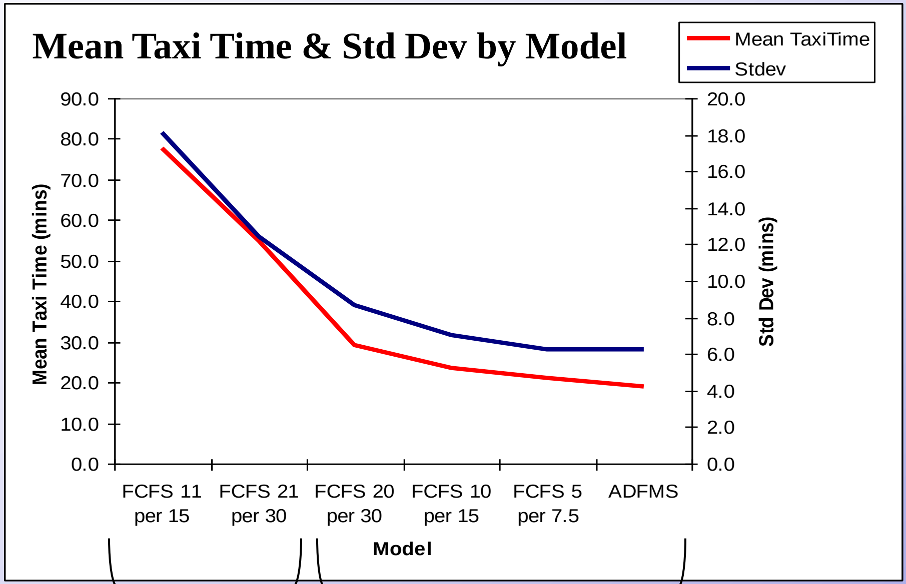
- Conflicts decrease and congestion gets lighter as less flights pushback simultaneously

Conflicts Experienced (Y=Yes, N=No)						
Segment	FCFS with Rate of 11 per 15 Minutes	FCFS with Rate of 21 per 30 Minutes	FCFS with Rate of 20 per 30 Minutes	FCFS with Rate of 10 per 15 Minutes	FCFS with Rate of 5 per 7.5 Minutes	With Departure Flow Management
Control Spot 3	Y	Y	N	N	N	N
Control Spot 6	Y	Y	Y	N	N	N
Control Spot 7	Y	Y	Y	Y	N	N
Control Spot 8	Y	Y	Y	Y	N	N
Control Spot 9	Y	Y	Y	Y	N	N
Control Spot 10	Y	Y	Y	Y	Y	N
Control Spot 11	Y	Y	Y	Y	N	N
Intersection Q	Y	N	N	N	N	N
Intersection TA	Y	N	N	N	N	N
Intersection ED	Y	Y	Y	N	N	N
Intersection EG	Y	Y	Y	Y	N	N
Intersection K3A	Y	Y	Y	Y	Y	N
Intersection NB	Y	Y	Y	Y	N	N
Intersection ND	Y	Y	Y	Y	Y	N
Intersection NE	Y	Y	Y	Y	Y	Y
Intersection S1	Y	Y	Y	Y	Y	Y
27L Runway	Y	Y	Y	Y	Y	Y

Modeling & Simulation

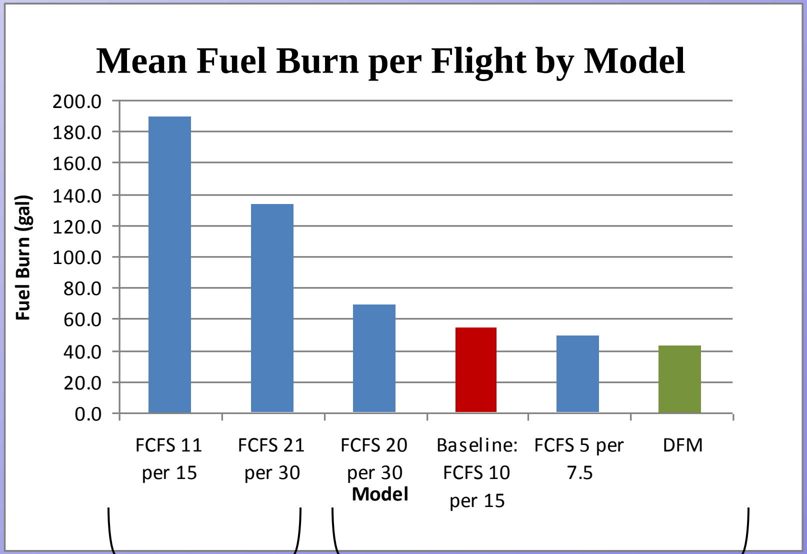
Results

- By leveling demand (departure slot scheduling) and reducing conflicts (queue management), ADFMS reduces the mean taxi time and mean fuel burn per flight



Over Capacity At Capacity

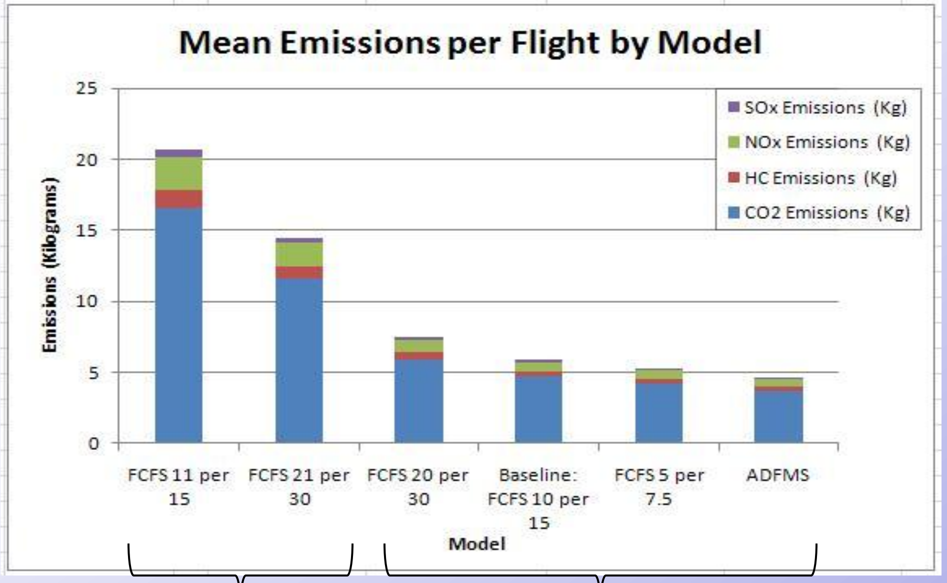
- ADFMS also reduces std deviation
- Reductions can be valued in $$$$$



Over Capacity At Capacity

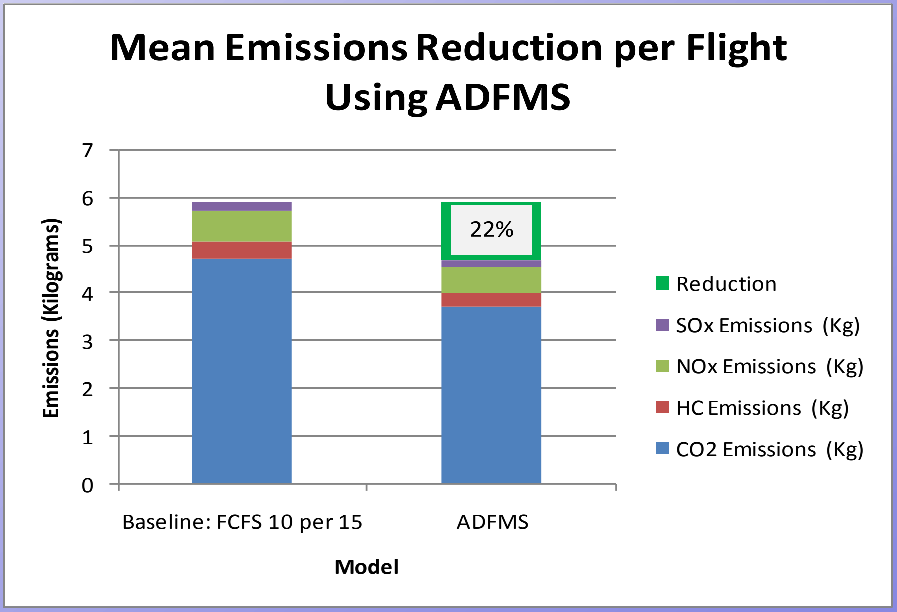
Modeling & Simulation
Results

- By reducing taxi time, ADFMS also reduces mean emissions per flight



Over Capacity

At Capacity



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Evaluation & Recommendations

Cost Benefit Analysis

				Return Rate	8.00%	
Year	**Fuel Burn Reduction ADFMS**	**Annual O&M Costs**	**Capital Expenditures**	**Net Savings**	**Net Savings (NPV) at Return Rate**	**Cumulative Net Savings**
0			**$5000**	-$5000	-$5000	-$5000
1	$5160	$2000		$3160	$2709	-$2291
2	$5631	$2000		$3631	$2882	$591
3	$6021	$2000		$4021	$2956	$3547
4	$6285	$2000		$4285	$2916	$6463
5	$6480	$2000		$4480	$2823	$9286
6	$6728	$2000		$4728	$2759	$12045
7	$6947	$2000		$4947	$2673	$14718
8	$7137	$2000		$5137	$2570	$17288
9	$7267	$2000		$5267	$2440	$19728
10	$7384	$2000		$5384	$2309	$22037
All numbers in thousands (000's)					**Total:**	$22037

- Assuming a $5 million investment with $2 million annual operating costs over a 10 year system life cycle, implementing ADFMS would:
  - Realize a Net Present Value to stakeholders of $22 million
  - Pay off in the second year of operation

Evaluation & Recommendations

Investment Scenarios

Investment scenarios	Pros	Cons
FAA	• **Unbiased arbitrator for perceived fairness of departure slot scheduling and queue management**	• **FAA avoids surface management issues: core competency is National Airspace System (NAS); avoid liability issues**
Airlines	• **Realize greatest dollar value to successful implementation to departure flow management**	• **Hypercompetitive behavior: inherently unable to cooperate without arbitrator**
PHL Airport Authority	• **Surface areas are traditionally managed by local airport authorities** • **Departure queue delays are directly attributed to PHL, not individual airlines: would improve image/reputation of PHL**	• **As a US Airways hub, PHL AA could be perceived as biased from the perspective of other airlines** • **Require investment recoupment from stakeholders (Passenger Facility Charge (PFC) option)**

Evaluation & Recommendations

Recommendation

- Implementation of ADFMS at PHL will:
  - Save airlines millions of dollars via reduced fuel consumption
  - Reduce emissions into the environment
  - Improve passenger satisfaction with airlines and PHL
  - Enable trading of departure slots amongst airlines

- Capital investment by PHL Airport Authority is best approach
  - Surface management is a local airport authority issue
  - Unbiased arbitrator amongst hypercompetitive airlines
  - Can levy fair recoupment fees from airlines and/or passengers

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Future Work & Acknowledgements

Future Work

- Simulation of Departure Slot Assignment function
- Simulation of the Trade Brokering function
- Continued analysis of PHL for out-of-scope constraints
  - Alternate runway configurations
  - Effects of weather, arrivals, GDPs, etc.

Future Work & Acknowledgements

Acknowledgements

- Guidance and support of Dr. Lance Sherry, GMU Center for Air Transportation System Research (CATSR)

- Continuous assessment and guidance from Dr. Laskey, Course Professor

- Wealth of information readily available on World-Wide Web

    - Airliners.net
    - AirNav.com
    - iFly.com
    - LiveATC.net
    - RITA/BTS
    - Eurocontrol.int
    - FAA.gov
    - PHL.org
    - DSpace@MIT
    - CATSR.ite.gmu

"Philadelphia International Airport - Google Maps." Google Maps. Google, n.d. Web. 13 Feb. 2010

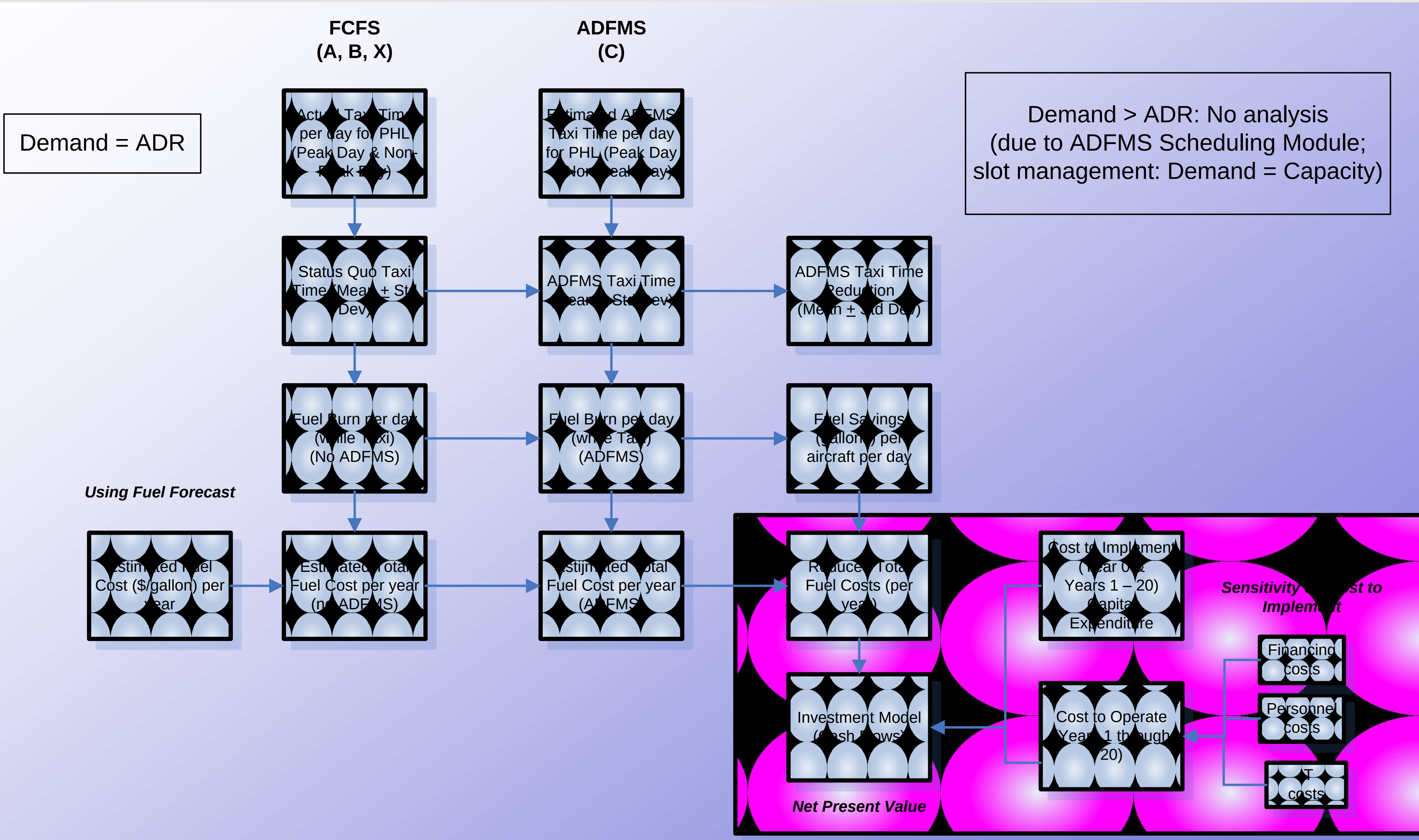
Questions

Questions?

Backup Slides

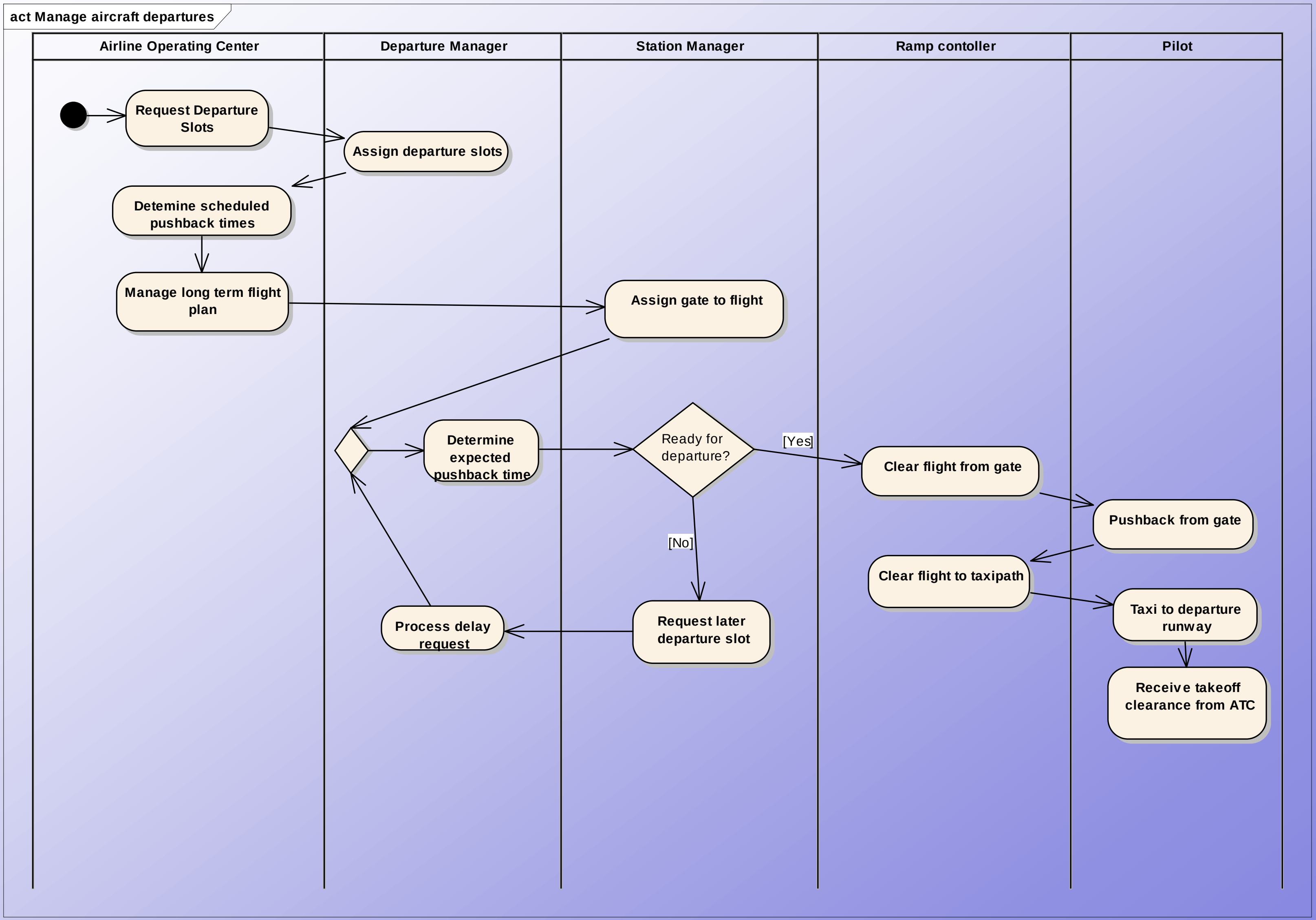
Evaluation & Recommendations

Cost Benefit Analysis



Architecture

Object-Orientation (Operational Activity Diagram)



Backups

Airline Points

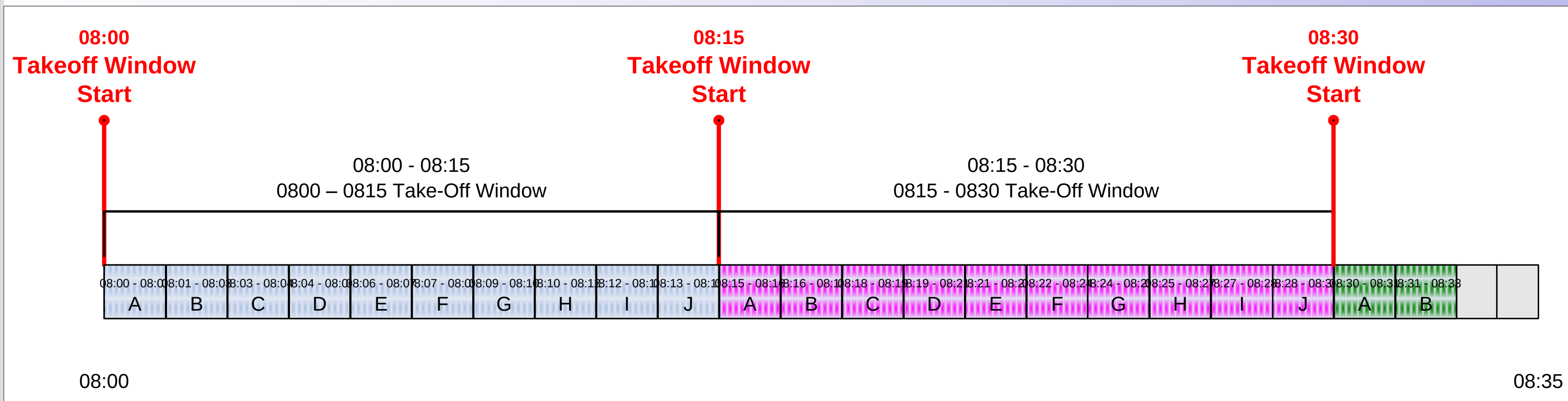
Airline	Equal Distribution	Based on % of scheduled Flights		Based on % of gates	
		% of Flights	Points	% of Gates	Points
9E	40	1.6%	6	2.0%	8
AA	40	5.9%	24	5.9%	24
CO	40	2.5%	10	2.0%	8
DL	40	3.9%	15	3.9%	15
OH	40	2.2%	9	2.6%	10
FL	40	3.1%	12	2.7%	11
NW	40	4.3%	17	4.3%	17
UA	40	5.6%	22	5.6%	22
US	40	46.9%	188	48.0%	192
WN	40	24.0%	96	23.0%	92
Total	**400**	**100.0%**	**400**	**100.0%**	**400**

Notional

Notes:

- System needs to appear fair
- Companies can trade between their own flights without affecting their point totals.
- Equal distribution
  - Companies with a lot of points per flight (e.g. 9e) tend to become buyers as they will have surplus points
  - Companies with lower points per flight (e.g. US) may tend to trade within their own schedule at least for buys
- Varying points by airport use
  - Companies with lower points (e.g. 9E – 6 points) have a difficult time initiating trading until they can sell some slots.
  - Companies with a lot of points (e.g. US – 188 points) tend to become buyers and can also trade within their own schedule.

Point System Overview



- An earlier slot is an asset (more valuable than a later slot) – buy/sell earlier slot
- If I want to take off early, I buy an earlier slot (#slots earlier = # points)
  - The seller earns points from buyer
  - Trade request to sell (earlier) slot must be made in Extended Virtual Queue (>schedule pushback time)
- If I want to take off later, I sell my earlier slot
  - The buyer spends points to get earlier slot. Buyer must be willing & “able.”
  - Able = time available > time request

Point System Overview

- Airline departure slots "missed" are assessed penalty if ADFMS not notified early enough
  - Notification needs to occur is prior to scheduled push-back time
  - Penalties suspended until threshold exceeded
- ADFMS allows 'falling back' to later departure slot due to an unforeseen circumstances
  - Bump up/ compression by subsequent flights in queue to ensure queue efficiency
- Points awarded periodically / unused points expire periodically
- Point exchange first-in first out (FIFO)
- Unfilled departure slots can be acquired without exchanging points
- No buying when points ≤ 0

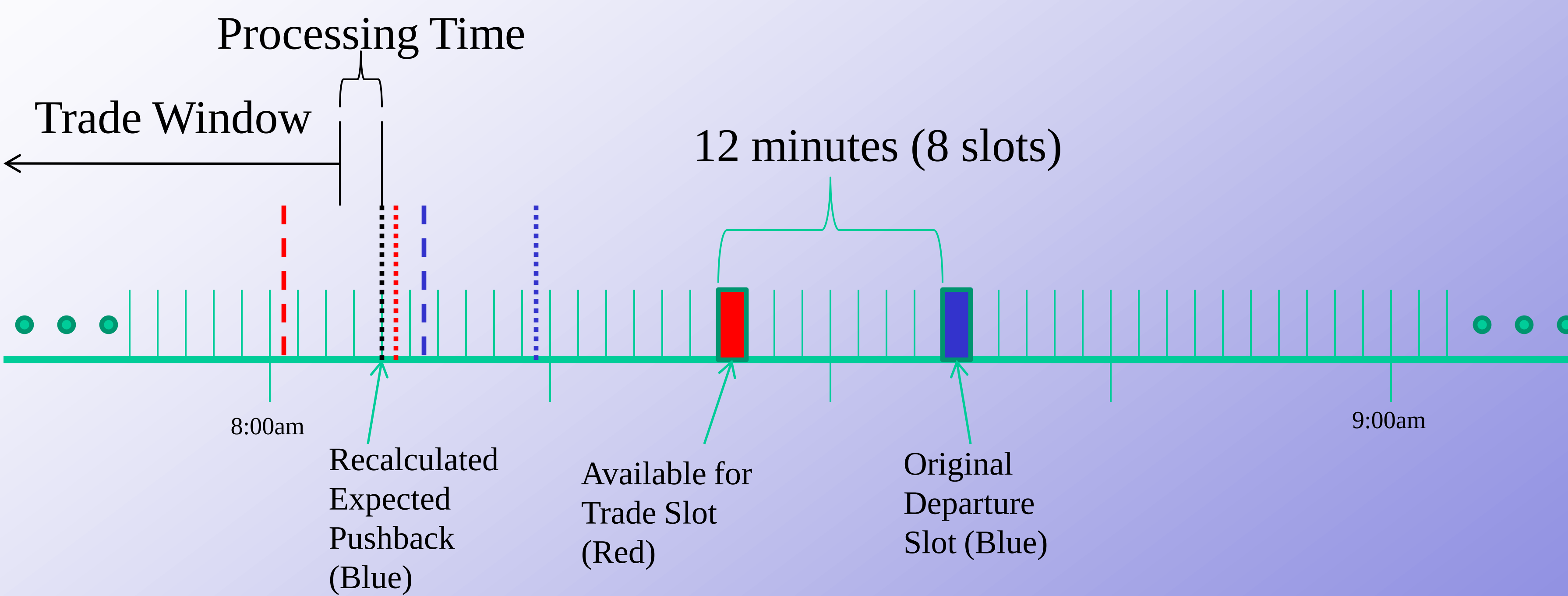
Rolling Points Based on Weeks

Week Ending	20-Feb	27-Feb	6-Mar	13-Mar	20-Mar	27-Mar	3-Apr	10-Apr	17-Apr	24-Apr	1-May
Weekly Starting Total	40	40	40	35	50	50	55	45	55	45	50
3 weeks	10	10	10	5	10	10	20	10	15	5	20
2 weeks	10	10	10	10	10	20	10	15	10	20	10
1 week	10	10	10	10	20	10	15	10	20	10	10
current week	10	10	10	10	10	10	10	10	10	10	10
Buys		10	15			10			20		10
Sells				10		5		10			
End of Week Total	40	30	25	45	50	45	55	55	35	45	40
3 weeks	~~10~~	~~0~~	0	5	10	0	20	10	0	5	10
2 weeks	10	10	5	10	10	20	10	15	5	20	10
1 week	10	10	10	10	20	10	15	10	20	10	10
current week	10	10	10	20	10	15	10	20	10	10	10

Expiring Points

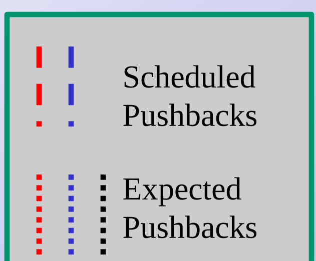
10 points acquired each week

Trade for an Earlier Departure

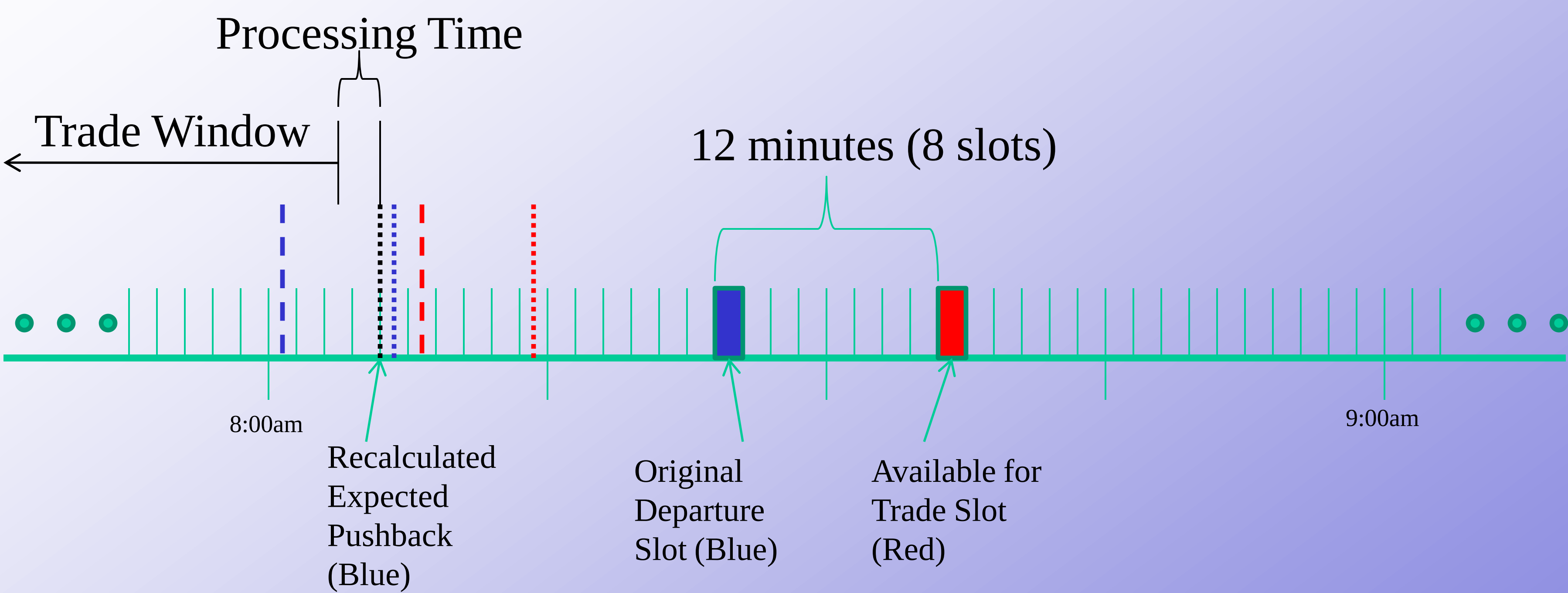


Notes:

1. Each slot is 1 minute & 30 seconds.
2. The processing of the change needs to occur prior to the recalculated expected departure time. This may or may not be the same as the current expected departure time because of the difference in location of the aircraft making the switch.



Trade for a Later Departure



Notes:

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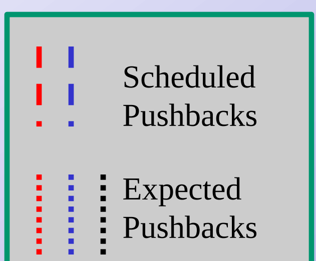
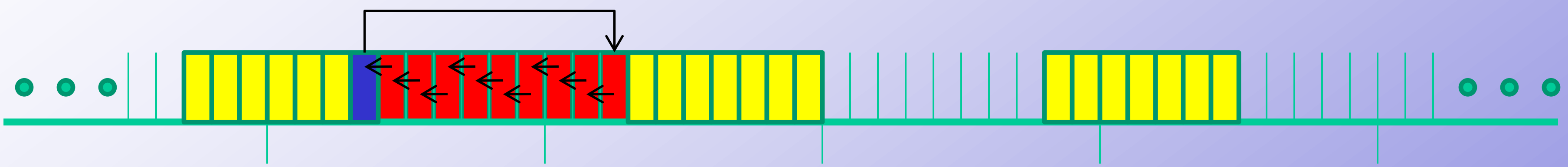
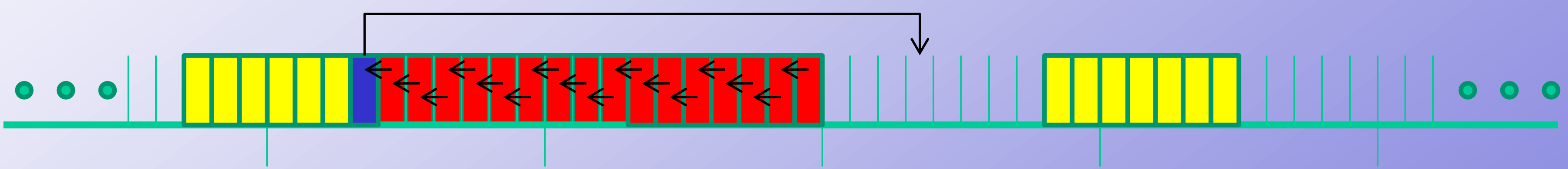


Later Departure Slot Excursions

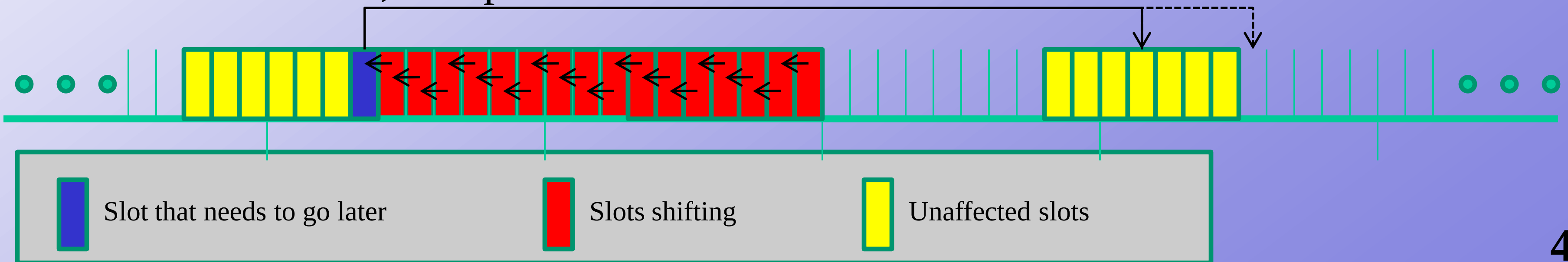
- Trade available was discussed on previous slide
- No trade available, open slot achieved through departure slot shifting



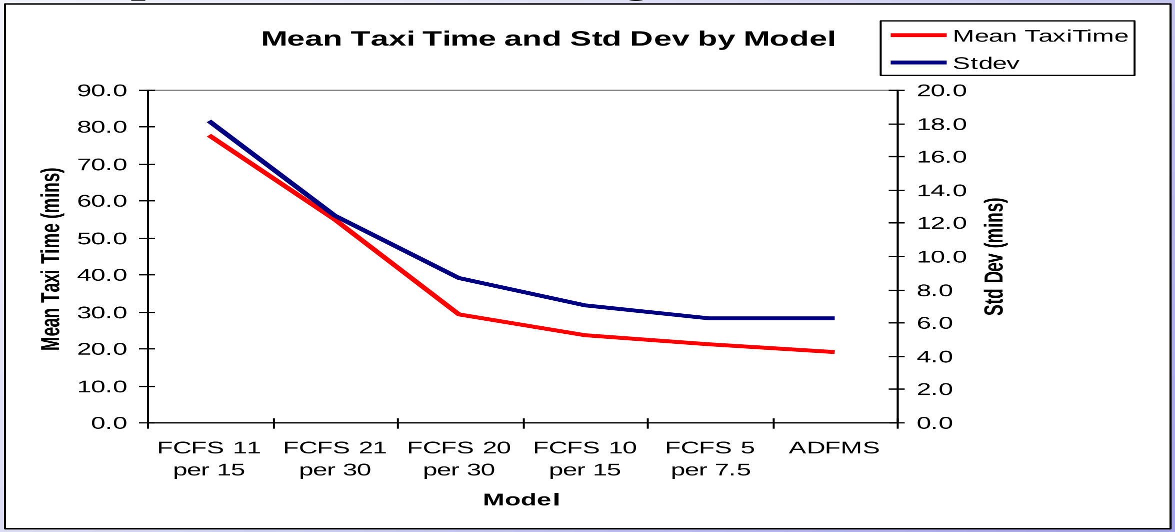
- No trade available, open slot available due to lack of traffic



- No trade available, no open slot available



Decreased Mean Taxi Time and Standard Deviation with Departure Flow Management



Fuel Burn and Emissions Reduction Using ADFMS

Per Flight	2005-2009 AVG	Baseline A: FCFS 10 per 15	ADFMS
Fuel Burned (gal)	55.3	54.2	42.4
Fuel Burn Reduction (gal) Using DFM	13.0	11.9	0.0
%Fuel Burn Reduction Using DFM	23.4%	21.9%	0.0%

Per Flight	2005-2009 AVG	Baseline A: FCFS 10 per 15	ADFMS
Emissions (Kg)	6.1	6.0	4.7
Emissions Reduction (Kg) Using DFM	1.5	1.3	0.0
% Emissions Reduction Using DFM	23.9%	22.2%	0.0%

Modeling & Simulation
Results

Comparison of Baseline Results with 2005-2009 Averages

Per Flight	2005-2009 AVG	Baseline A: FCFS 10 per 15	ADFMS
Fuel Burned (gal)	55.3	54.2	42.4
Fuel Burn Reduction (gal) Using DFM	13.0	11.9	0.0
%Fuel Burn Reduction Using DFM	23.4%	21.9%	0.0%

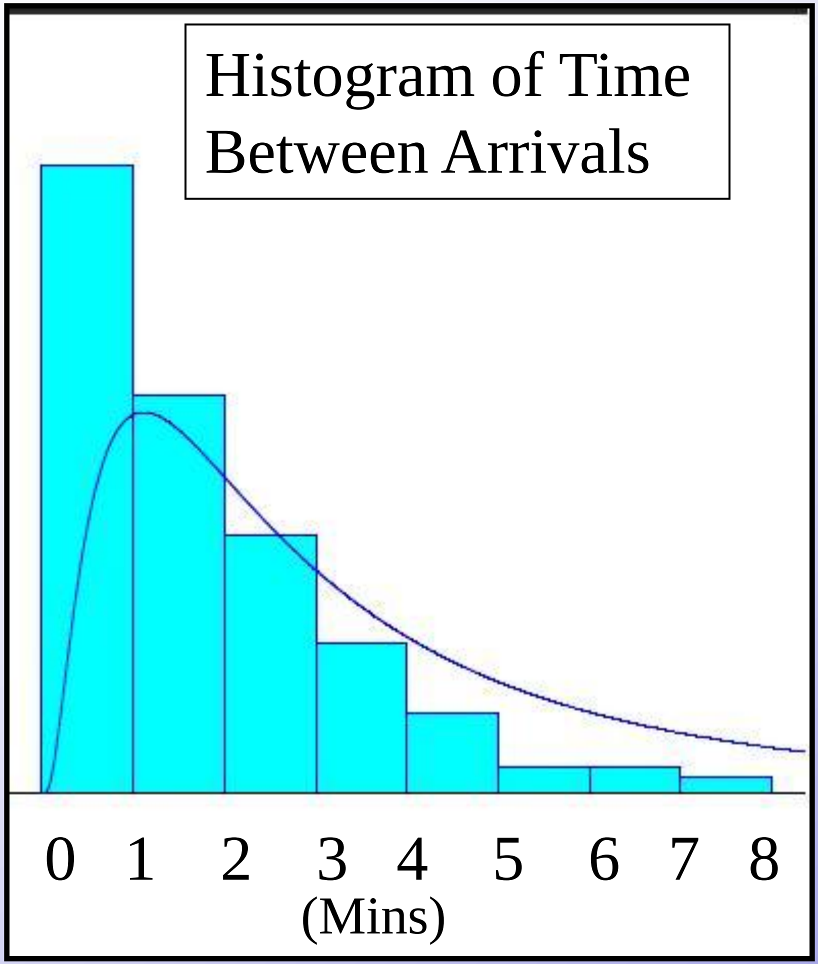
Per Flight	2005-2009 AVG	Baseline A: FCFS 10 per 15	ADFMS
Emissions (Kg)	6.1	6.0	4.7
Emissions Reduction (Kg) Using DFM	1.5	1.3	0.0
% Emissions Reduction Using DFM	23.9%	22.2%	0.0%

Results Consistent with Analogous Departure Slot Implementation Studies

Study	Hours of Taxi Time Saved per Day at PHL
Collaborative Airport Surface Metering-Conservative (May 2007)	43
GRA Inc Airport CDM at NEXTOR Symposium (Jan 2010)	49
ADFMS	50

http://acast.grc.nasa.gov/wp-content/uploads/icns/2007/Session_H/05-Brinton.pdf
http://www.nextor.org/Conferences/201001_NEXTOR_Symposium/Berardino.pdf

Distribution of Time Between Arrivals



Distribution Summary	
Distribution:	Lognormal
Expression:	=-0.001 + LOGN(4.16, 5.11)
Square Error:	0.00169

Chi Square Test	
Number of intervals	10
Degrees of freedom	7
Test Statistic	8.66
Corresponding p-value	0.285

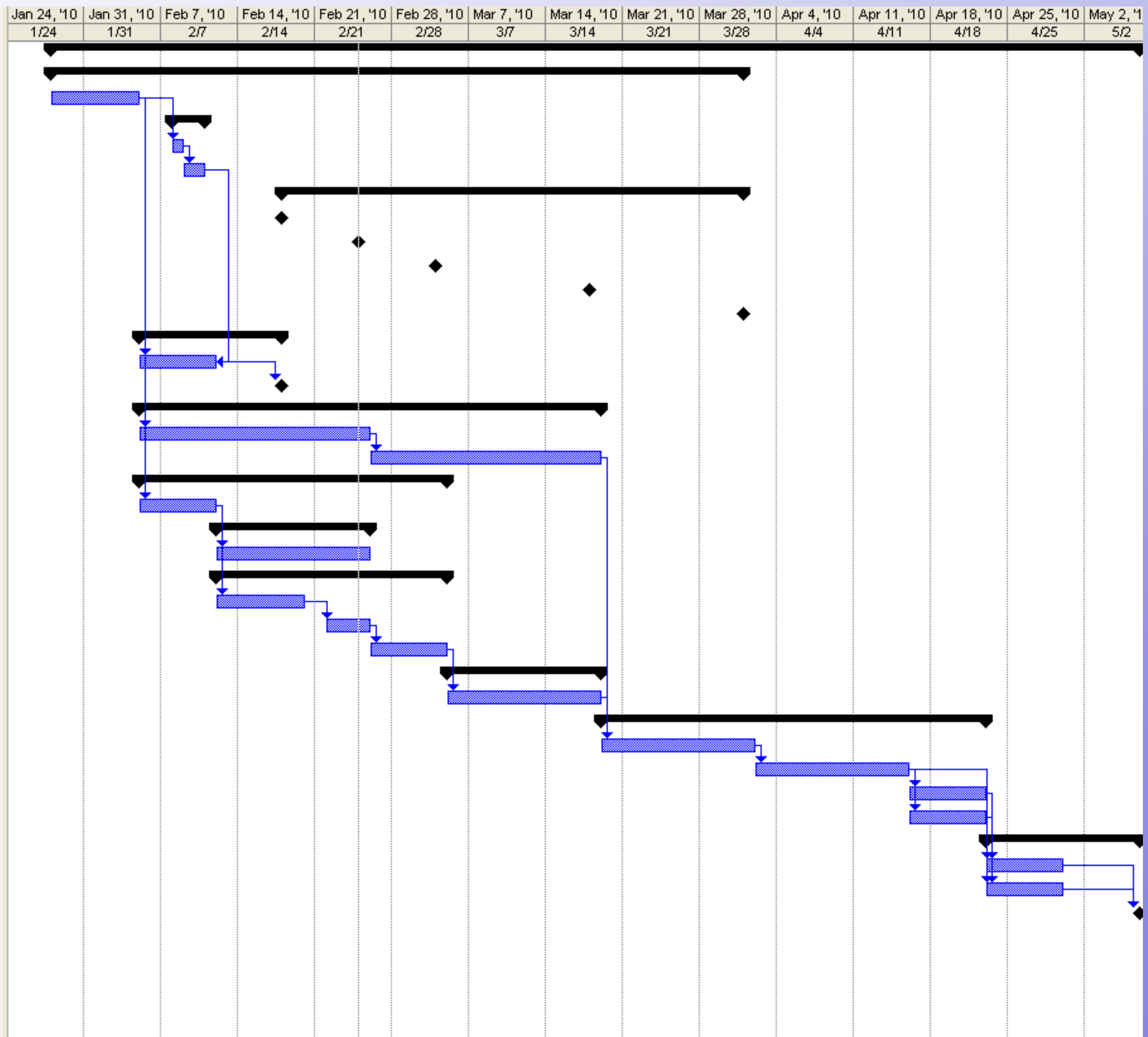
Kolmogorov-Smirnov Test	
Test Statistic	6.55E-223
Corresponding p-value	6.55E-223

Data Summary	
Number of Data Points	602
Min Data Value	0
Max Data Value	18
Sample Mean	1.88
Sample Std Dev	2.2

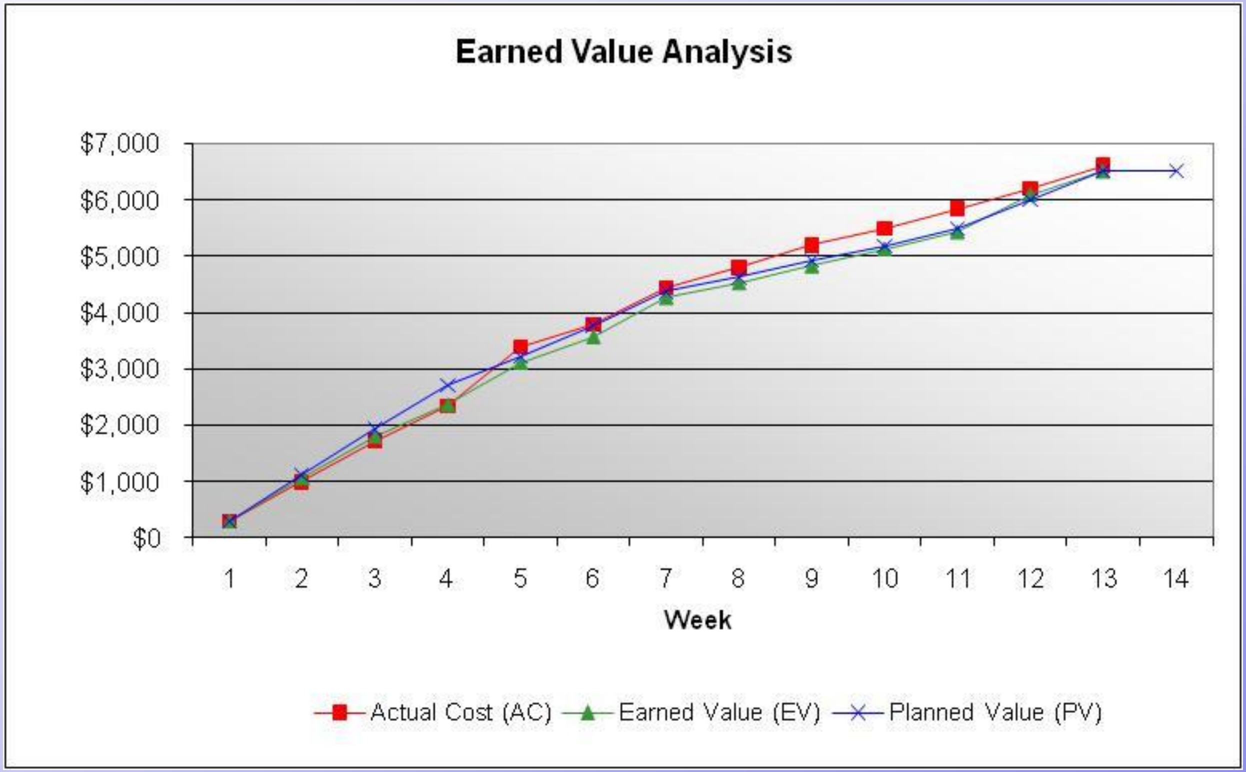
Histogram Summary	
Histogram Range	= -0.001 to 18
Number of Intervals	16

Project Schedule / Progress

WBS	Task Name
1	**AirportDFM System Project**
1.1	**Project Management**
1.1.1	Form Project Team
1.1.2	**Initial Project Plan**
1.1.2.1	WBS
1.1.2.2	Project Schedule
1.1.3	**Project Reporting**
1.1.3.1	Project Proposal Presentation
1.1.3.2	Status Report
1.1.3.3	Progress Report
1.1.3.4	Status Report
1.1.3.5	Formal Progress Presentation
1.2	**Project Proposal**
1.2.1	Proposal Development
1.2.2	Proposal Presentaiton
1.3	**Queuing Model Development**
1.3.1	Data Analysis
1.3.2	Data Simulation
1.4	**System Definition**
1.4.1	Subject Research
1.4.2	**DRAFT System Requirements**
1.4.2.1	Requirements Decomposition
1.4.3	**DRAFT System CONOPS**
1.4.3.1	Operational Concept
1.4.3.2	Use Cases
1.4.3.3	Operational Architecture
1.5	**System Design**
1.5.1	System Architecture
1.6	**Assessment**
1.6.1	System Simulation
1.6.2	Scenario Analysis
1.6.3	Refined System Requirements
1.6.4	Refined System CONOPS
1.7	**Transition**
1.7.1	Final Report
1.7.2	Final Web Site
1.7.3	Presentation



Earned Value Management



Earned Value Management