Adjusting Ground Delay Programs for Demand and Capacity Uncertainties

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Outline

- Problem: Uncertainty in GDP planning
- Approach: Computational experiments
- Results: How uncertainty affects a GDP
  - Result #1: Optimal GDP may change in response to uncertainty
  - Result #2: GDP can be futile in the face of uncertainty
  - Result #3: GDP can be effective even with uncertainty

The Problem

- If assume no uncertainty, can compute optimal ground delays to eliminate airborne delay
  - Assign a ground delay equal to the predicted airborne delay in the absence of a GDP
- But there are two kinds of uncertainty
  - Capacity: Duration and depth of reductions in AAR
  - Demand: Actual arrival times of flights at airport
- What is the effect of uncertainty
  - On optimal assigned ground delays?
  - On the expected payoff of imposing a GDP?

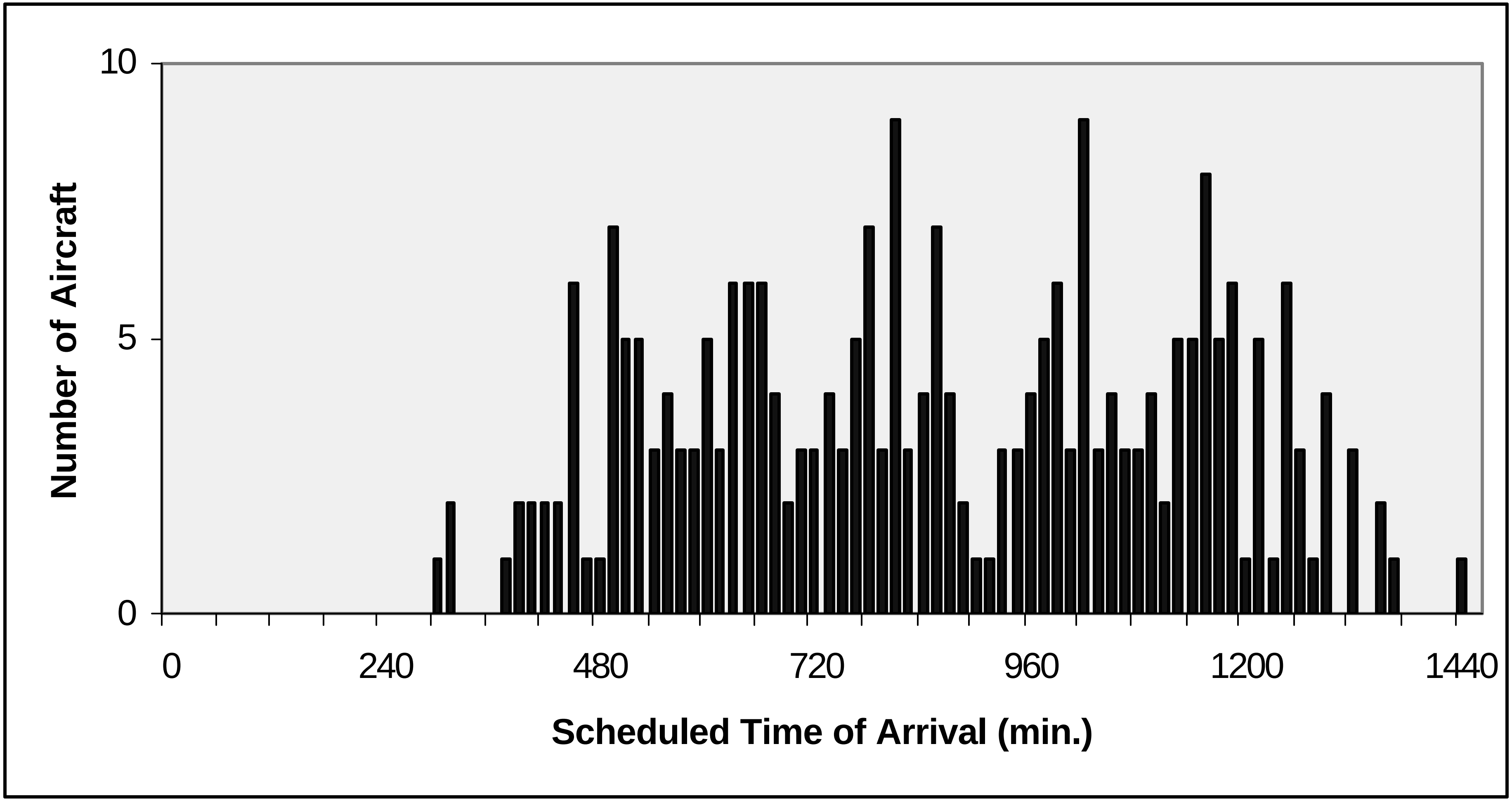
Prior Work

- Theory underlying GDP planning
  – Odoni, Ball, Hoffman, Richetta, Rifkin, etc.
- Implications of uncertainty in GDPs
  – Inniss and Ball (Nextor NR-2002-002)
    - Study of AAR reductions at SFO
  – Willemain (ATCQ 2002 and Nextor WP-01-3)
    - Assumed small number of aircraft and all in GDP
    - Only 2 capacity scenarios: nominal and other
    - Can ignore pessimistic scenario when $(1-P)C < 1$

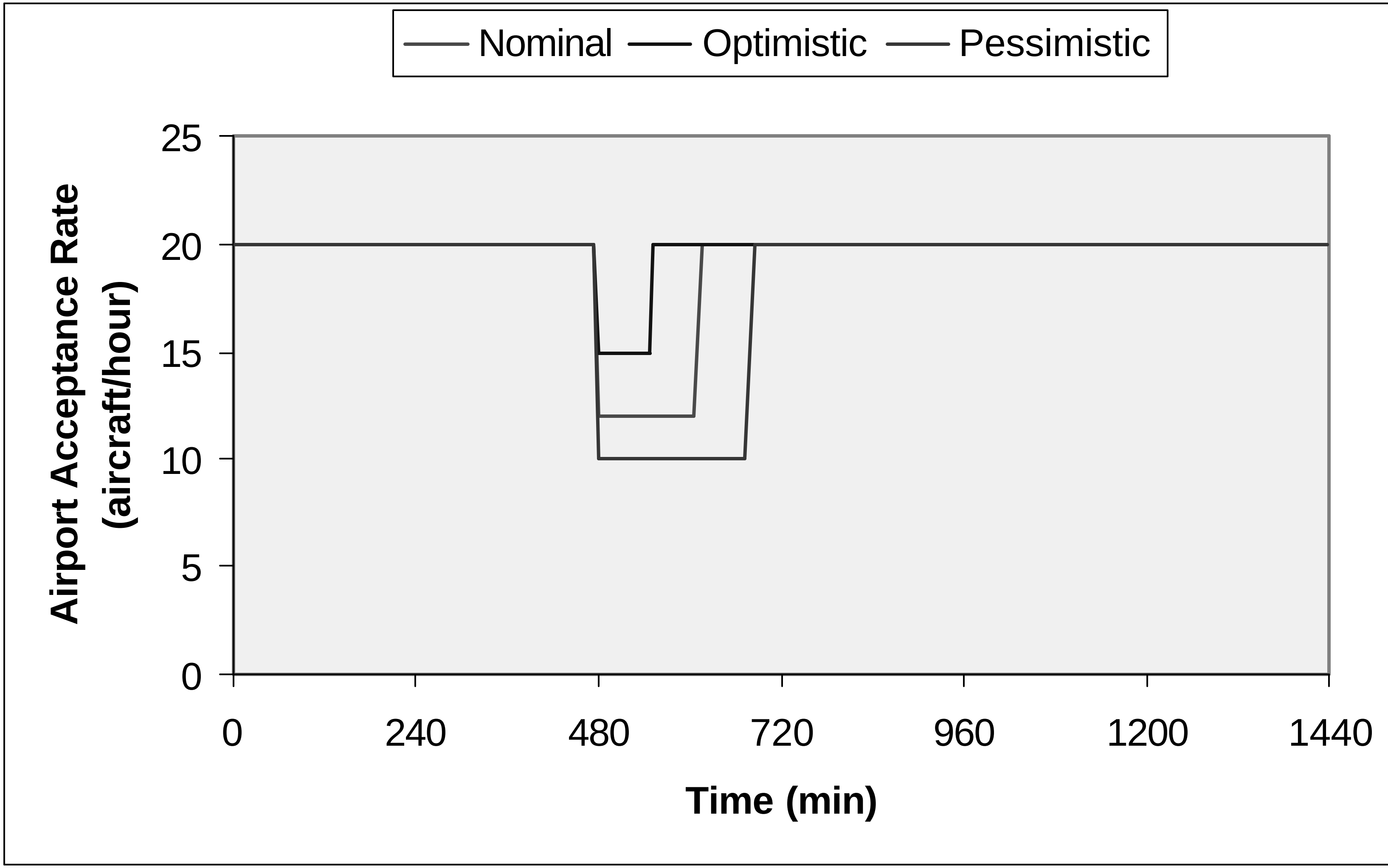
Situation Analyzed

- A very tough situation for GDPs
- Airport with one runway for arrivals
- Demand profile has multiple rushes per day
- Normal AAR = 20 aircraft per hour
- Anticipate AAR drop to 12 from 8 -11 am
- Capacity uncertainty
  - Nominal scenario: AAR = 12 for 3 hours
  - Optimistic scenario: AAR = 15 for 1.5 hours
  - Pessimistic scenario: AAR = 10 for 6 hours
- Demand uncertainty
  - Actual arrival = Scheduled + Ground delay + Random
  - Random ~ Normal$(1,5^2)$
- No changes to GDP once planned (for tractability)

Demand Pattern: Multiple Banks



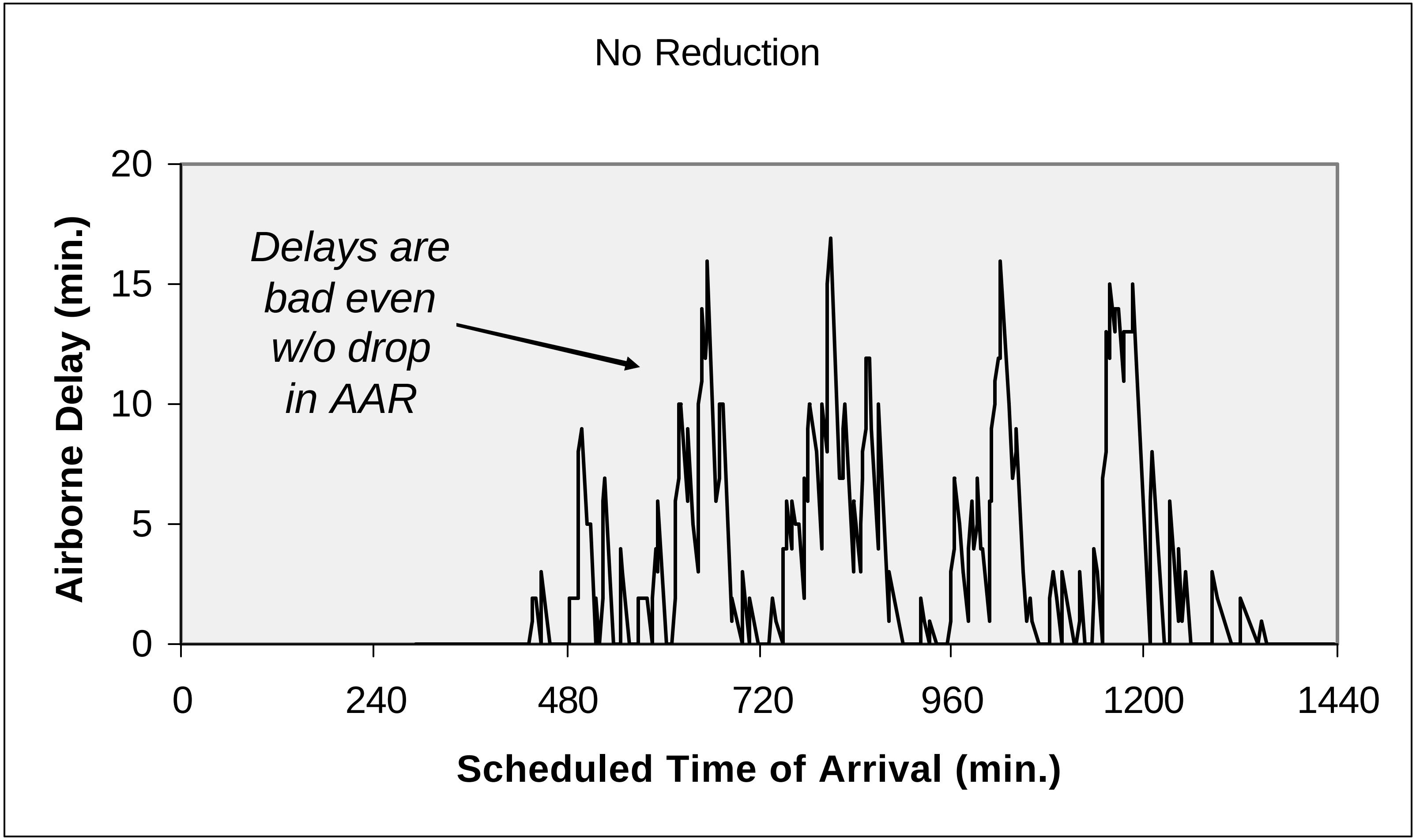
Capacity Scenarios



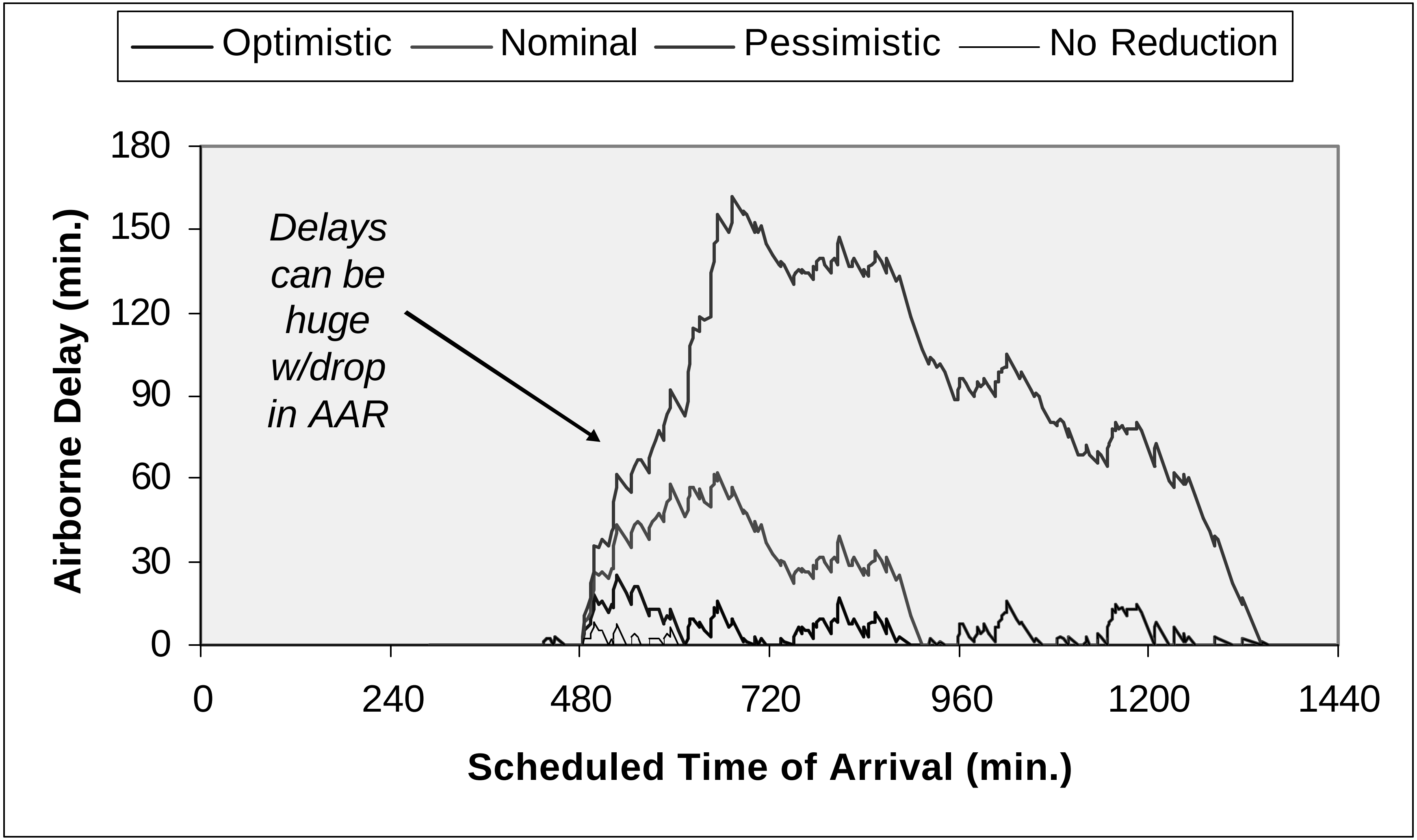
Spreadsheet Queueing Model

	U	V	W	X	Y	Z	AA	AB	AC
26	Pessimistic Scenario								
27	**#**	**SchdArr**	**GndDly**	**ActArr**	**AirDly**	**Start Svc**	**Svc Time**	**End Svc**	**TotalDly**
28	1	291	0	291	0	291	3	294	0
29	2	306	0	306	0	306	3	309	0
30	3	310	0	310	0	310	3	313	0
31	4	372	0	372	0	372	3	375	0
32	5	378	0	378	0	378	3	381	0
33	6	387	0	387	0	387	3	390	0
34	7	401	0	401	0	401	3	404	0
35	8	404	0	404	0	404	3	407	0
36	9	407	0	407	0	407	3	410	0
37	10	412	0	412	0	412	3	415	0
38	11	422	0	422	0	422	3	425	0
39	12	434	0	434	0	434	3	437	0
40	13	436	0	436	1	437	3	440	1
41	14	438	0	438	2	440	3	443	2
42	15	441	0	441	2	443	3	446	2
43	16	447	0	447	0	447	3	450	0
44	17	448	0	448	2	450	3	453	2
45	18	450	0	450	3	453	3	456	3
46	19	459	0	459	0	459	3	462	0
47	20	472	0	472	0	472	3	475	0
48	21	481	0	481	0	481	6	487	0
49	22	484	2	486	1	487	6	493	3
50	23	485	6	491	2	493	6	499	8
51	24	488	8	496	3	499	6	505	11
52	25	491	10	501	4	505	6	511	14
53	26	494	12	506	5	511	6	517	17
54	27	495	16	511	6	517	6	523	22

Delays If No Reduction in AAR



Delays If No GDP



Approach to Analysis

- Key parameters
  - Relative cost of air vs ground delay
  - Probabilities of the 3 scenarios
  - Mean and standard deviation of uncertainty in arrival times
- Assignment of ground delays
  1. None (a reference case)
  2. Unhedged: Optimal assuming no contingencies
  3. Hedged: Approximately optimal accounting for uncertainties
  4. Nonlinear programming problem
     - Objective function: Minimize expected value of weighted sum of ground and air delays
     - Decision variables: Ground delay assigned to flights scheduled to arrive during 8-11 am
     - Spreadsheet implementation
     - Initial solution is unhedged (idealized) solution
     - Hedged solution may not be implementable but shows Expected Value of Perfect Information (EVPI)

Sources of Uncertainty

- Demand uncertainty alone
  - Aircraft arrive at times other than scheduled
  - Destroys perfect synchronization of unhedged GDP
- Capacity uncertainty alone
  - AAR reduction may not be as expected
    - May be deeper or less deep
    - may last for longer or shorter time
  - Unhedged GDP may put system in inferior position
- Both sources of uncertainty at once

Result #1

Optimal GDP may change in response to uncertainty

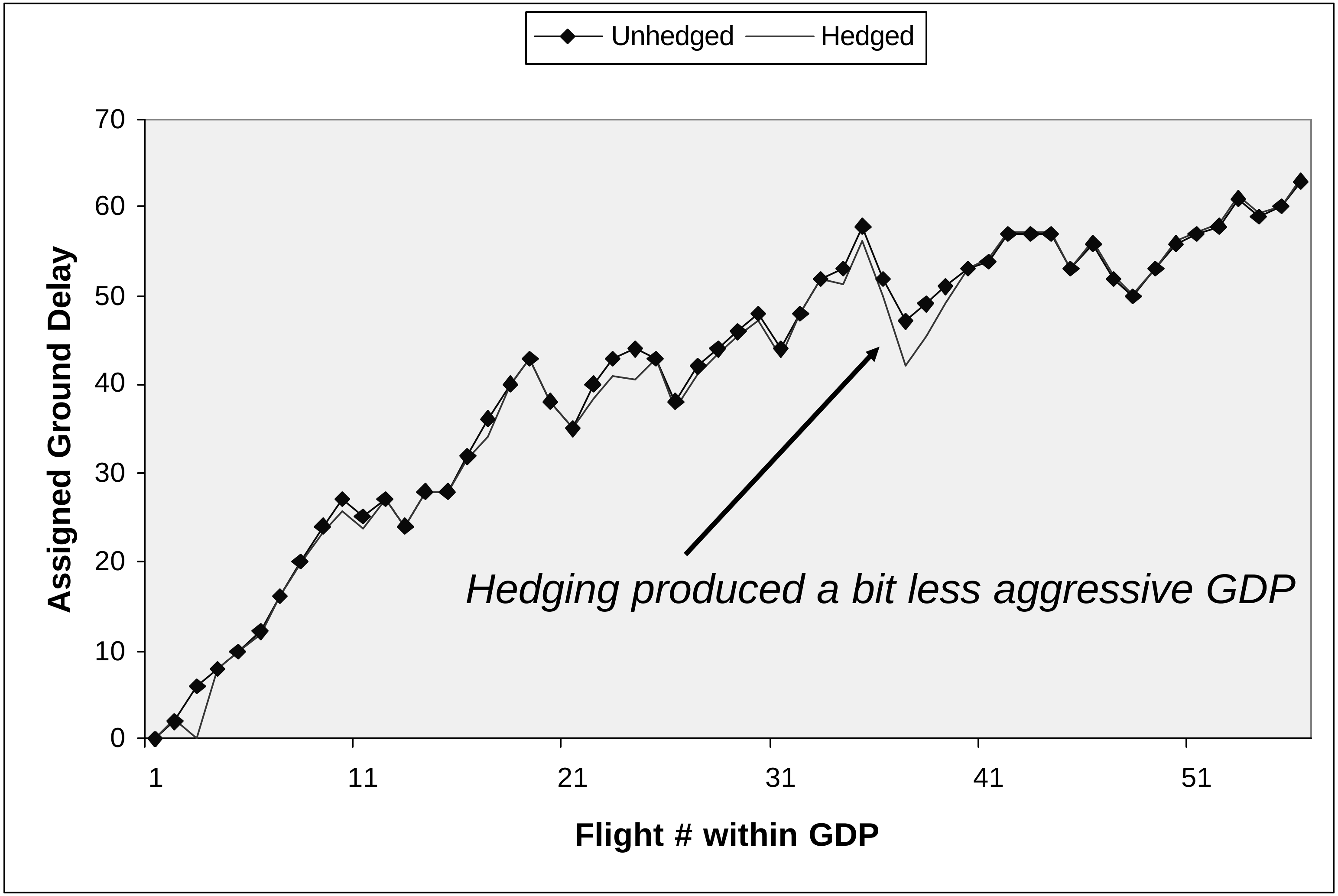
Example: Capacity Contingencies Change the Optimal GDP

Assignment of Ground Delay	Average Ground Delay	Nominal Average Air Delay	Optimistic Average Air Delay	Pessimistic Average Air Delay	Expected Weighted Avg Delay
None	0.0	19.4	6.0	85.9	70.7
Unhedged	9.1	10.3	10.3	76.8	69.6
Hedged	9.0	10.4	9.6	77.0	69.3
Times in minutes, rounded to nearest minute. Assumptions: C = 2; Probabilities = 40:30:30; No demand uncertainty					

In ideal case, ideal (unhedged) GDP helps a lot.

Accounting for risks, best GDP is a bit less aggressive and only a bit more effective than no GDP.

Assigned Ground Delays



Result #2

GDP can be futile in the face of uncertainty

Effects of Uncertainty in Demand and Capacity

Expected value of (GroundDelay + 2*AirDelay)

	Type of Uncertainty			
Type of GDP	None	Demand	Capacity	Both
None	38.8	39.6	70.6	70.4
Unhedged	29.6	35.8	69.6	73.3
Hedged v. Demand	34.7	34.7	n/a	n/a
Hedged v. Capacity	29.8	n/a	69.3	n/a
Hedged v. Both	33.6	n/a	n/a	70.7

Assumes: C = 2. P(nominal)=0.4; P(optimistic)=0.3; P(pessimistic)=0.3.

With No Uncertainty, Unhedged GDP is Effective

Expected value of (GroundDelay + 2*AirDelay)

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With No Uncertainty, Hedging Degrades Solution

Expected value of (GroundDelay + 2*AirDelay)

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Uncertain Arrival Times Reduce Effectiveness of GDP

Expected value of (GroundDelay + 2*AirDelay)

	Type of Uncertainty			
Type of GDP	None	Demand	Capacity	Both
None	38.8	39.6	70.6	70.4
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Hedging the Ground Delays Recovers Some Benefit

Expected value of (GroundDelay + 2*AirDelay)

Type of GDP	**Type of Uncertainty** None	 Demand	 Capacity	 Both
None	38.8	39.6	70.6	70.4
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Hedged v. Both	33.6	n/a	n/a	70.7

May not be able to implement this hedging strategy in practice. Result shows EVPI.

Capacity Uncertainty Reduces Expected Gain from GDP

Expected value of (GroundDelay + 2*AirDelay)

	Type of Uncertainty			
Type of GDP	None	Demand	Capacity	Both
None	38.8	39.6	70.6	70.4
Unhedged	29.6	35.8	69.6	73.3
Hedged v. Demand	34.7	34.7	n/a	n/a
Hedged v. Capacity	29.8	n/a	69.3	n/a
Hedged v. Both	33.6	n/a	n/a	70.7

Expected costs increase from 30’s to 70’s because pessimistic scenario is possible.

Proper Hedging Regains Some Benefit

Expected value of (GroundDelay + 2*AirDelay)

Type of GDP	**Type of Uncertainty**			
	None	Demand	Capacity	Both
None	38.8	39.6	70.6	70.4
Unhedged	29.6	35.8	69.6	73.3
Hedged v. Demand	34.7	34.7	n/a	n/a
Hedged v. Capacity	29.8	n/a	69.3	n/a
Hedged v. Both	33.6	n/a	n/a	70.7

With Both Uncertainties, Idealized GDP Does Not Help

Expected value of (GroundDelay + 2*AirDelay)

	Type of Uncertainty			
Type of GDP	None	Demand	Capacity	Both
None	38.8	39.6	70.6	70.4
Unhedged	29.6	35.8	69.6	73.3
Hedged v. Demand	34.7	34.7	n/a	n/a
Hedged v. Capacity	29.8	n/a	69.3	n/a
Hedged v. Both	33.6	n/a	n/a	70.7

Even Perfect Hedging Fails to Recover Benefit from GDP

Expected value of (GroundDelay + 2*AirDelay)

Type of GDP	**Type of Uncertainty** None	 Demand	 Capacity	 Both
None	38.8	39.6	70.6	70.4
Unhedged	29.6	35.8	69.6	73.3
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Result #3

GDP can be effective even with uncertainty

Change in Scenario Parameters

- Drop in AAR occurs at 6 pm not 8 am.
  - GDP doesn't push delayed flights into a subsequent rush.
- With no demand uncertainty, the unhedged solution is optimal over a range of parameter values.
  - Varied C, scenario probabilities, normal AAR.
- Demand uncertainty degrades the solution by about 10%.
  - But still better than no GDP.

Unhedged GDP is Optimal but Slightly Degraded by Demand Uncertainty

Assignment of Ground Delay	Average Ground Delay	Nominal Average Air Delay	Optimistic Average Air Delay	Pessimistic Average Air Delay	Expected Weighted Avg Delay
None	0.0	11.9	5.8	21.9	26.1
Unhedged	7.7	4.2	4.2	14.3	22.1
+ Dem Unc	7.7	5.9 ± 0.4	4.5 ± 0.2	14.8 ± 0.4	23.9 ± 0.6
Assumptions: C = 2; Scenario probabilities = 40:30:30; AAR drops at 6 pm; Demand uncertainty ~ N(1,5) -> 95% CI's, unhedged					

Summary

- GDP planning should reflect uncertainties about AAR and arrival times.
- Accounting for uncertainties may require changes to assigned ground delays.
- For some situations, the uncertainties destroy the effectiveness of a GDP.
- For other situations, uncertainties can be ignored: They do not change the optimal GDP, nor do they degrade performance significantly.
- Possible further work might move beyond a few computational experiments to more fundamental analysis.

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