Airport Throughput Capacity Limits For Demand Management Planning

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Airport Capacity

- Airport Capacity is a significant “Control Lever” for NAS performance
  - Airport Arrival Rate (AAR)
  - Airport Departure Rate (ADR)
- Airport Capacity determined by:
  1. Runway Configuration
     - Wind, Noise abatement
  2. Runway Throughputs
     - Separation distance (Ceiling, visibility)
     - Staffing

Demand Management

- Demand Management is conducted under the jurisdiction of:
  - IATA Slot Allocation (IATA, 2000)
  - FAA High Density Rule (FAA, 1968)
- Demand Management curtails flights delays by scheduling flights within the Capacity Limits of the airport

HDR

- High Density Rule, established limits on the number of takeoffs and landings allowed by the incumbent airlines at five U.S. airports
    1. Chicago O'Hare International,
    2. Newark
        - 81 arrivals and departures slots per hour (i.e. 1458 slots between 6am and 10pm or 20.25 slots per 15 minutes)
    3. JFK
        - 81 arrivals and departures slots per hour (i.e. 1458 slots between 6am and 10pm or 20.25 slots per 15 minutes)
    4. LaGuardia
        - 75 arrival and departure slots per hour (i.e. 1350 slots between 6am and 10pm or 18.75 slots per 15 minutes)
    5. Washington Reagan National

Requirements on Demand Management Capacity Limits:

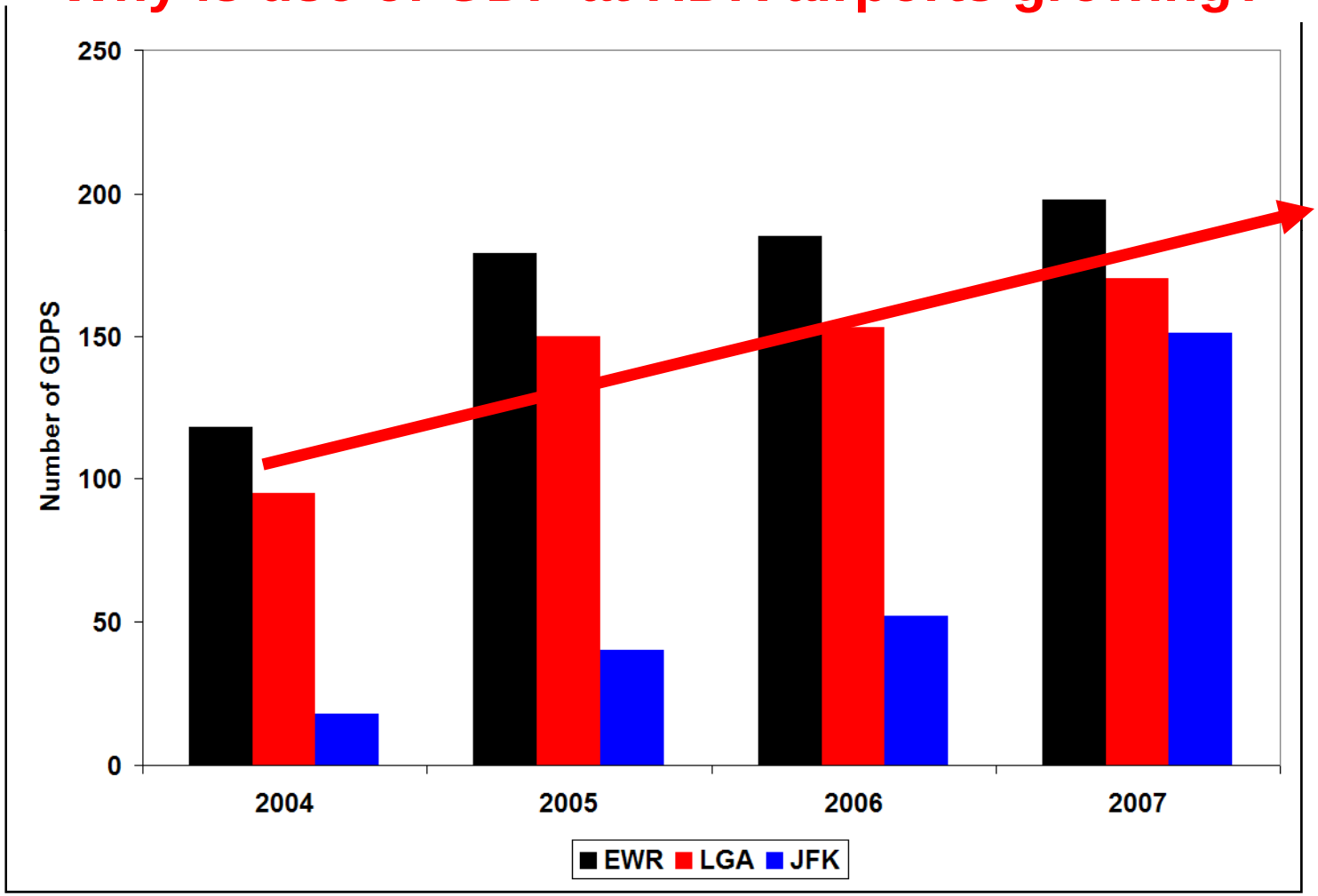
1. Established at least one year/six months in advance
2. Should account for variability in Airport Capacity
    - Runway configuration changes
        - Wind direction and magnitude
    - Throughput changes due to separation distance (IFR, MVFR, VFR)
        - Visibility and ceiling
    - Staffing, Service Reliability, etc..
3. Reflect economics of operations
    - Cost of Delays vs. Cost of Under-utilized Capacity

Performance at HDR Airports

- When Schedule is in excess of Capacity -> Ground Delay Program (GDP)
- GDP allocates delays according to Schedule arrival times
  - First-Scheduled/First-Allocated
- GDP allows airlines to prioritize their own flights (by swapping) according to their objective functions (i.e. cost, revenue structures)
  - Continental prefers all day GDP at EWR
    - to maintain network schedule integrity (not end GDP in middle of bank)
    - to swap flights

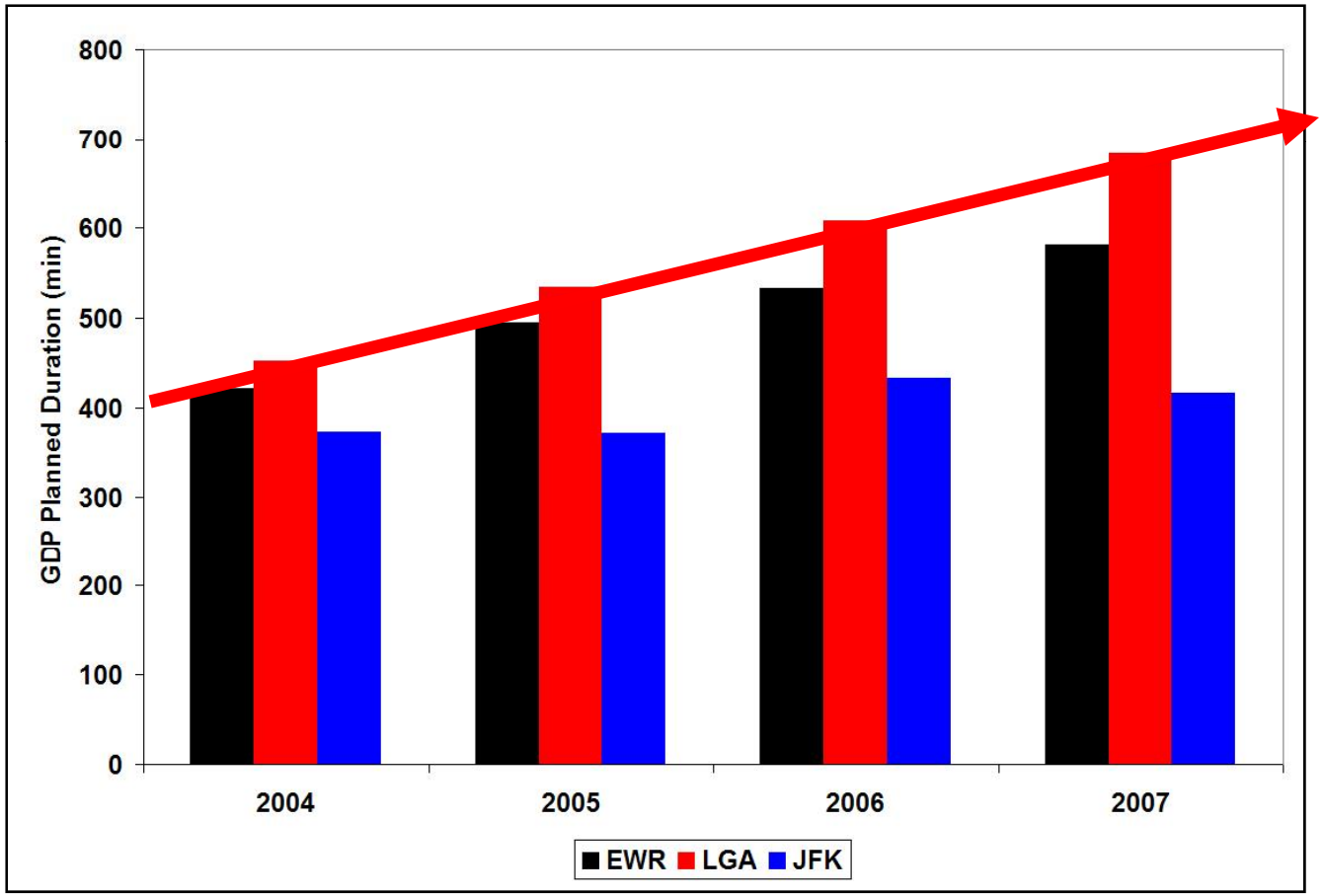
Performance at HDR Airport

- **Why is use of GDP at HDR airports growing?**



Performance at HDR Airports

- **Why is Duration of GDPs at HDR airports increasing?**



Questions

1. What is the variability in Seasonal Airport Capacity at OEP-35 airports?
2. What is the Optimal Airport Capacity in the presence of variability
   - minimize under-utilization AND over-scheduling
3. What is the Optimal Airport Capacity in the presence of variability AND operator preferences?
   - What is the value of Lost Profit for Under-scheduled Capacity?
   - What is the Cost of Delays for Over Scheduled Capacity?

Objective

- Analysis of:
  1. Seasonal Declared capacity at the OEP-35 airports
  2. Profits and Costs of Delays of operations at these airports
  3. The “economically optimal” airport capacity
     - The optimal airport capacity trades
       - the value of lost profits of under-utilized capacity during a season
       - costs of delays that are the result of variability in the available capacity during this season

Data Sources

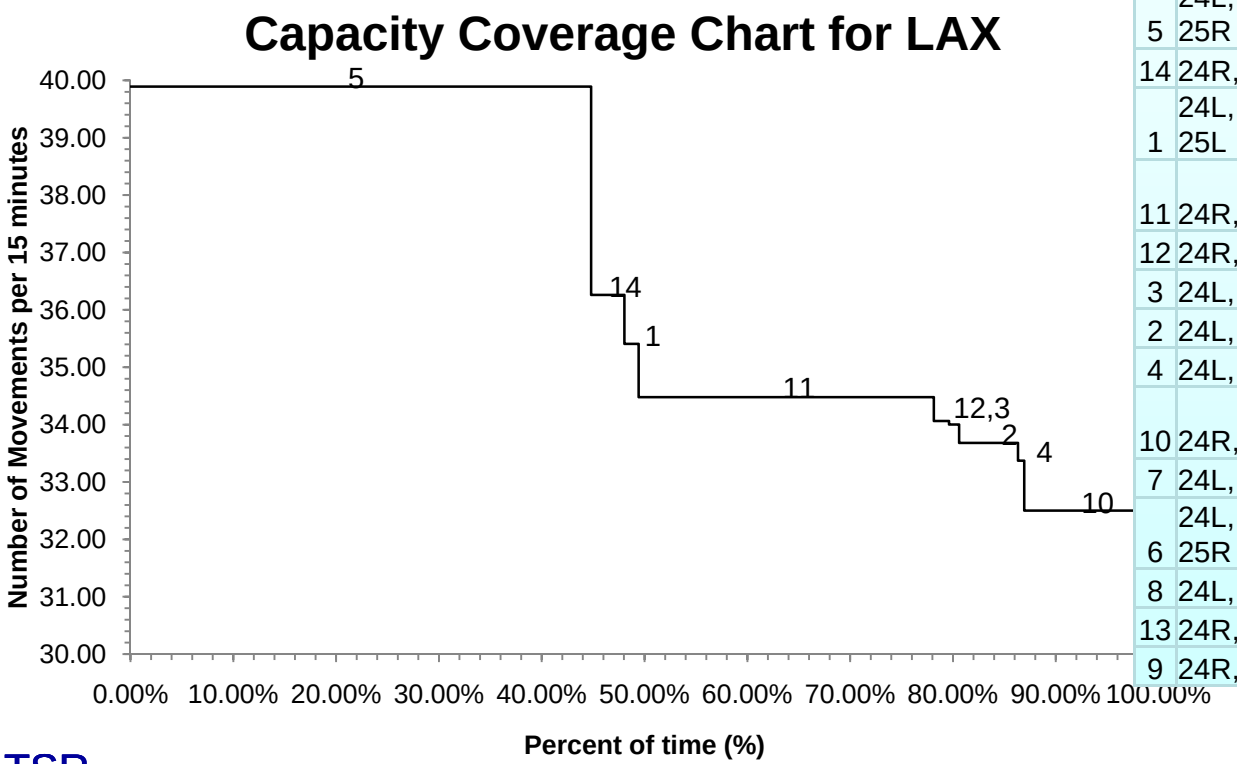
- Federal Aviation Administration (FAA) Aviation System Performance Metrics (ASPM) airport database
  - June 2008 to August 2008
  - The following fields were used:
    - Airport ID – this field identifies the airport with the FAA 3 letter code
    - AAR (Airport Arrival Rate) – declared arrival capacity for airport in each 15 minute period between 6am and 10pm local time
    - ADR" (Airport Departure Rate) – declared departure capacity fore the airport for each 15 minute period between 6am and 10pm local time
    - RwyConf (Runway configuration) – the configuration of the runways during the 15 minute period

- BTS (Bureau of Transportation Statistics)
  - Airline On-Time Performance (AOTP) - Average delay
  - T100 (BTS) - 'number of passengers'
  - DB1B (BTS) - Airfare

Capacity Coverage Chart (CCC)

CCC – Capacity Coverage Chart

For a given runway configuration, how much capacity is available for what percentage of time

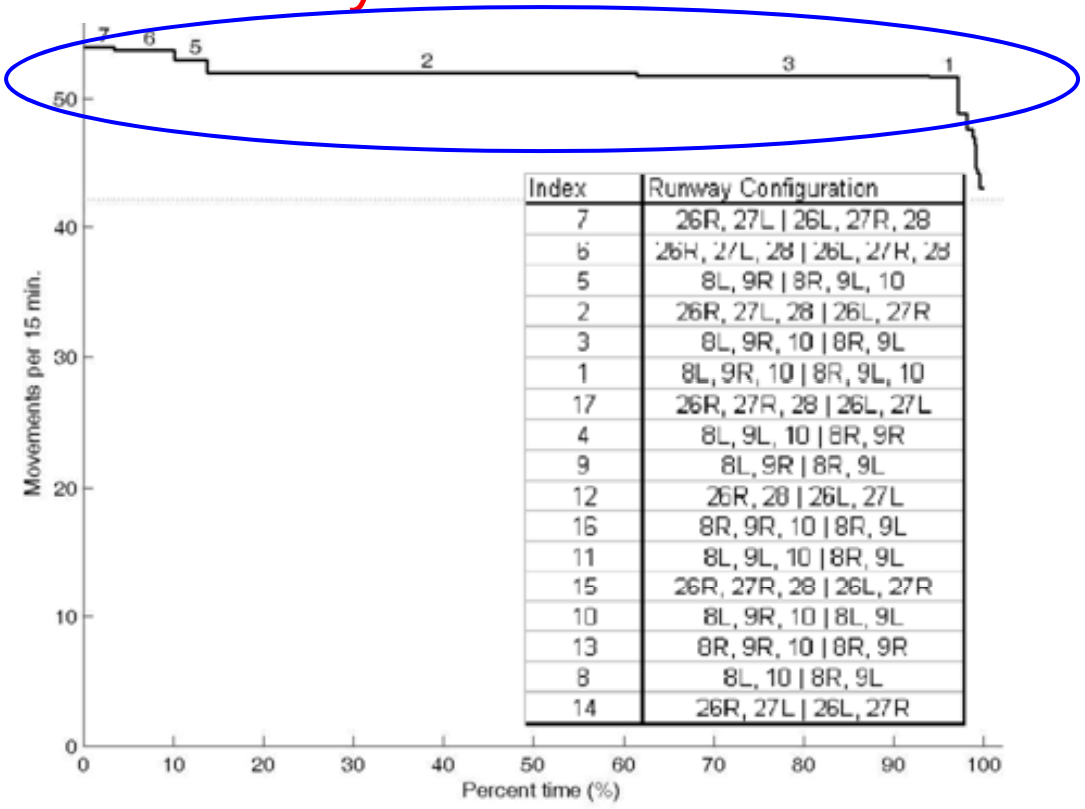


	RNWY Configurations *arrivals* | *departures*	Avg Moves	% Time
5	24L, 24R, 25L, 25R | 24L, 25R	39.89	44.81 %
14	24R, 25R | 24L, 25R	36.26	3.24%
1	24L, 24R, 25L | 24L, 24R, 25L	35.40	1.38%
11	24R, 25L | 24L, 25R	34.48	28.72 %
12	24R, 25L | 24R, 25L	34.06	1.47%
3	24L, 24R, 25L | 24L, 25R	34.00	0.99%
2	24L, 24R, 25L | 24L, 25L	33.68	5.72%
4	24L, 24R, 25L | 24R, 25L	33.37	0.62%
10	24R, 25L | 24L, 25L	32.50	11.07 %
7	24L, 24R, 25R | 24L, 25L	32.00	0.05%
6	24L, 24R, 25R | 24L, 24R, 25R	31.63	0.18%
8	24L, 25R | 24L, 25L	31.17	0.14%
13	24R, 25R | 24L, 25L	30.79	1.58%
9	24R, 25L | 24L, 24R, 25L	30.00	0.05%

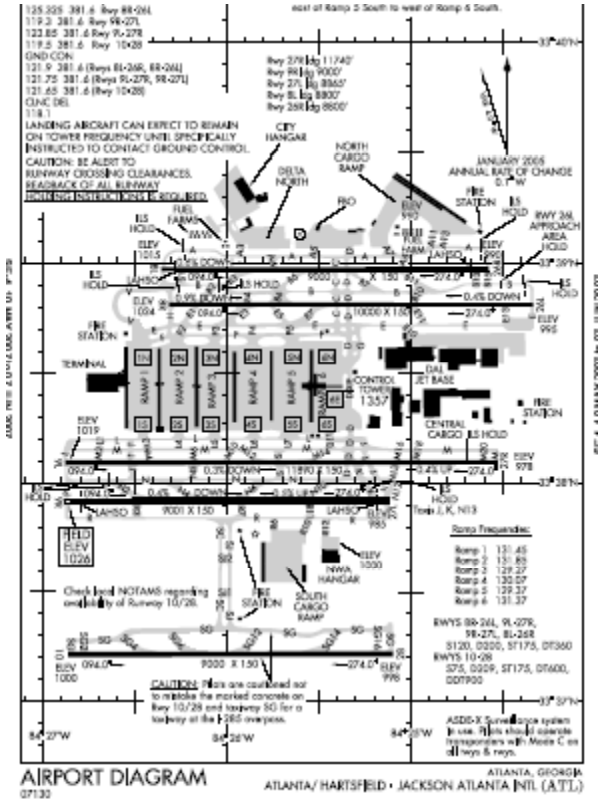
OEP-35 Airport Variability

Less Fluctuation in Capacity - ATL (Flat CCC)

- Probability distributions for 15 minute Capacity at Airports



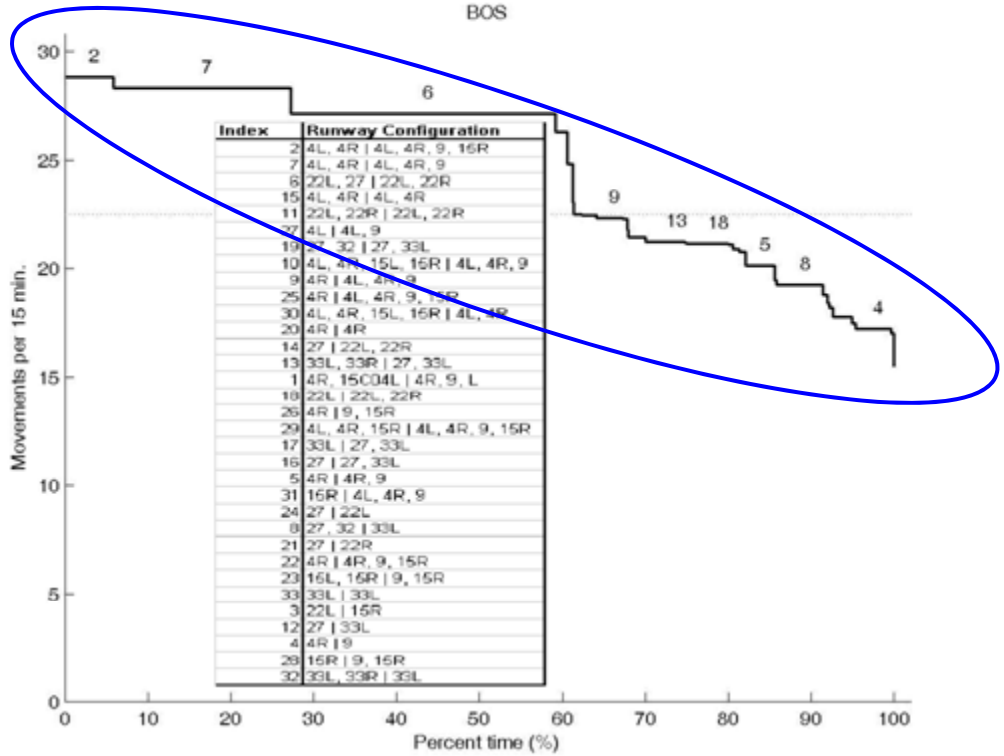
Index	Runway Configuration
7	26R, 27L | 26L, 27R, 28
6	26R, 27L, 28 | 26L, 27R, 28
5	8L, 9R | 8R, 9L, 10
2	26R, 27L, 28 | 26L, 27R
3	8L, 9R, 10 | 8R, 9L
1	8L, 9R, 10 | 8R, 9L, 10
17	26R, 27R, 28 | 26L, 27L
4	8L, 9L, 10 | 8R, 9R
9	8L, 9R | 8R, 9L
12	26R, 28 | 26L, 27L
16	8R, 9R, 10 | 8R, 9L
11	8L, 9L, 10 | 8R, 9L
15	26R, 27R, 28 | 26L, 27R
10	8L, 9R, 10 | 8L, 9L
13	8R, 9R, 10 | 8R, 9R
8	8L, 10 | 8R, 9L
14	26R, 27L | 26L, 27R



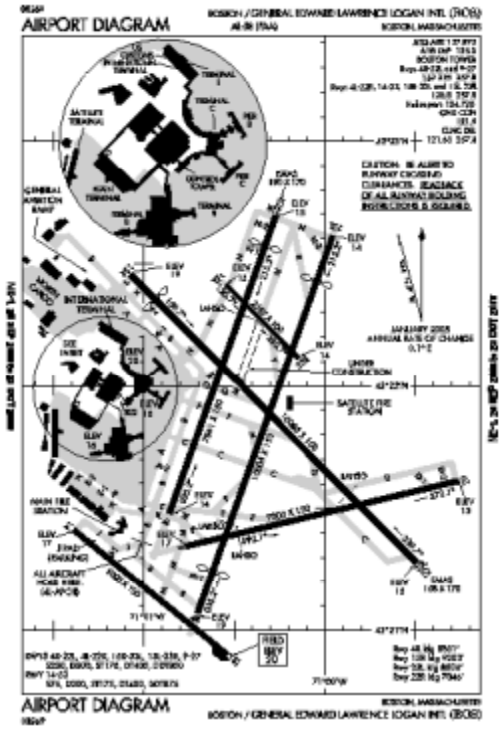
Uniformly distributed capacity (symmetric runway config, throughput)

High Fluctuation in Capacity - BOS (Step-like CCC)

- Probability distributions for 15 minute Capacity at Airports

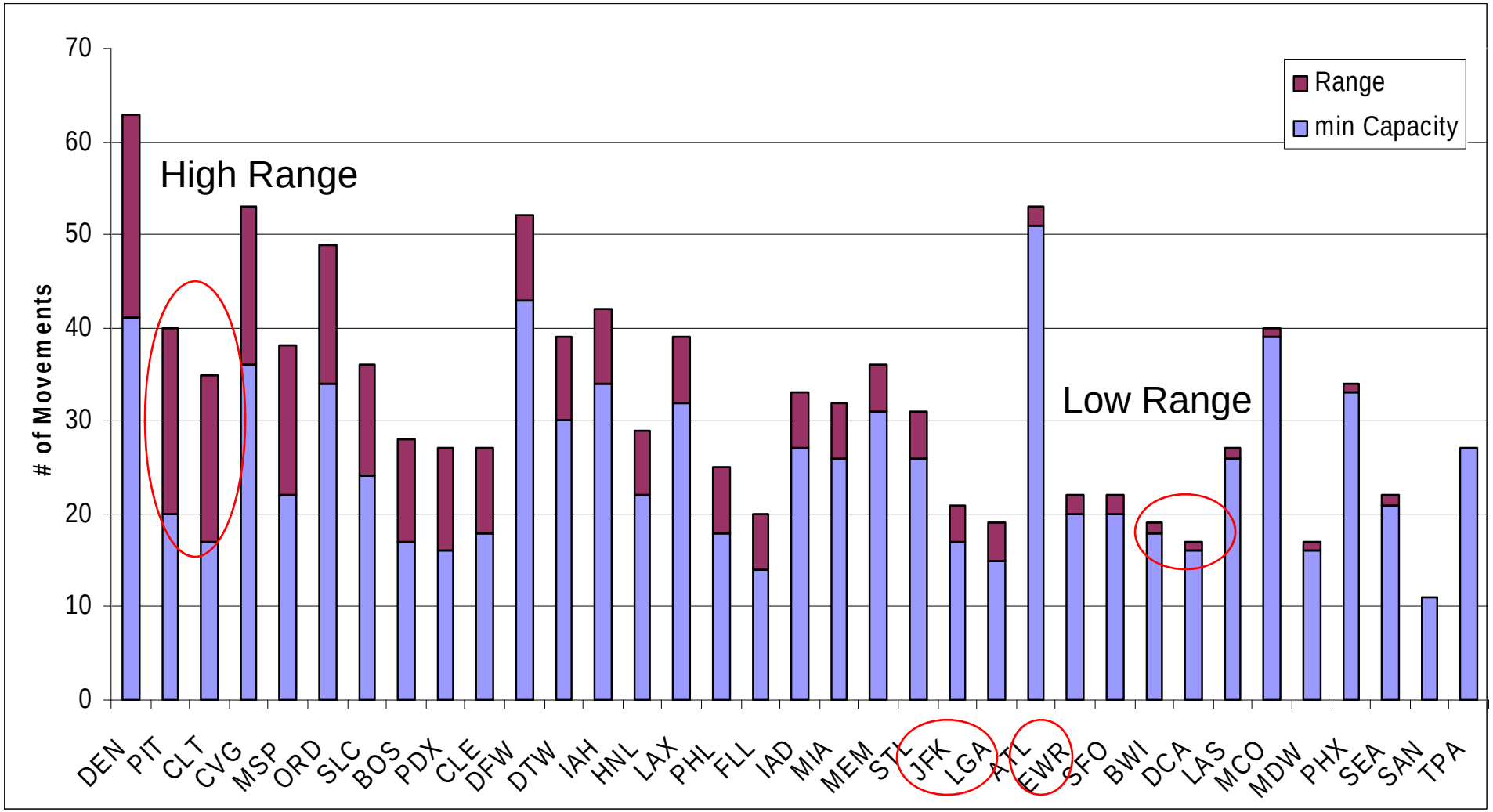


Index	Runway Configuration
2	4L, 4R | 4L, 4R, 9, 15R
7	4L, 4R | 4L, 4R, 9
6	22L, 27 | 22L, 22R
15	4L, 4R | 4L, 4R
11	22L, 22R | 22L, 22R
27	4L | 4L, 9
19	27, 32 | 27, 33L
10	4L, 4R, 15L, 15R | 4L, 4R, 9
9	4R | 4L, 4R, 9
25	4R | 4L, 4R, 9, 15R
30	4L, 4R, 15L, 15R | 4L, 4R
20	4R | 4R
14	27 | 22L, 22R
13	33L, 33R | 27, 33L
1	4R, 15C04L | 4R, 9, L
18	22L | 22L, 22R
26	4R | 9, 15R
29	4L, 4R, 15R | 4L, 4R, 9, 15R
17	33L | 27, 33L
16	27 | 27, 33L
5	4R | 4R, 9
31	16R | 4L, 4R, 9
24	27 | 22L
8	27, 32 | 33L
21	27 | 22R
22	4R | 4R, 9, 15R
23	16L, 16R | 9, 15R
33	33L | 33L
3	22L | 15R
12	27 | 33L
4	4R | 9
28	16R | 9, 15R
32	33L, 33R | 33L



<u>Non-uniformly</u> distributed capacity (asymmetric runway config, throughput)

Range of Variation in Seasonal Airport Capacity for OEP-35 Airports



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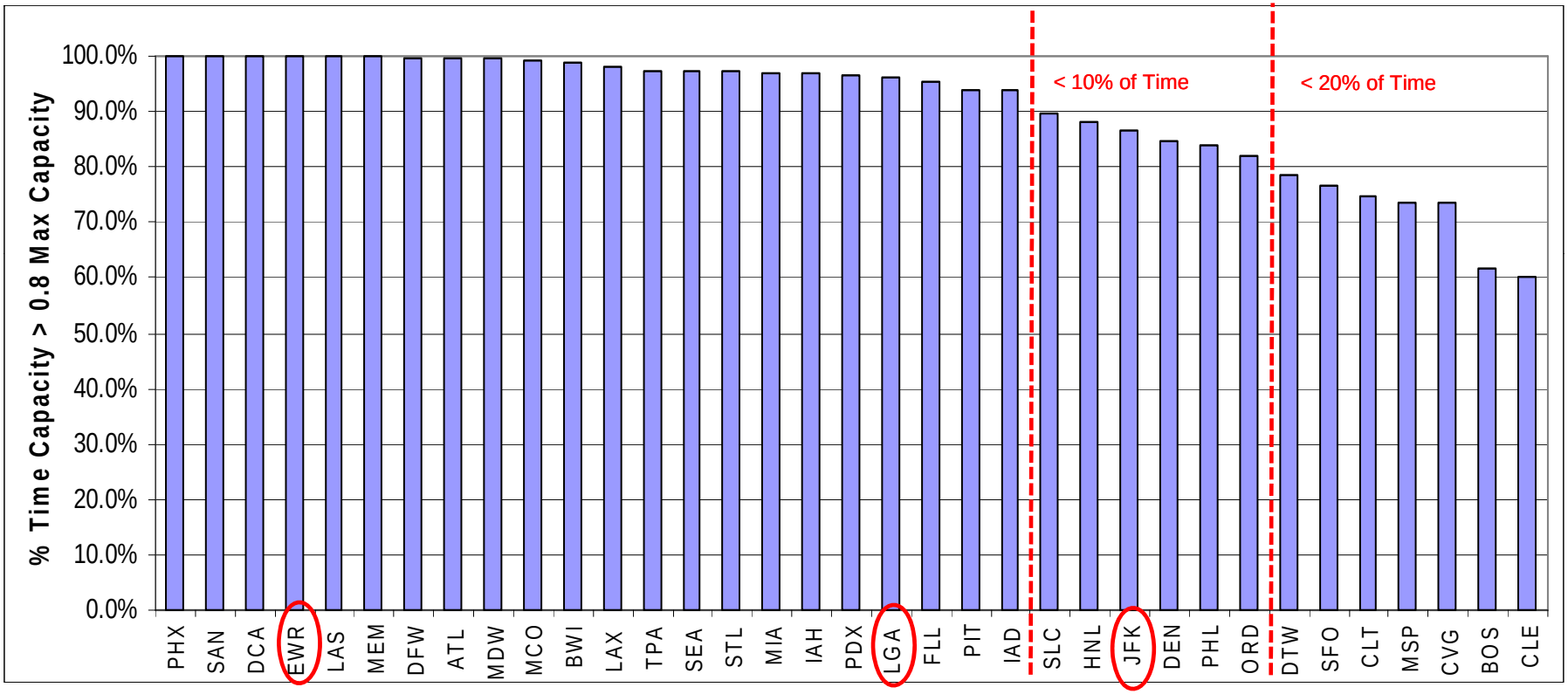
OEP-35 Airport Variability

% of time OEP-35 airports experienced airport throughput capacity greater than 80% of the maximum throughput capacity for the airport.



7 airports experience declared capacity below 0.8 of maximum capacity more than 20% of the time.

•13 airports experience declared capacity below 0.8 maximum capacity more than 10% of the time

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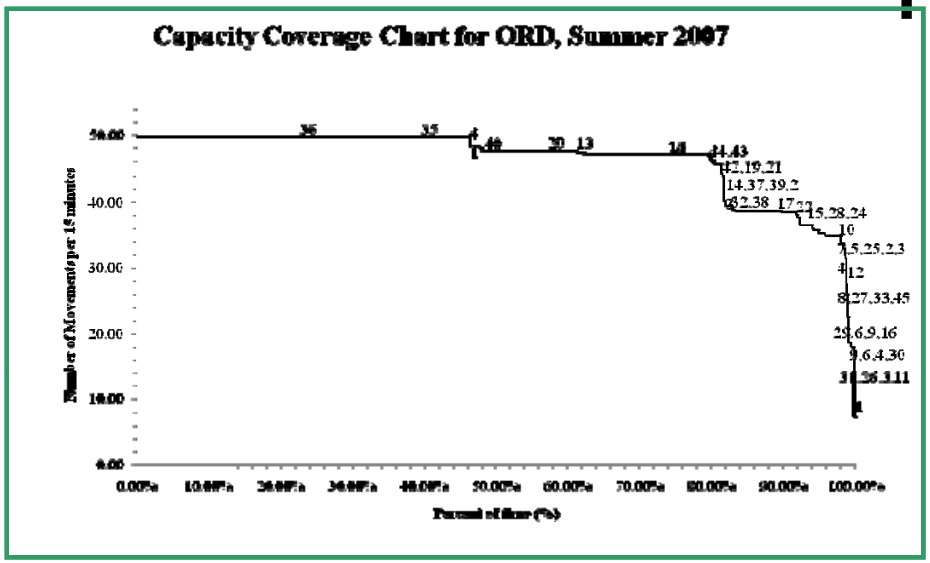
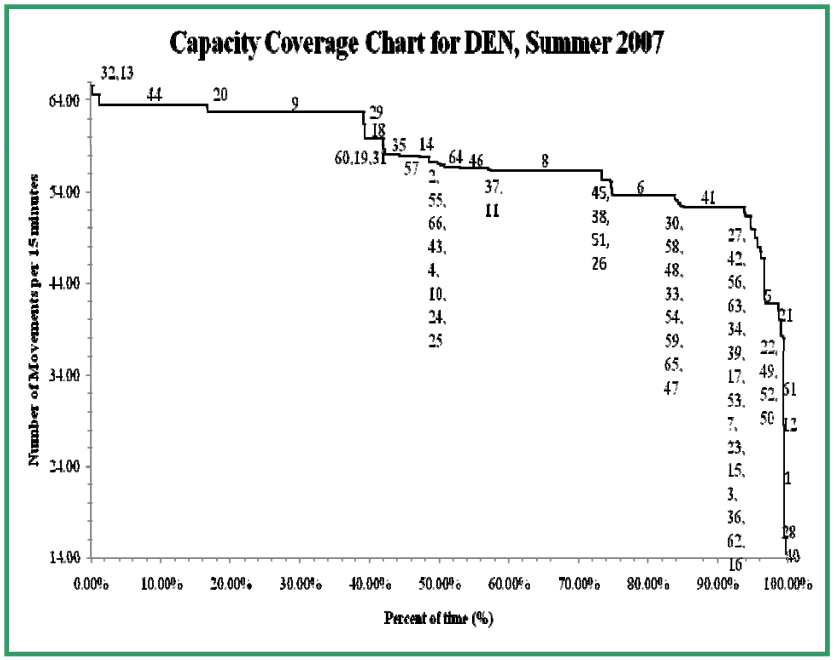
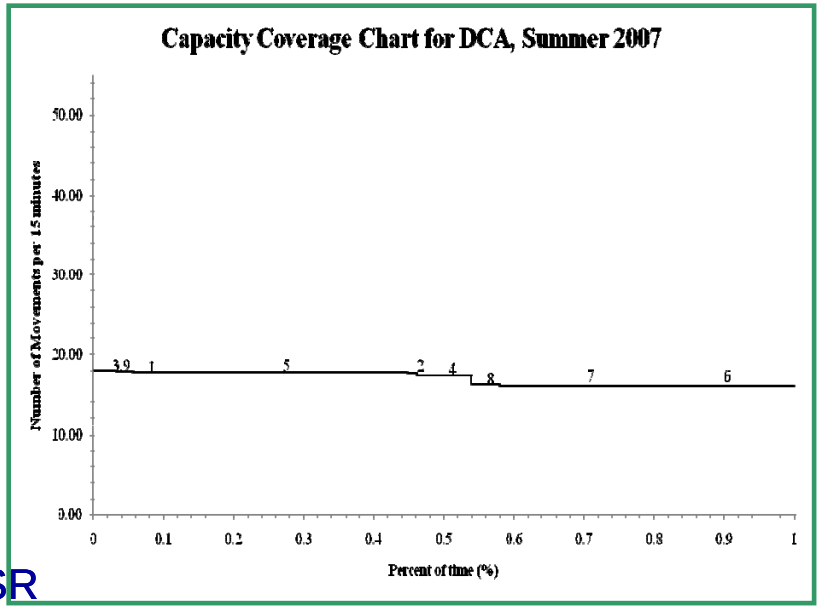
Quantify the better CCC of Airports?







Airport Capacity Reliability

ACR = (Weighted Mean) / (Standard Deviation)

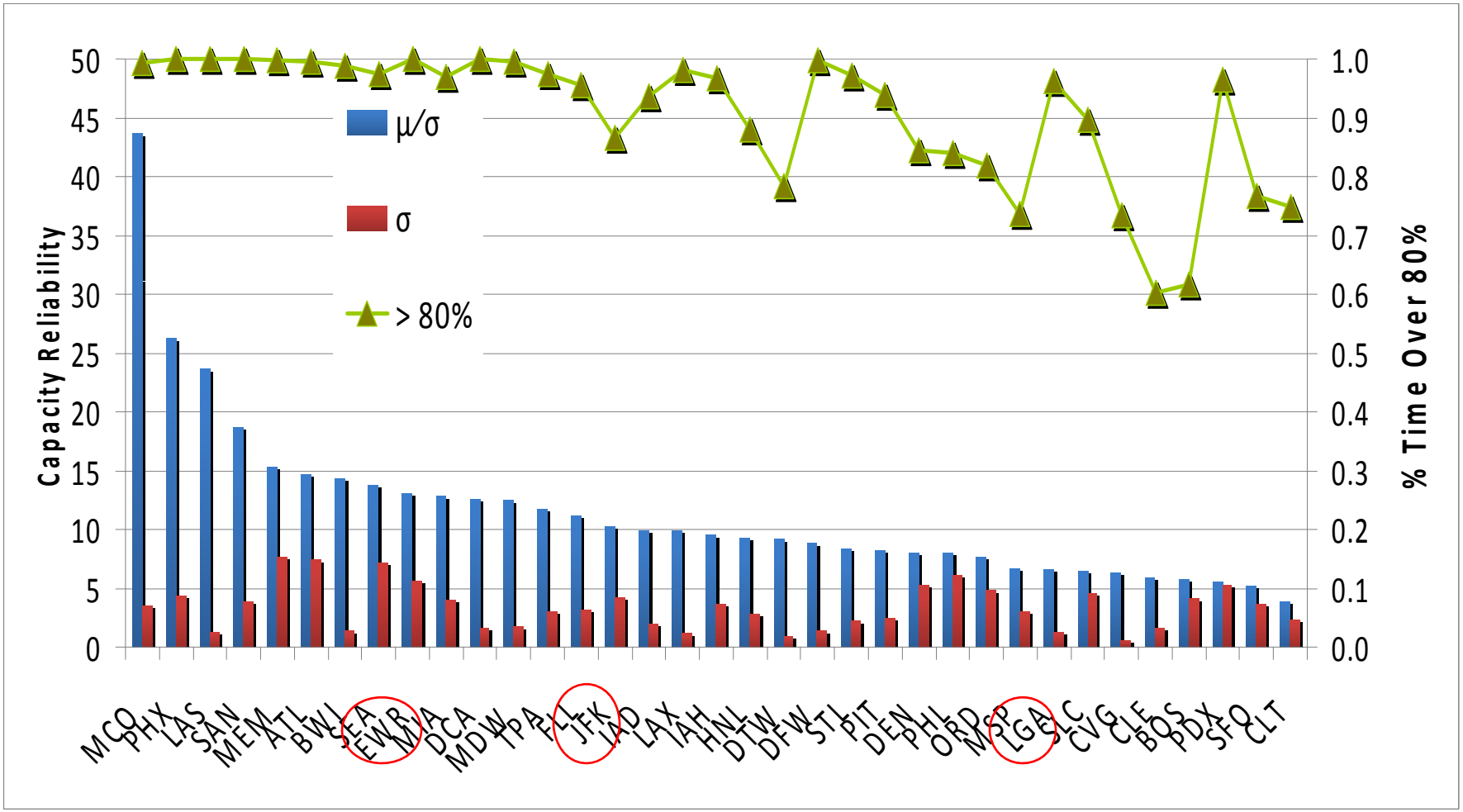
$$movments = [12 \quad 14 \quad 15 \quad 16...]$$

$$count = [9 \quad 72 \quad 15 \quad 714...]$$

$$weighted\_mean = \frac{\sum movements * count}{\sum count}$$

$$st\_dev = std([12 \quad 12 \quad 12 \quad 12...14 \quad 14 \quad 14 \quad 14...])$$

OEP-35 Airports Ranked by Airport Capacity Reliability (ACR)



More Reliable **Less Reliable**

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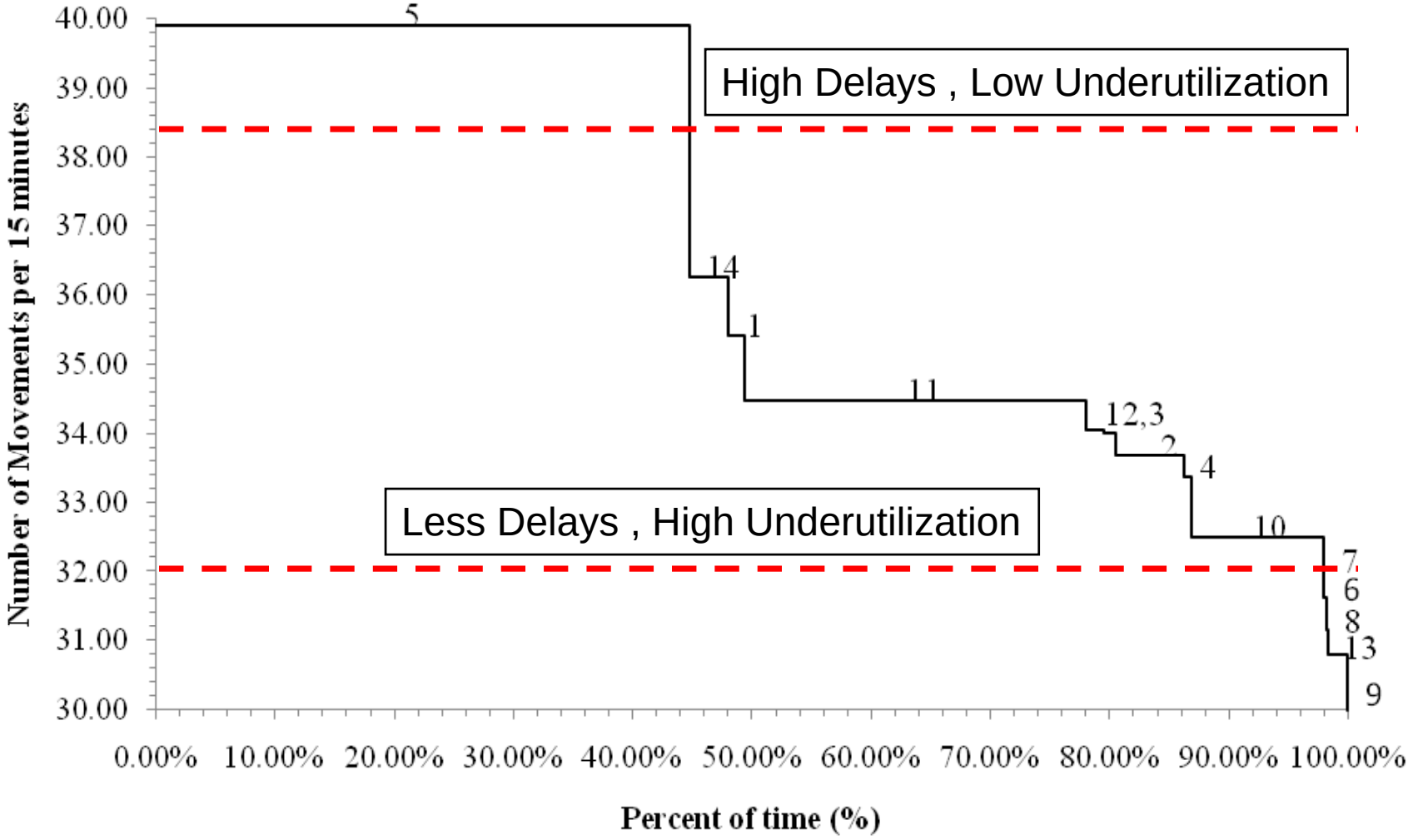
Trade-Off Between Delay and Underutilization



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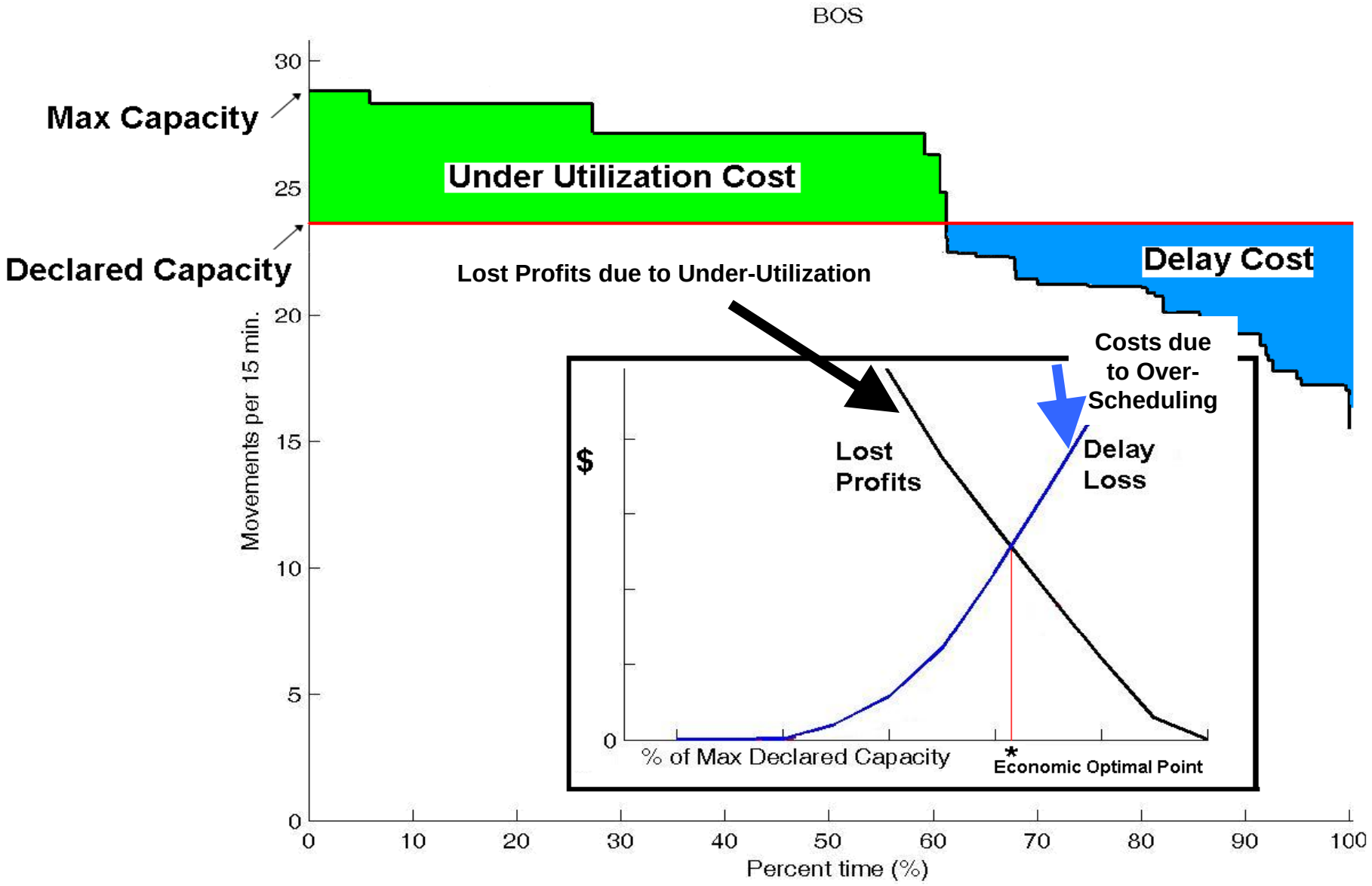
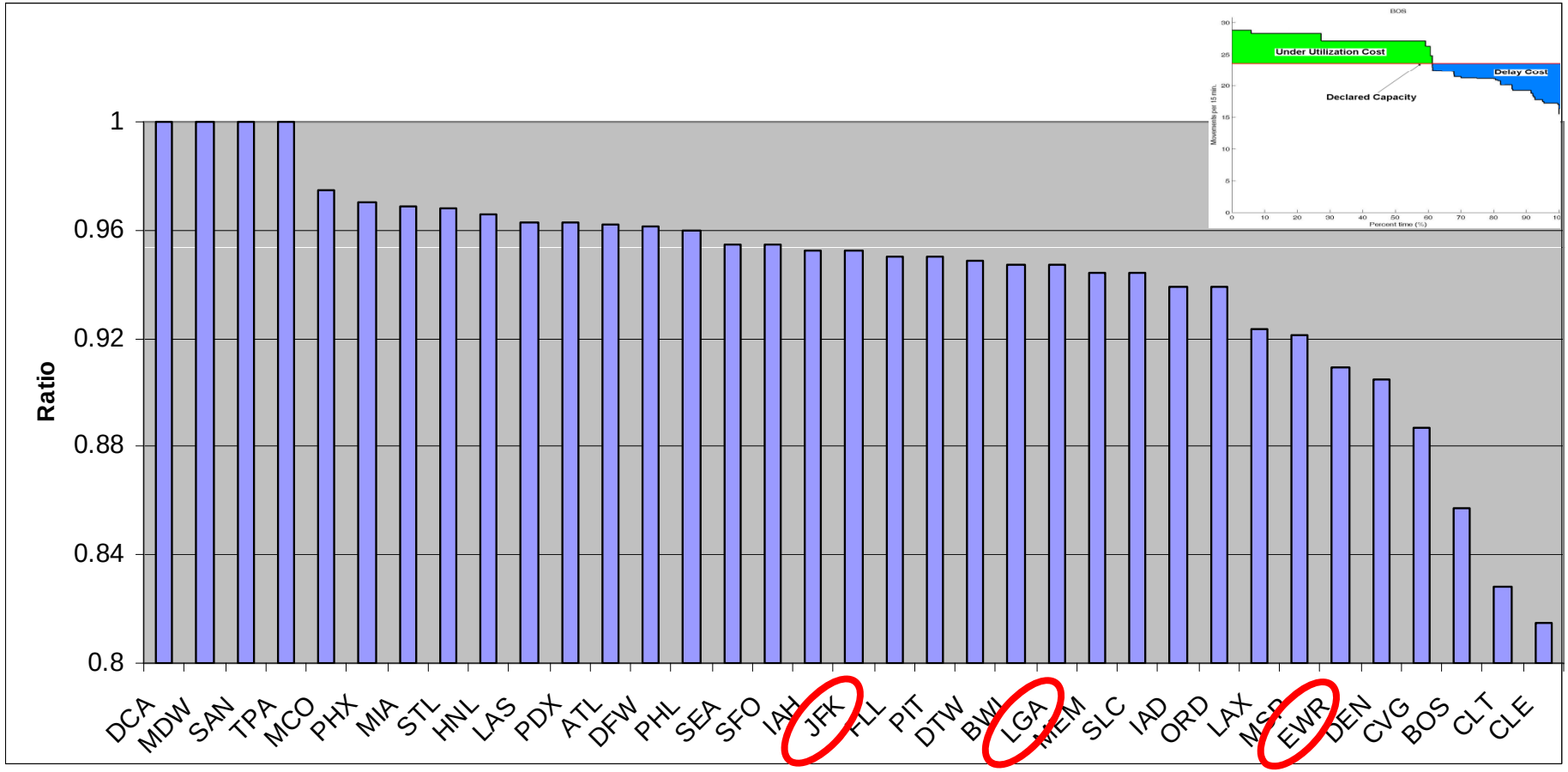
Declared Capacity Limit

Trade-off Lost Profits v. Delay Costs



“Optimum” Airport Capacity

- **Optimum Airport Capacity as a percent of Max Capacity where:**
  Number of Under-utilized Slots = Number of Over-scheduled Slots



Assumption: Cost of Delay for over-scheduled flight = Cost of lost Revenue for under-utilized flight

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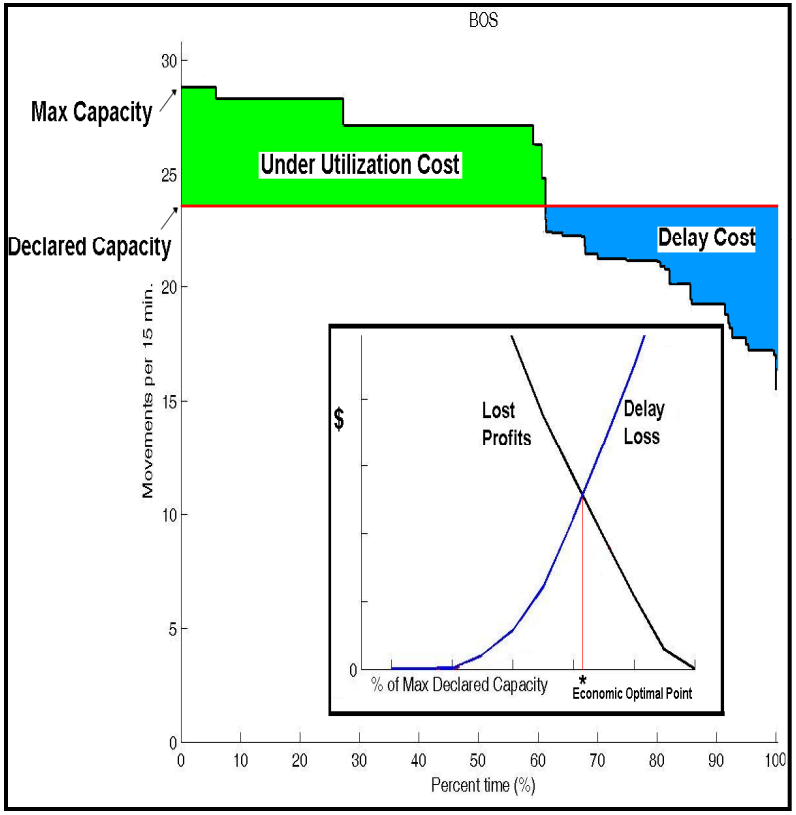
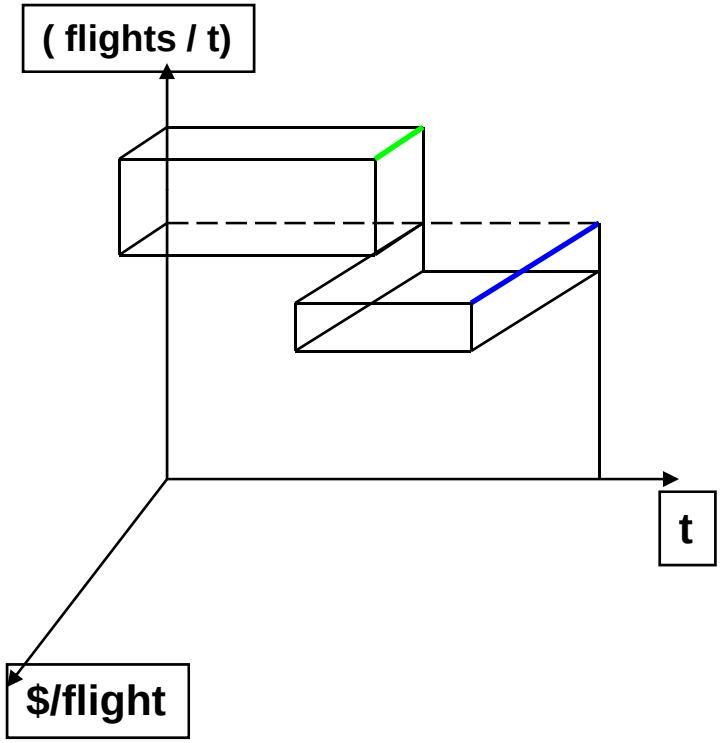
Asymmetry in Delay and Underutilization Cost

Unit Delay Cost = Unit Underutilization Cost





Delay Cost per aircraft
Profit Lost per unutilized slot

Assumptions

- No economies of scale:
  - Delay incurred per additional aircraft = Current average delay
  - Revenue generated per aircraft = Average revenue generated by aircraft flying in/out of the airport
- For a given airport, all aircrafts have equal # of seats (= average size of aircraft for that airport). Also, load factor is assumed t be 100%.
- Market competition is not taken into account.
- Cargo revenue is not included.

Delay Cost

- Estimated Direct Operating Cost per aircraft hour = $2000* (~ $33/min)

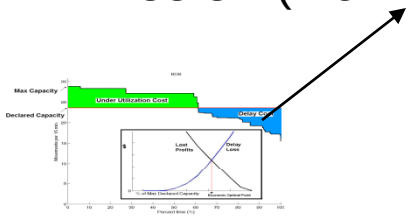
dAr_i = average arrival delay for flights landing at airport i
dDp_i = average departure delay for flights departing airport i
nAr_i = total number of arrivals at airport i
nDp_i = total number of departures at airport i
$avgDel_i$ = average delay per operation at airport i

$$avgDel_i = [(dAr_i * nAr_i) + (dDp_i * nDp_i)] / (nAr_i + nDp_i)$$

i is **index for Airport**

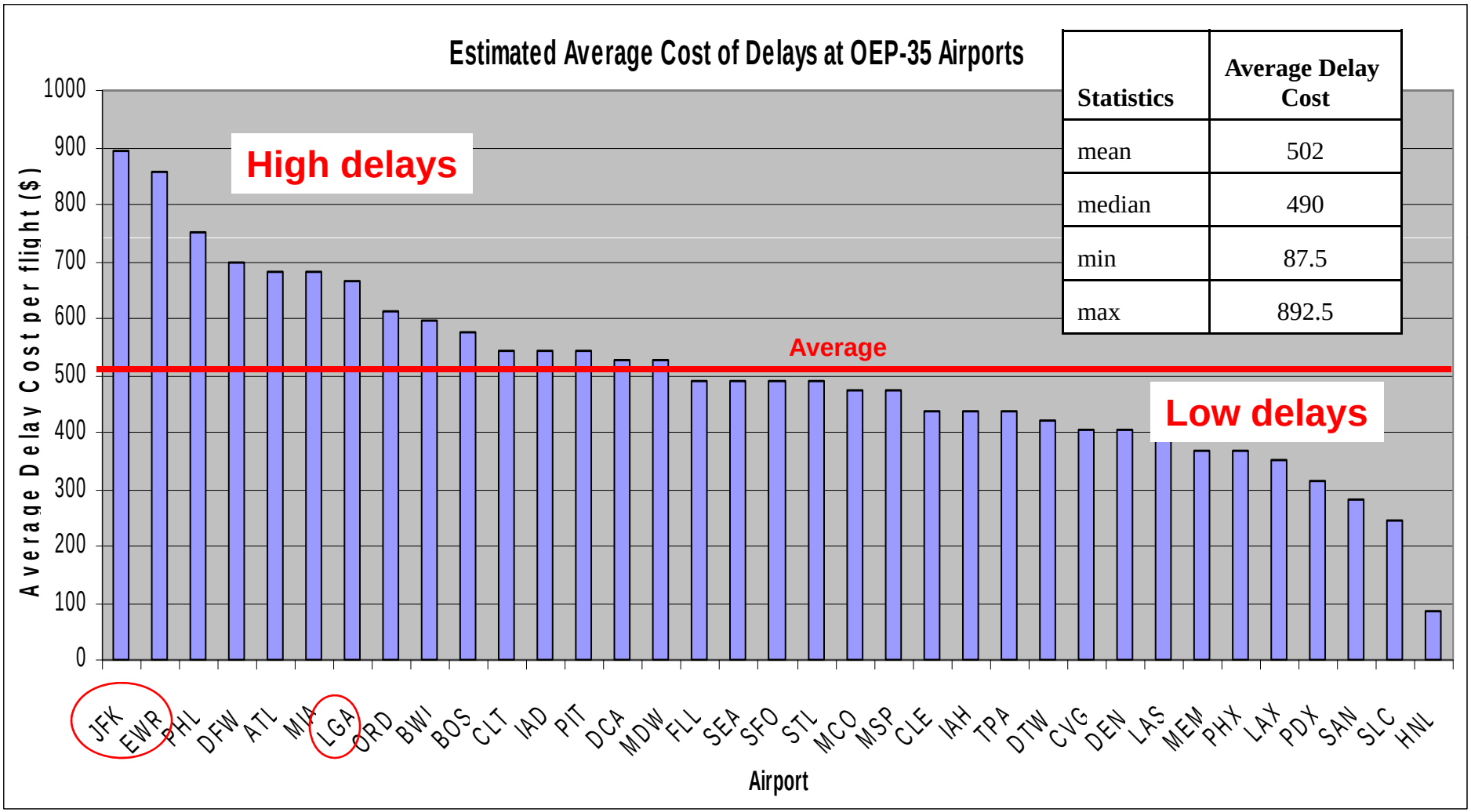
- Total Delay Cost =

  33.3 * (# of Flight Delayed) * ($avgDel_i$)



* - deNeufville, Odoni - 2003

Estimated Average Costs of Delay per Flight



Statistics	Average Delay Cost
mean	502
median	490
min	87.5
max	892.5

Loss of Profit Due to Underutilization

- ticketArr(j,k) = average ticket price for j-k O-D pair, where $j \in arr(i)$, $\vee$ $k \in i$
- ticketDep(j,k) = average ticket price for j-k O-D pair, where $k \in dep(i)$, $\vee$ $j \in i$
- paxArr(j,k) = average # of passengers on j-k O-D pair, where $j \in arr(i)$, $\vee$ $k \in i$
- paxDep(j,k) = average # of passengers on j-k O-D pair, where $k \in dep(i)$, $\vee$ $j \in i$
- $avgRev_i$ = average revenue per operation(arrival or departure) at airport i

$$= \tfrac{1}{2} * \left(\sum_{j \in arr(i)} paxArr(j,i) * ticketArr(j,i) + \sum_{k \in dep(i)} paxDep(i,k) * ticketDep(i,k) \right)$$

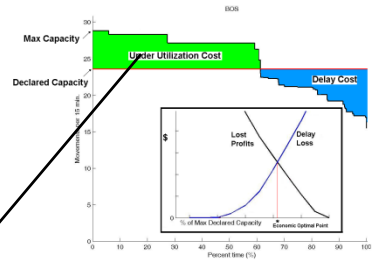
INDICES:

Airport index i = {1,2,....35} – All the OEP-35 airports

arr(i) = All the airports which are origin for flights ending at airport i.

dep(i) = All the airports which are destination for flights out of airport i.

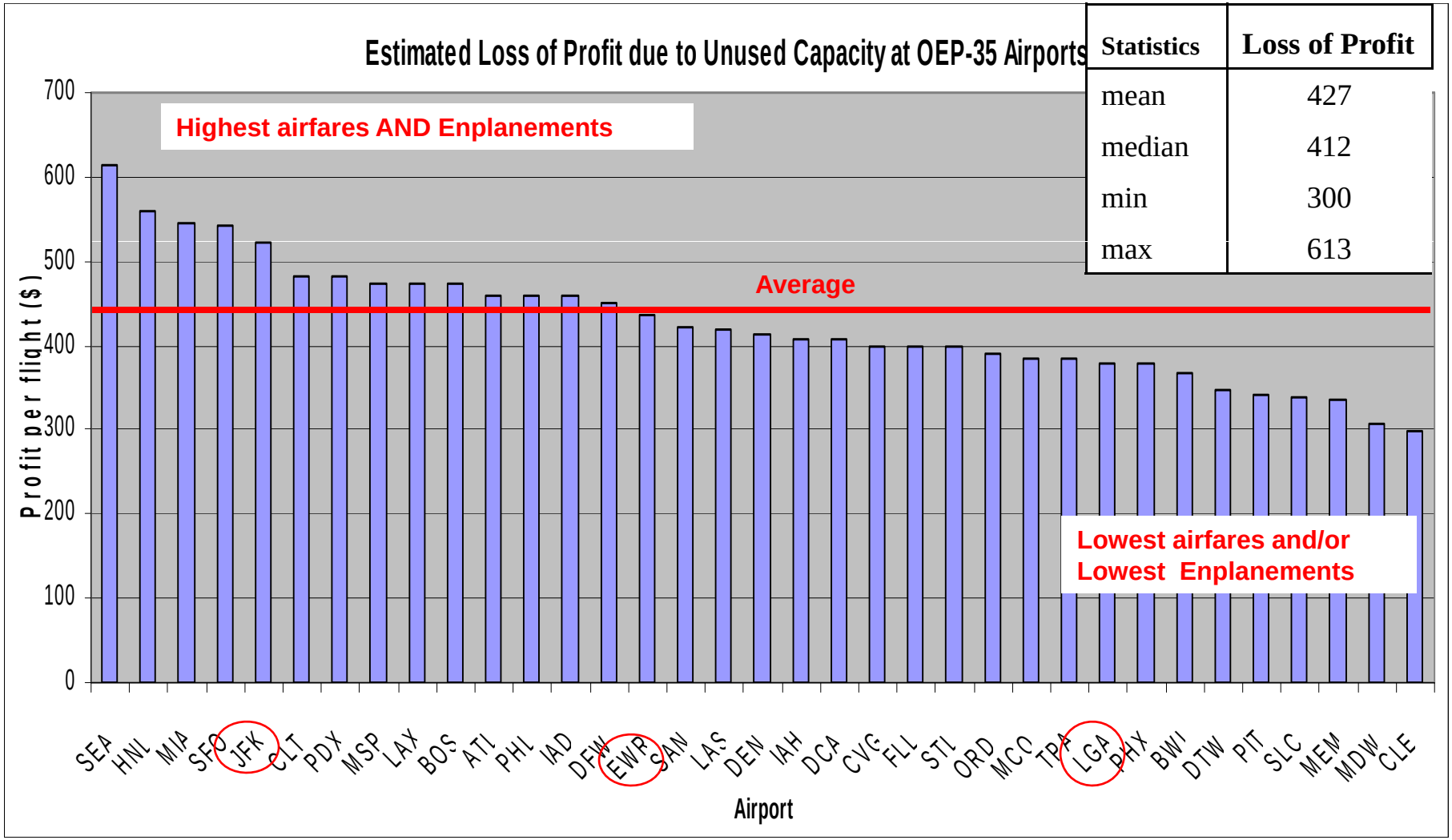
Note: arr(i) and dep(i) are not subsets of i



$avgProfit_i = 2.5\% * avgRev_i$

Total Lost Profit =
(# of Slots Unused) * ($avgProfit_i$)

Estimated Average Lost Profits per Flight

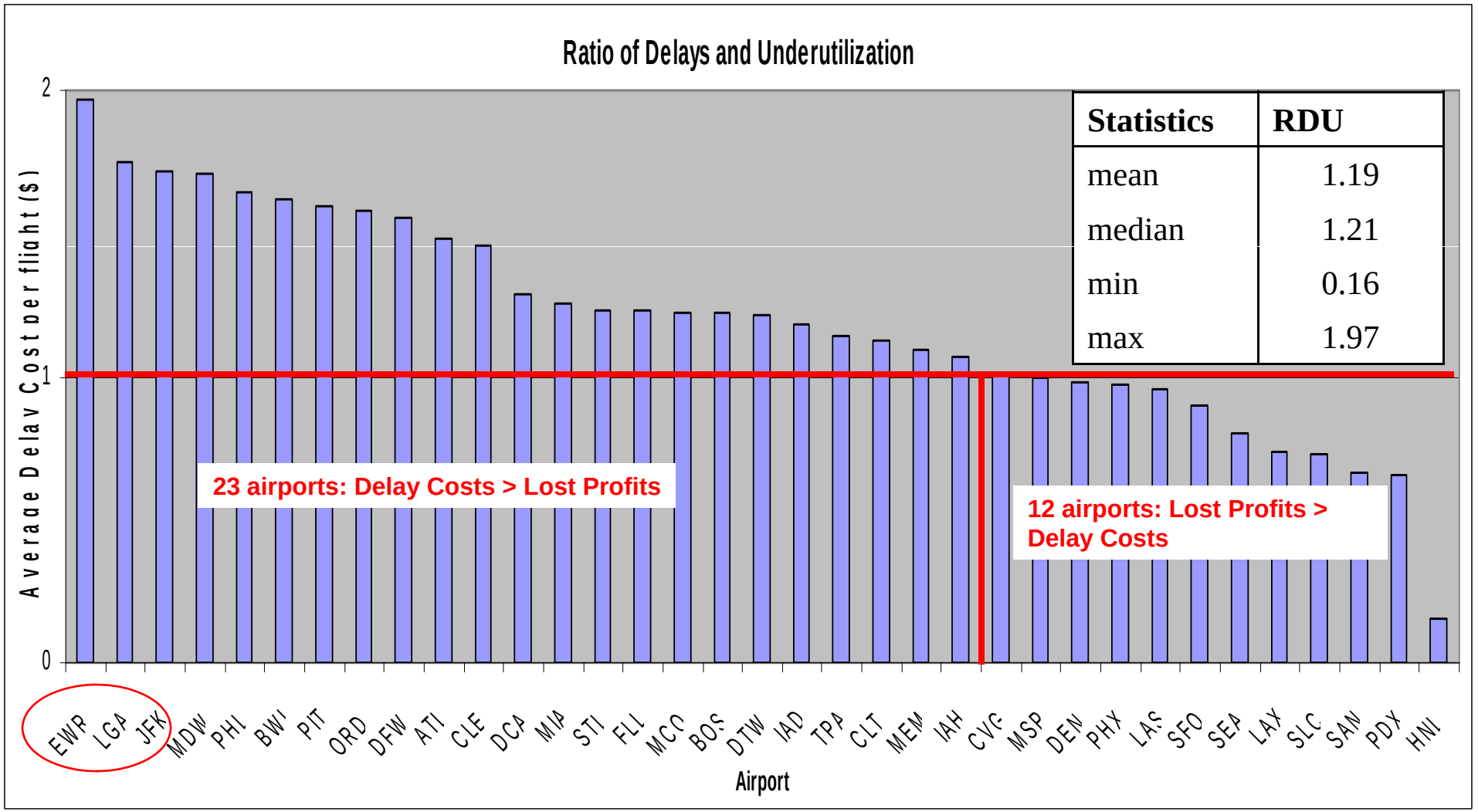


Statistics	Loss of Profit
mean	427
median	412
min	300
max	613

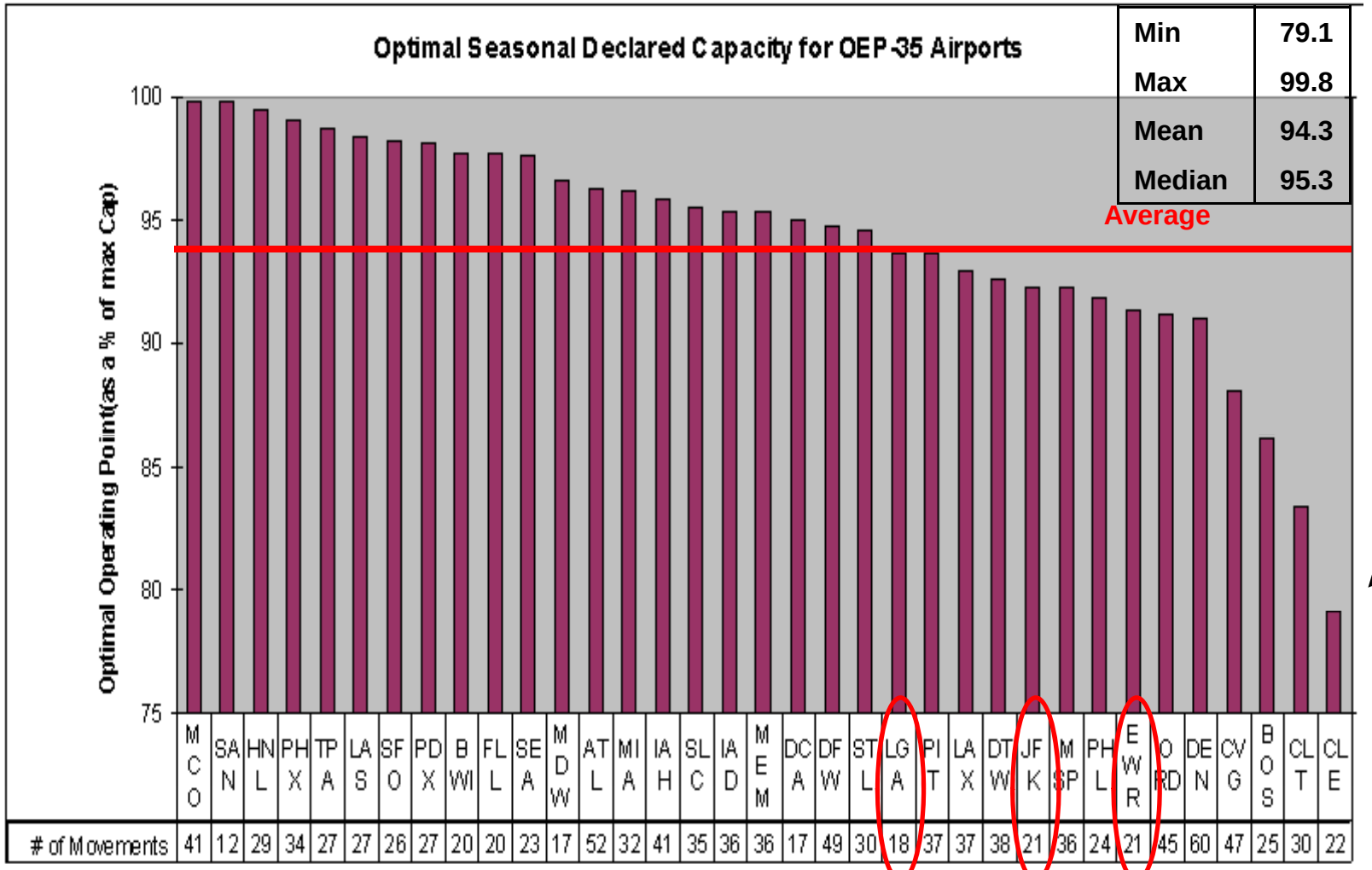
Ratio of Delay and Underutilization Cost Per Flight (RDU)

- $RDU_i = avgDel_i / avgProfit_i$
- RDU for an airport is the ratio of cost of delay due to scheduling an extra flight to the opportunity cost lost due to not using an available slot.
  - RDU > 1 : Delays more costly than Underutilization
  - RDU < 1 : Underutilization more expensive than Delays

Ratio Delay Costs/Lost Profits (RDU)



Optimal Airport Capacity (with Cost of Delays and Underutilization)



Conclusions

1. 13 of the OEP-35 airports exhibit variations in runway configurations that result in a reduction of more than 20% in capacity more than 10% of the time.
   - Cleveland, Boston, Cincinnati, San Francisco, Chicago O'Hare, JFK.
2. 24 of the OEP-35 airports –
   - Average Costs of Delays per Flight > Average Profits per Flight
   - JFK, Newark, La Guardia
3. Optimum airport capacity for Demand Management
   - ranged from 81% to 100% of the maximum airport capacity
   - average optimum airport capacity was 93% of the maximum airport capacity.
   - Twelve airports, including Boston, JFK, Newark, and San Francisco, exhibited an optimum airport capacity below the average 93%.
4. The range of the RDU per flight indicates the non-homogeneous nature of the service providers in the NAS and the need to take into account the airline revenue and cost structures in determining resource availability.
5. Third, "economically optimal" capacity limits established to trade-off delays and underutilization, provide a rational approach to assigning capacity limits that take into account airline preferences.

Future Work

- Improved fidelity of Airline Direct Operating Cost and Profit Margin
- Actual throughput per 15 mins vs reported AAR and ADR
- Using Marginal Cost of Delays and Underutilization to include ‘Economies of Scale’

Questions?

3. Optimal Capacity (Variance & Ops)

ADOC

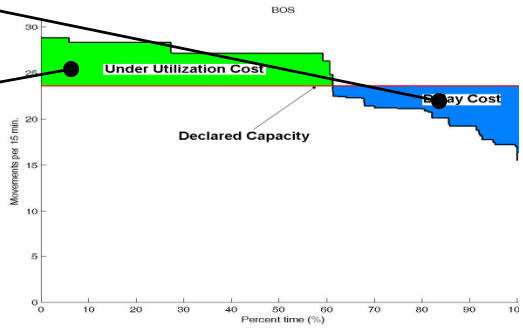
Actual Flights Operated ← *Cancelled Flights*

Scheduled Flights

Delay Costs ← Average Delay → *Actual Airport Capacity*

Ratio Cost of Delays/Lost Profit

Flights Delayed



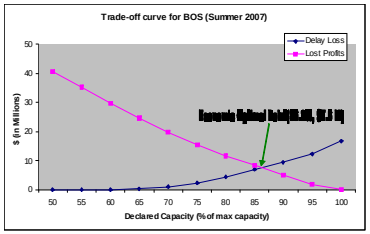
Airport Capacity Probability Distribution

Declared Capacity

Flights not Scheduled

Loss of Profits

Optimal Declared Capacity



Average Revenue per Flight

Average Revenue per Departure

Departures

Average Revenue per Arrival

Arrivals

% Profit

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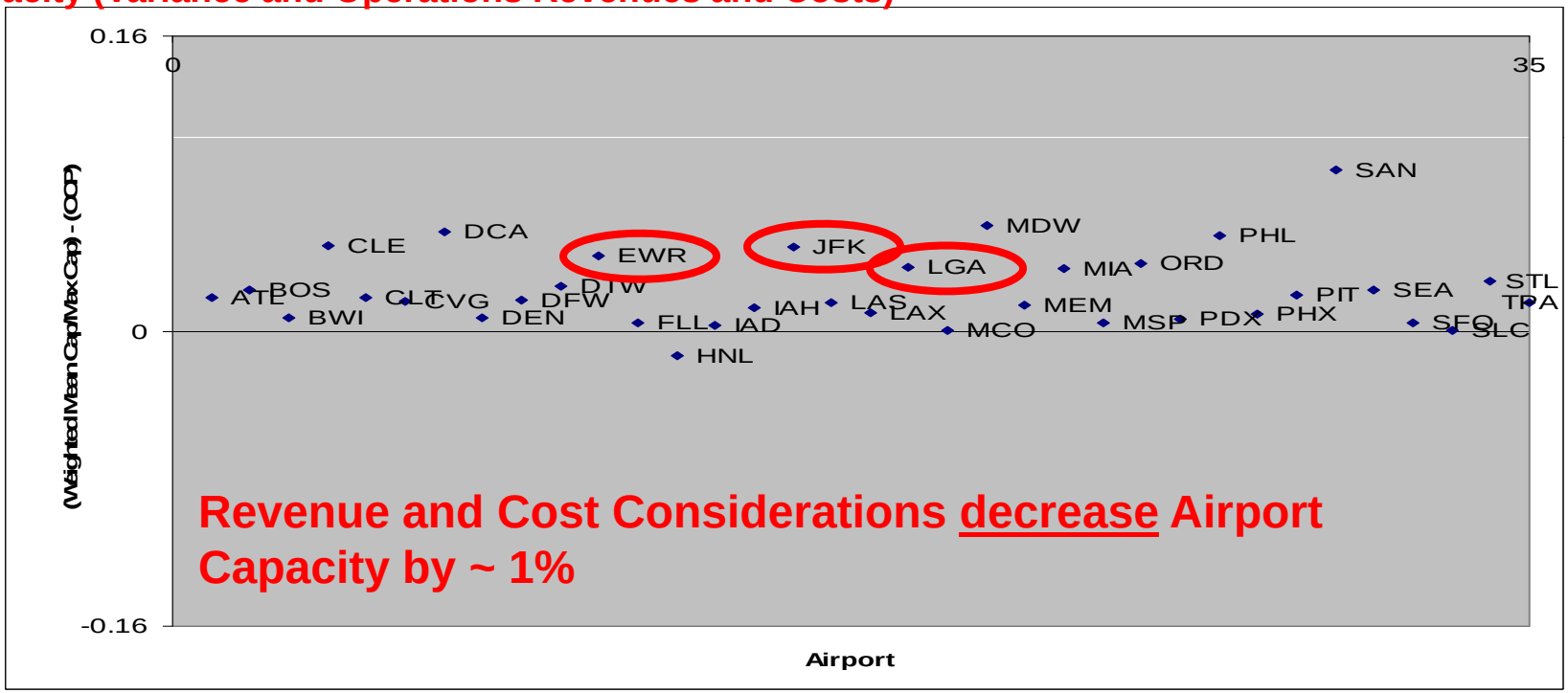
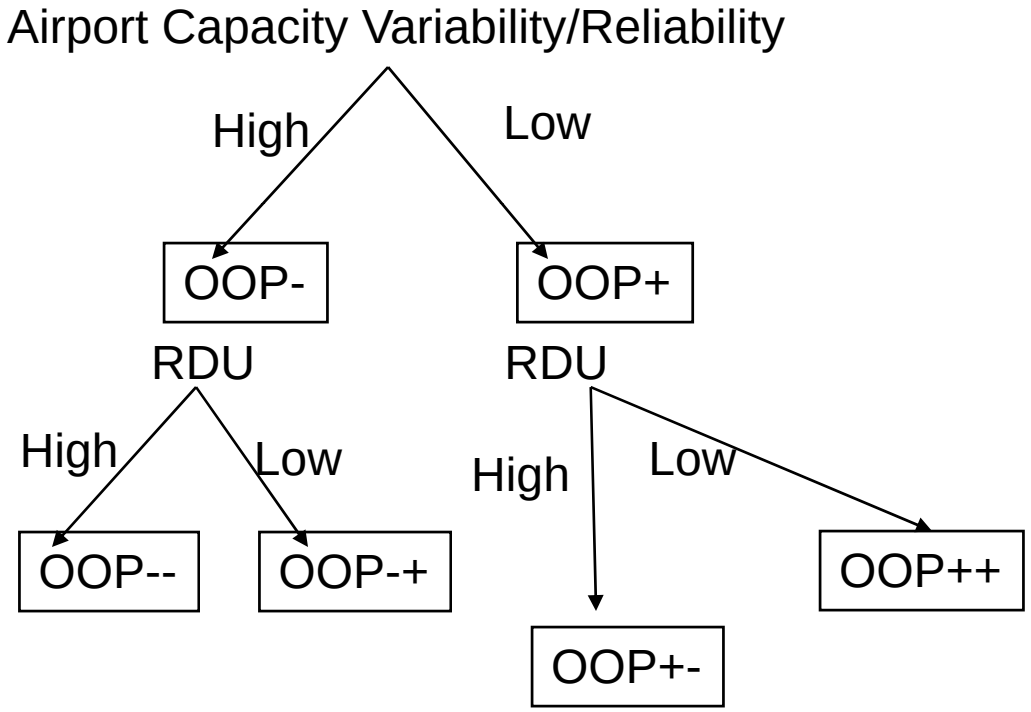
Impact of "Economics" on Optimal Airport Capacity

Optimum Airport Capacity (Variance Only) – Optimum Airport Capacity (Variance and Operations Revenues and Costs)

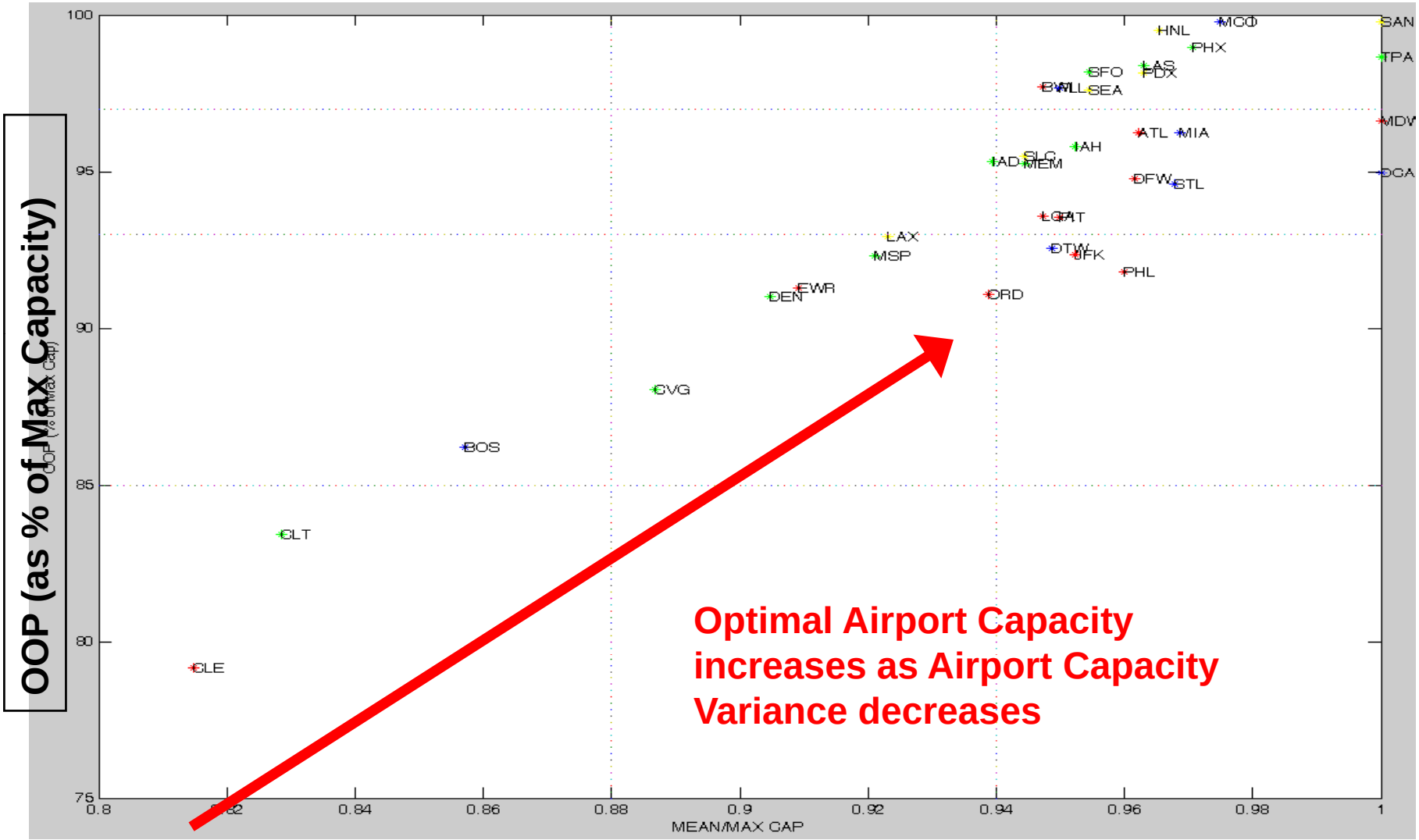


Summary of Results

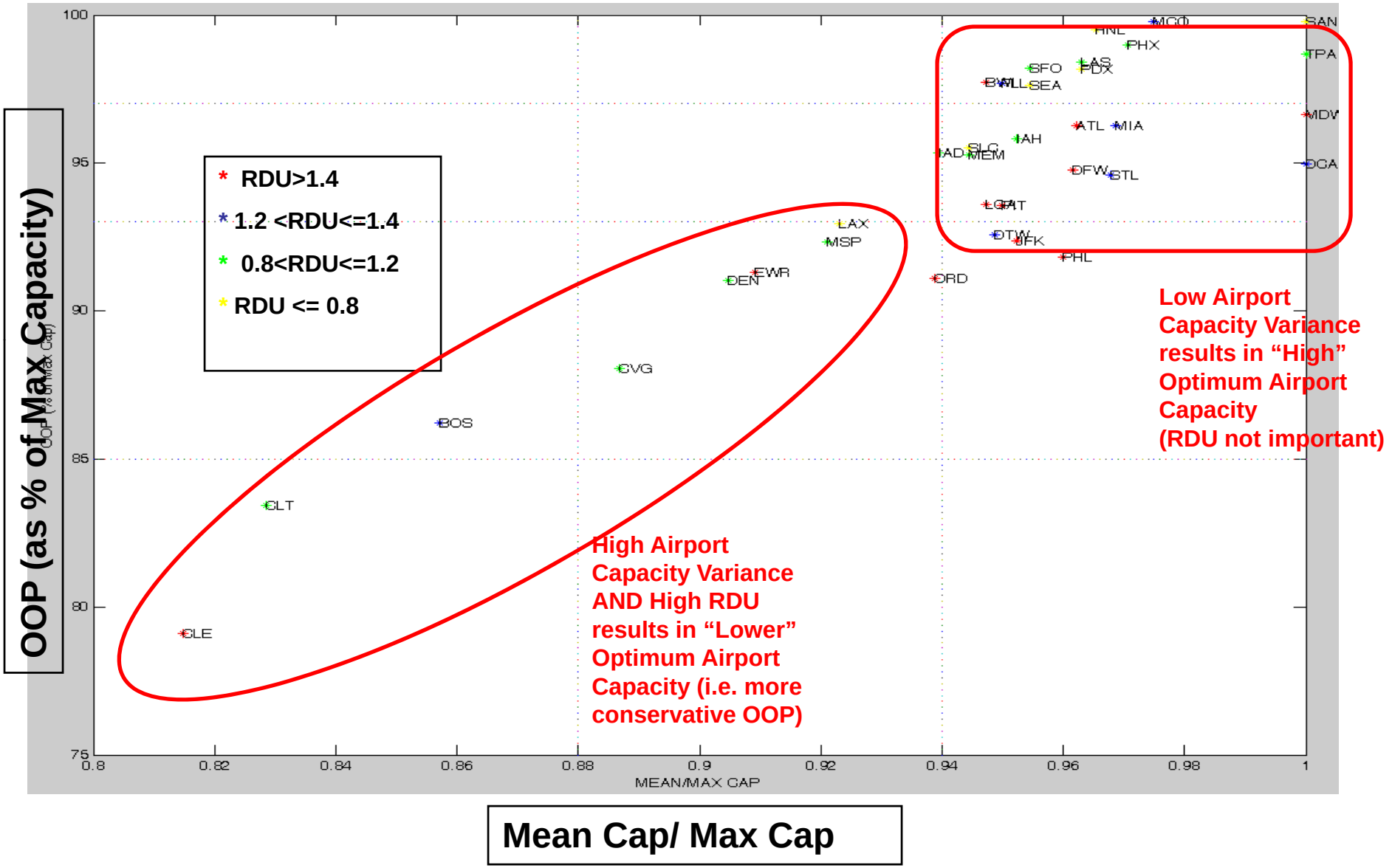


How does OOP change

Optimal Airport Capacity

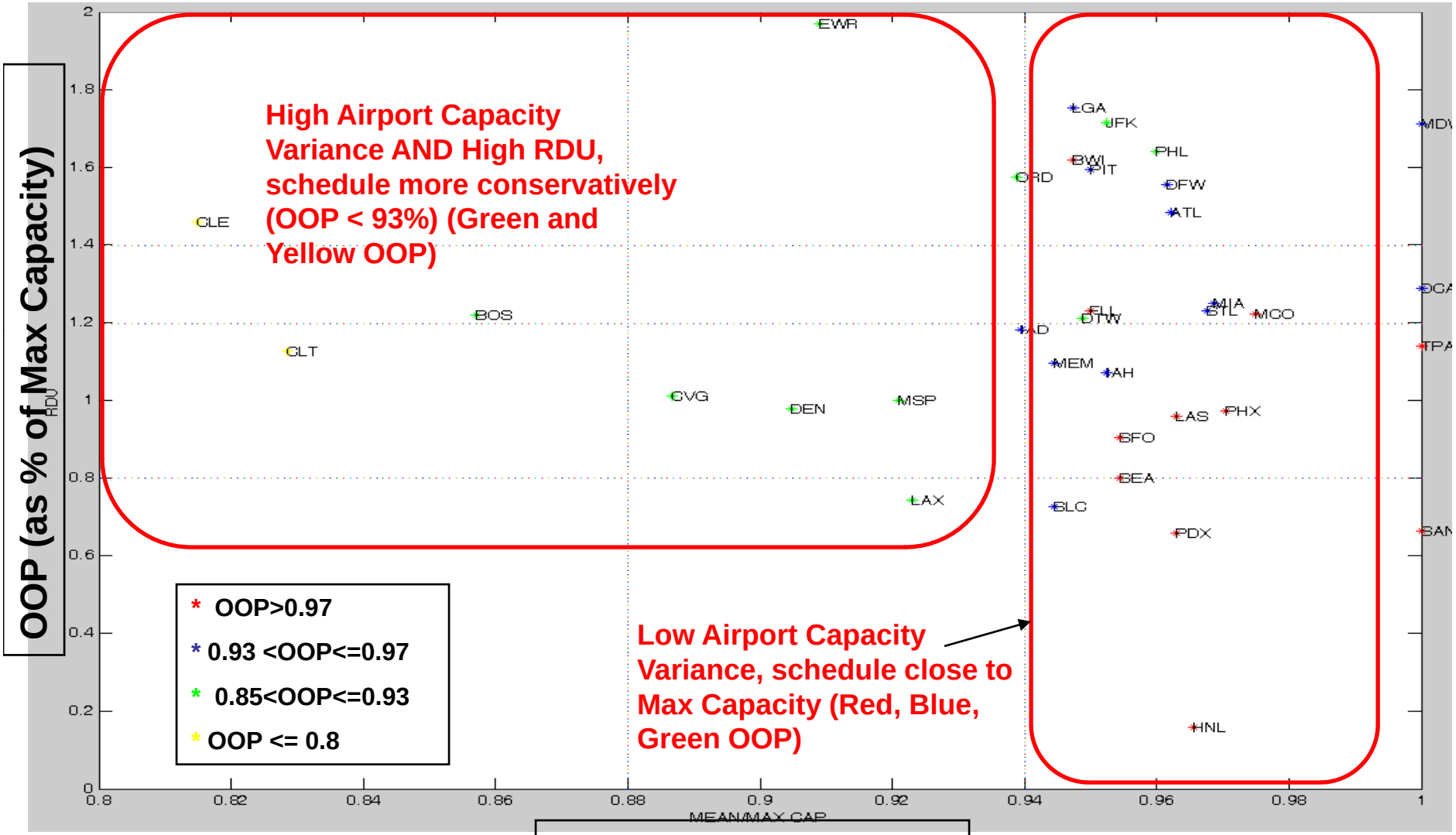


Optimal Airport Capacity

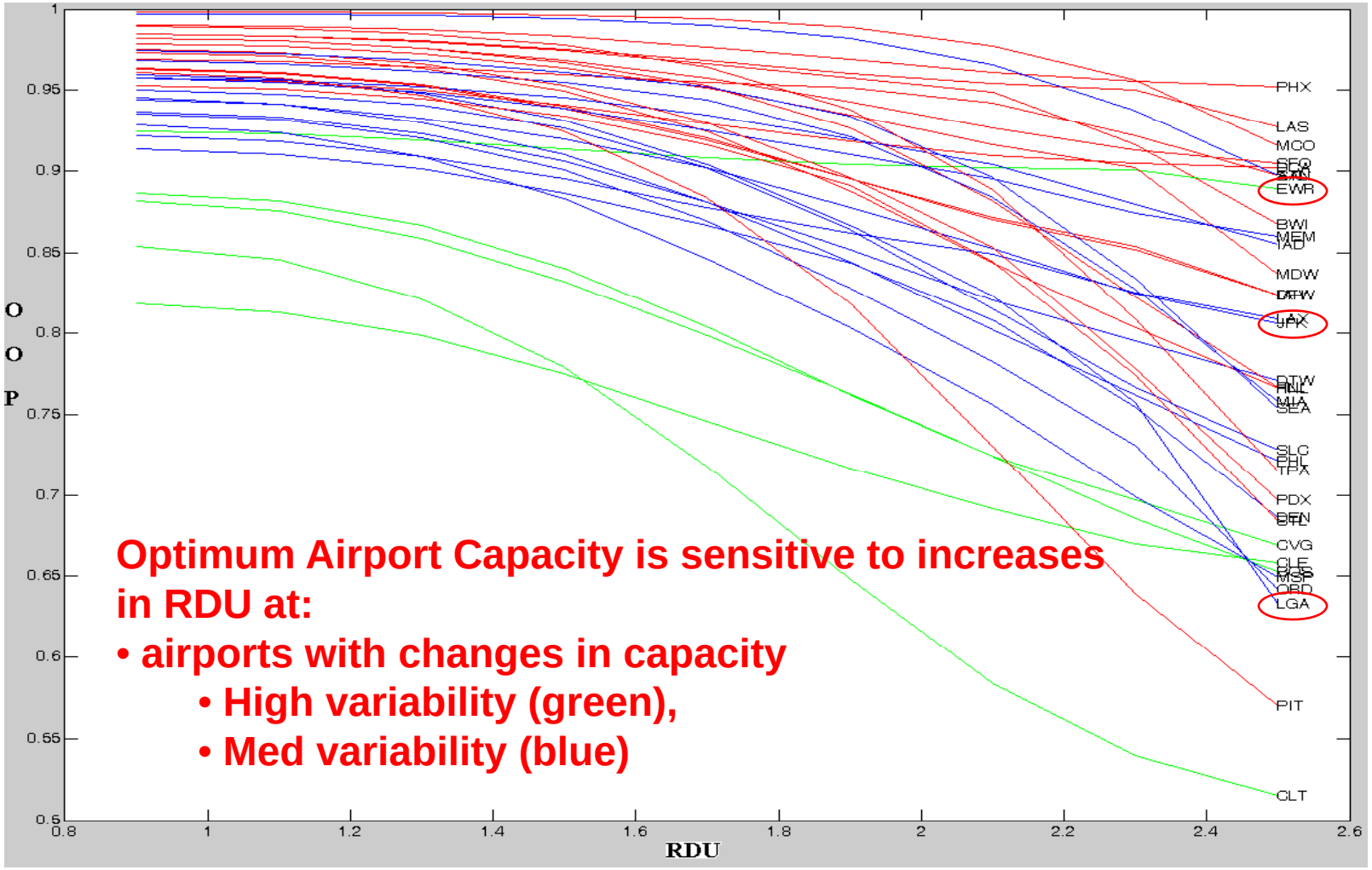


Mean Cap/ Max Cap

RDU vs Optimal Capacity (Var Only)



Sensitivity of RDU to Fuel Prices



Optimum Airport Capacity is sensitive to increases in RDU at:

- **airports with changes in capacity**
  - **High variability (green),**
  - **Med variability (blue)**

Increasing fuel prices →