# Modeling Demand Uncertainties During Ground Delay Programs

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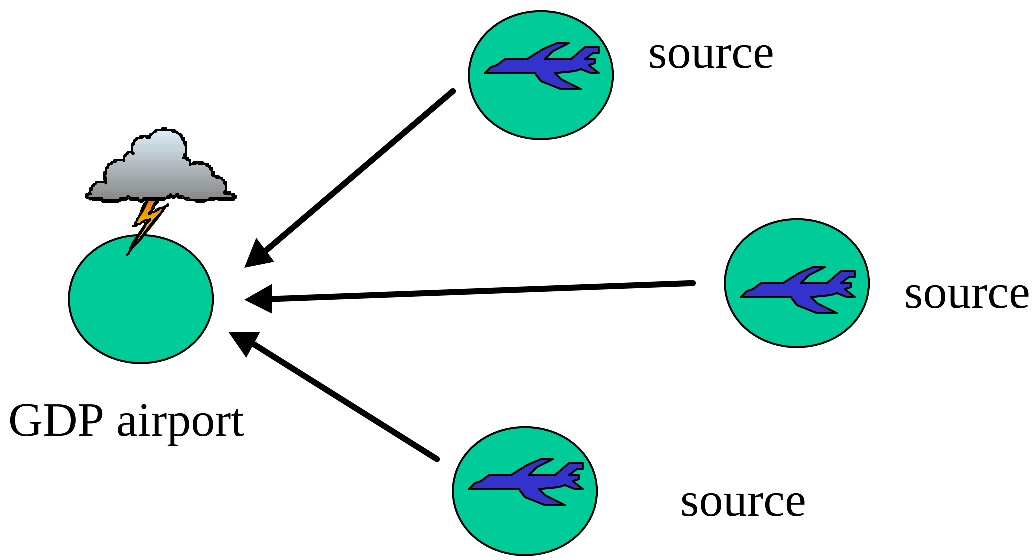
# Ground Delay Programs (GDPs)

- To balance arrival demand and capacity at the afflicted airport
- Transfer costly airborne delay to less expensive ground delay




- Input parameters - Airport Capacity and Arrival Demand
- Capacity and demand , both stochastic in nature

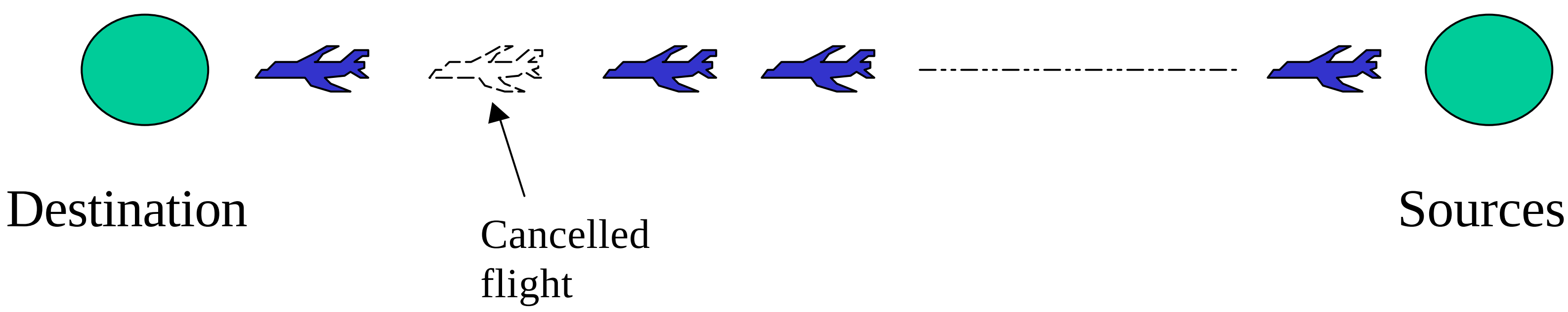
# Demand Uncertainties

- Three main sources of demand uncertainties
  - Flight Drifts,
  - Flight Cancellations, and
  - Pop-up Flights

- Combined Effects
  - Under-Utilization of the airport resources (slots)
  - Unpredictable arrival sequence
  - Increased airborne holding

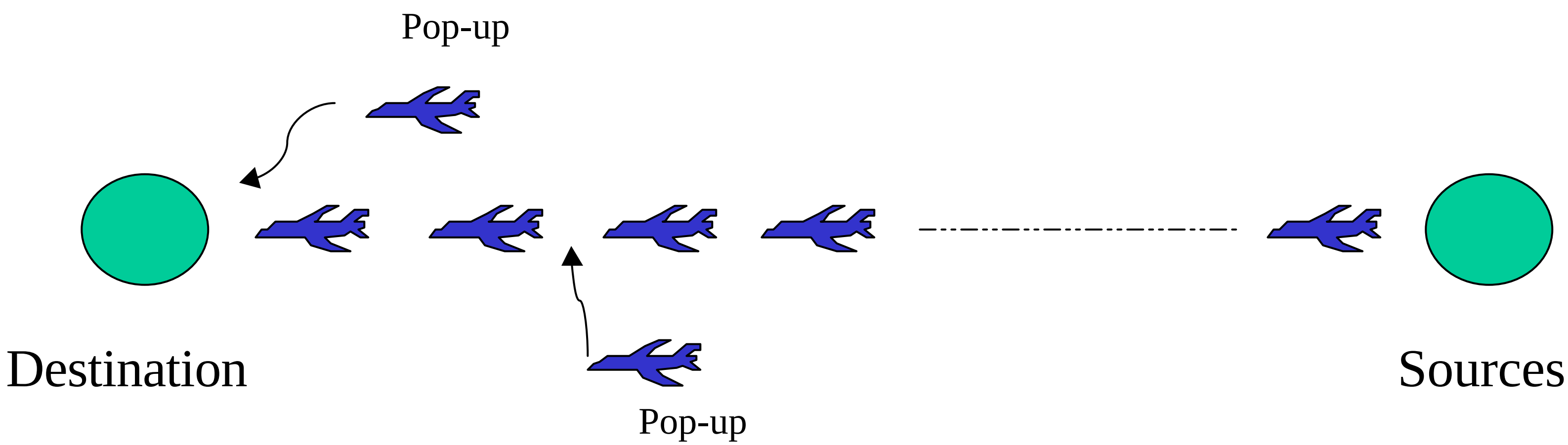
# Flight Cancellations

- Flight Cancellations without notices in advance, cause "holes" in the arrival sequence
- Timed Out (TO) Cancellations almost always result in slots being unused



# Pop-up Flights

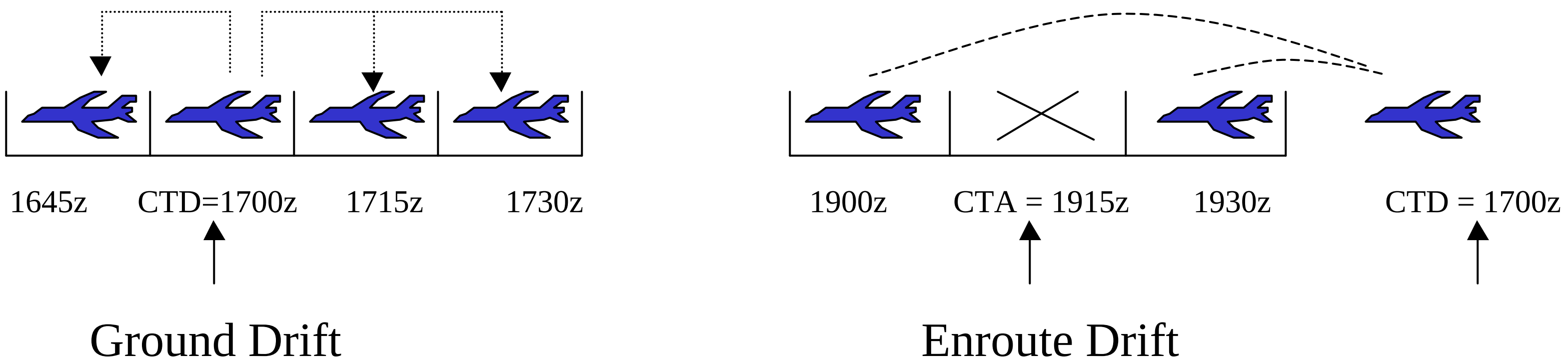
- Any flight that arrived during a GDP and that first appeared in the ADL after the GDP model time




- Pop-ups add to the arrival demand and displace the actual arrival sequence

# Flight Drifts

- Flight Drifts are results of :
  - CTD non-compliance , where ARTD > or < CTD
  - CTA non-compliance , where AETE > or <  OETE




- Net Drift  =  Ground Drift  +  Enroute Drift

•ARTA - Actual Runway Time of Arrival
•ARTD - Actual Runway Time of Departure
•AETE  - Actual Enroute  Time

•CTA    - Control Time of Arrival
•CTD    - Control Time of Departure
•OETE  - Original Estimated Enroute Time

# Modeling Demand Uncertainties

- Stochastic Mixed Integer Optimization (SMIO) Model
  - Incorporates only flight cancellations and pop-ups
  - Generates Optimal Planned Arrival Rates (PAARs) for any GDP scenario
- Simulation Model
  - Incorporates flight cancellations, pop-ups and drifts
  - Validates the SMIO model by generating Pareto Optimal PAARs for a large set of scenarios

# Details on SMIO Model

- **Objective Function :** Minimize the expected airborne queue

- **Variables :** $X_{paar}(k,t) = 1$ if PAAR = k in time period t; else 0

  $Y(k,j,t)$ : probability that at the end of time period "t" an airborne queue of size "j" exists and PAAR = k in time period "t"

- **Main Input Parameters :** AAR(t), $P_{cnx}$, $P_{pop}$, and Utilization Parameter "ε"

- **Main Constraints**

  - **Markovian Constraint :** $\sum_k Y(k,j,t) = \sum_i q(k,i,j,t)\, Y(k,i,t-1)$,

    where $q(k,i,j,t) = \Pr\{i + \text{number of arrivals in } t - AAR(t) = j \,/\, PAAR = k\}$

  - **Utilization Constraint :** Expected Number of unutilized slots $\leq$ e

- **Outputs :** Optimal PAARs and Optimal Expected Queue Size

# Formulation of SMIO Model

Minimize $\Sigma_t \Sigma_k \Sigma_j \; j \, Y(k,j,t)$

Subject to:

$\Sigma_k \; X_{paar}(k,t) = 1 \quad \forall \; t = 1, 2, \ldots P$ ………………….. (1)

$\Sigma_j \; Y(k,j,t) \leq X_{paar}(k,t) \quad \forall \; j = 1,2,\ldots MaxQ$ ………………….. (2)

$\Sigma_{k*} \; Y(k^*,j,t) \leq \Sigma_k \Sigma_i \; q(k,i,j,t) \, Y(k,i,t-1) \quad \forall \; j, \forall \; t$ ...…….. (3)

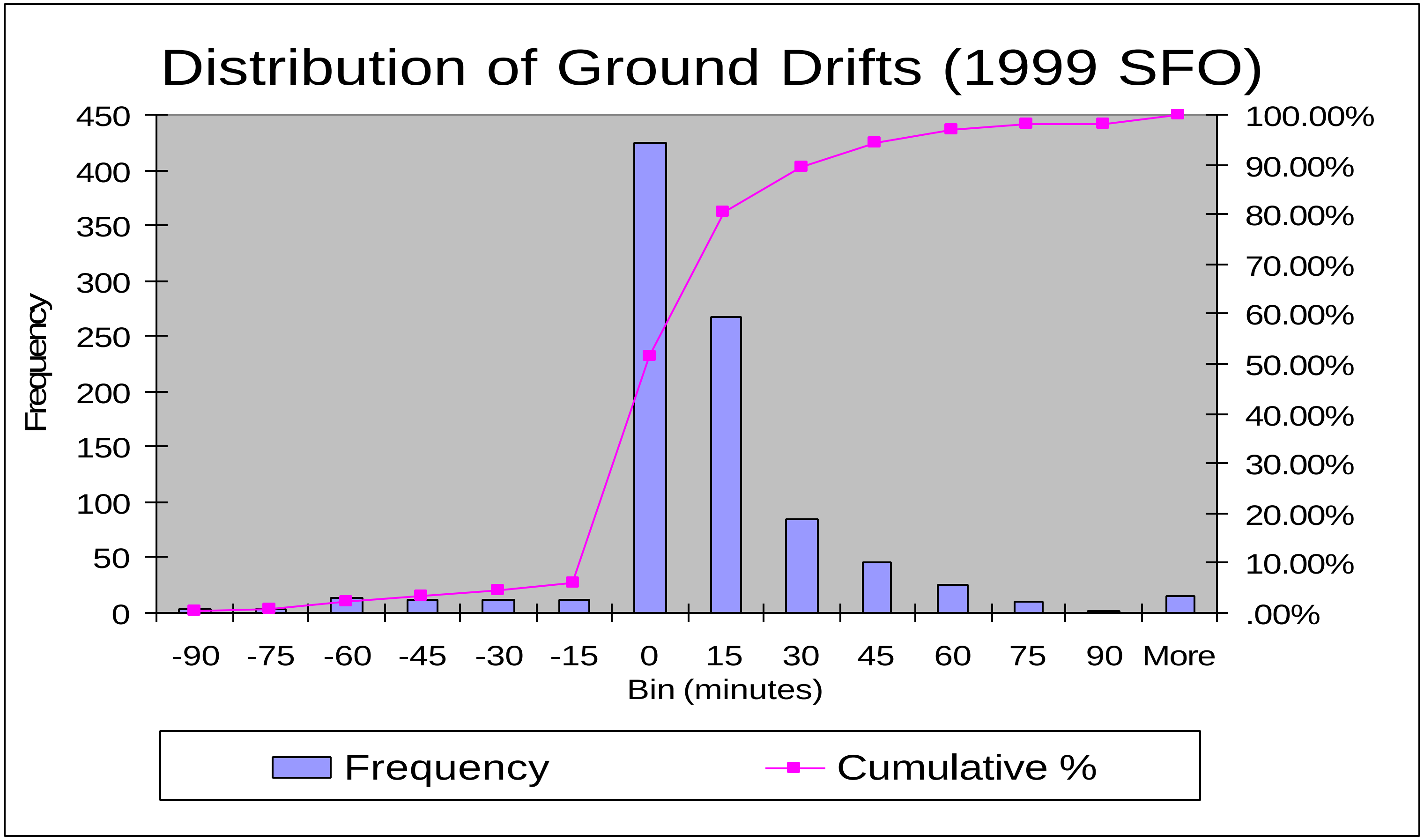
$\Sigma_t \Sigma_k \Sigma_i \; Q_e(k,i,t) \, Y(k,i,t-1) \leq \varepsilon$ ………………….. (4)

$X_{paar}(k,t) \; \varepsilon \; \{0,1\}$

# Details on Simulation Model

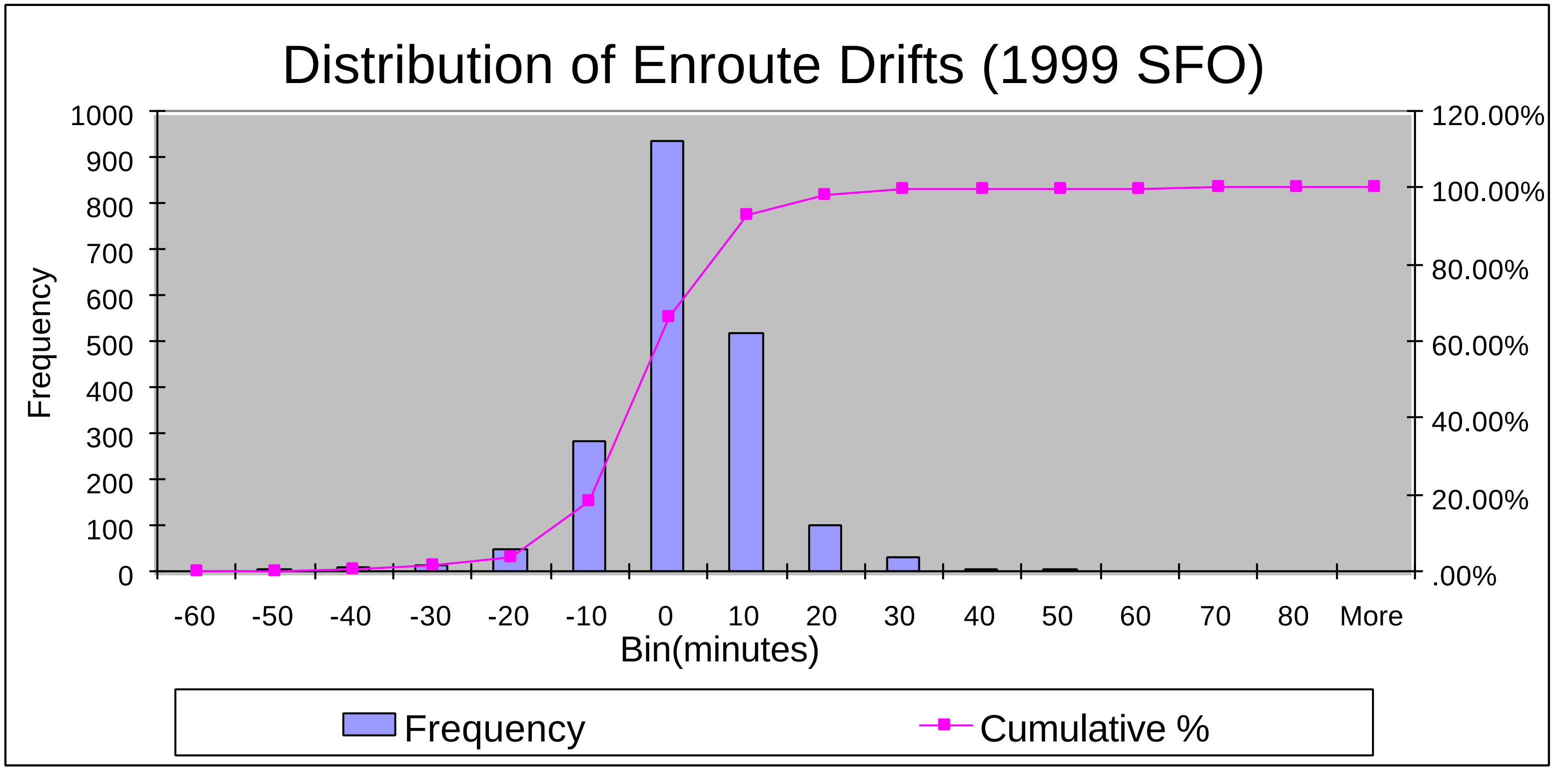
- Single-Server Queuing Model
- Input Distributions
  - Geometric distribution for flight cancellations
  - Empirical distribution for drifts
  - Exponential distribution for pop-ups
- Performance Measures
  - Ground delay
  - Airborne delay
  - Utilization

# Empirical Analysis of Drifts



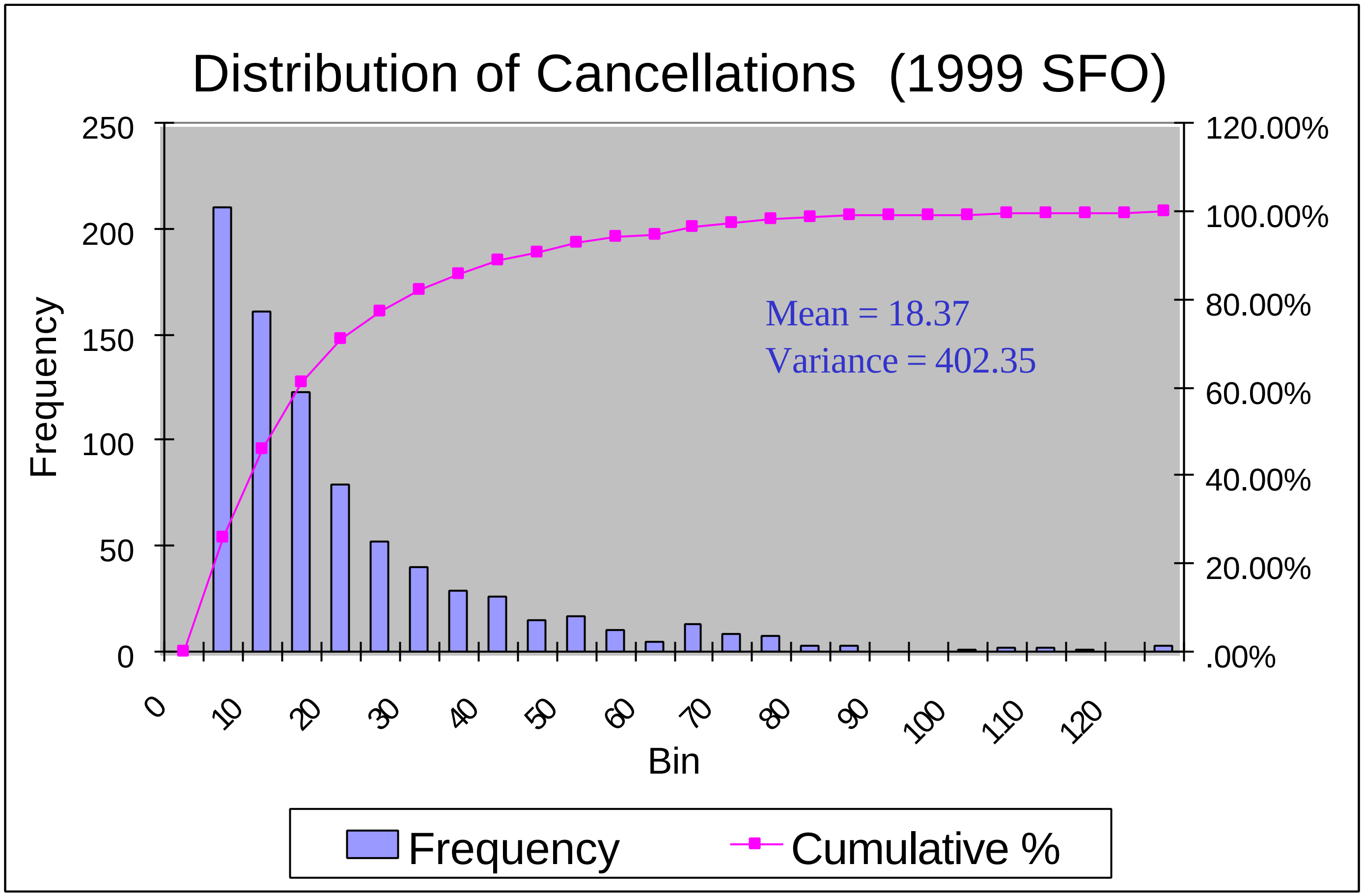

- ✈ Ground Drift = ARTD - CTD
- ✈ Mean is shifted to the right - more forward drifts

# Empirical Analysis of Drifts (contd..)



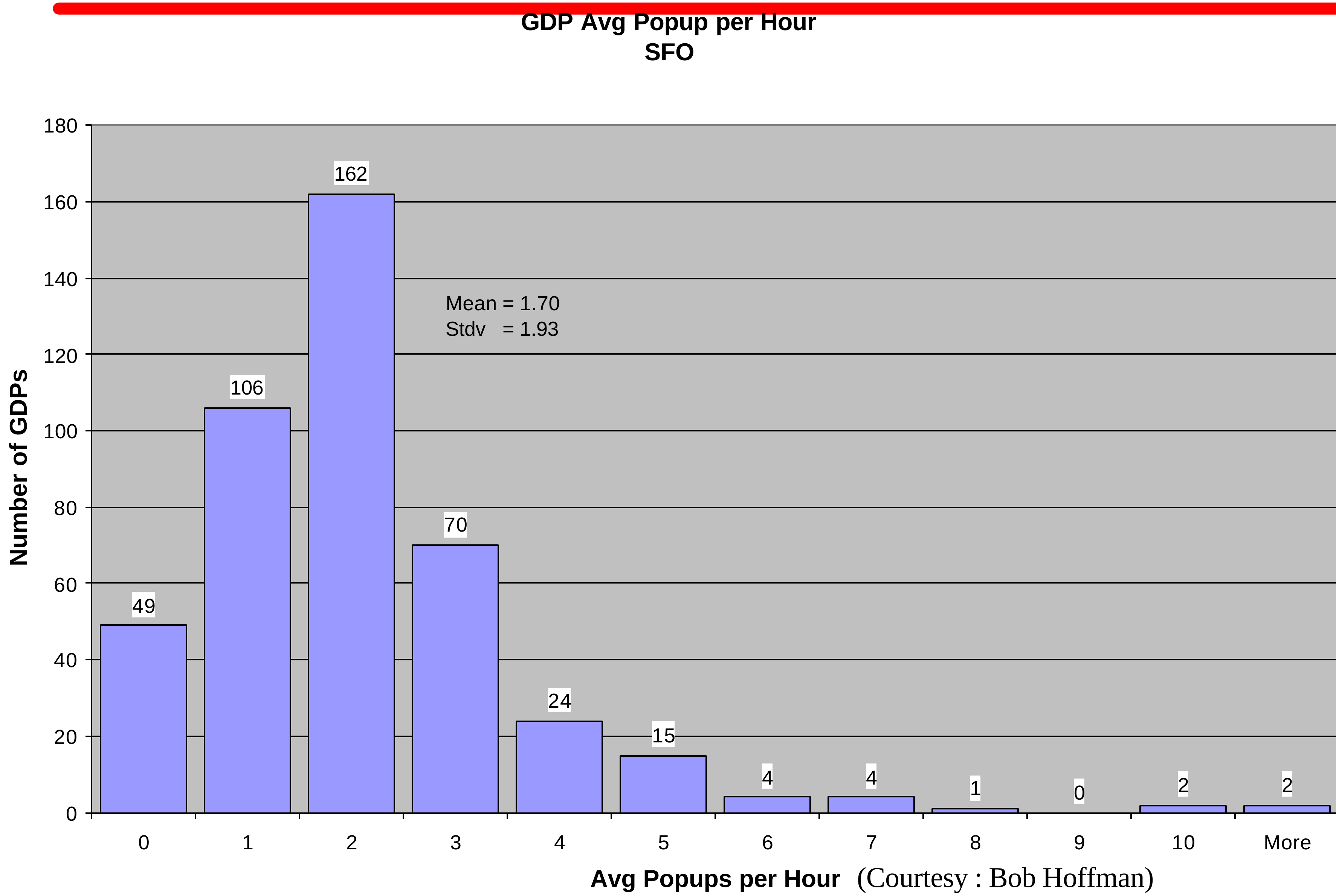

- Enroute Drift = AETE - OETE
- Actual Enroute Time less than expected
- Enroute Drifts confined to a small window

# Empirical Analysis of Cancellations




- ✈ Cancellations follow a geometric distribution during GDP

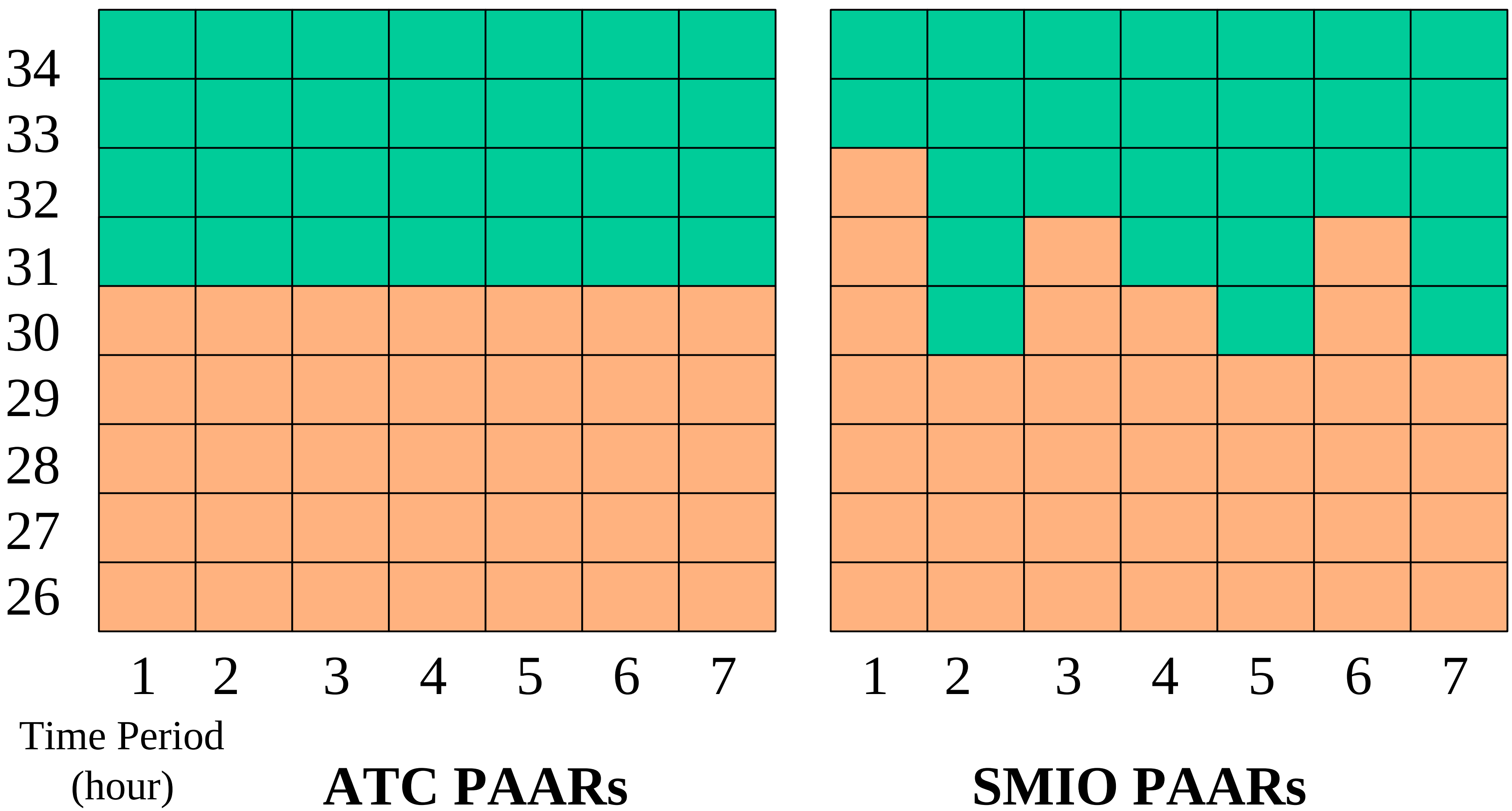
# Empirical Analysis of Pop-up Flights



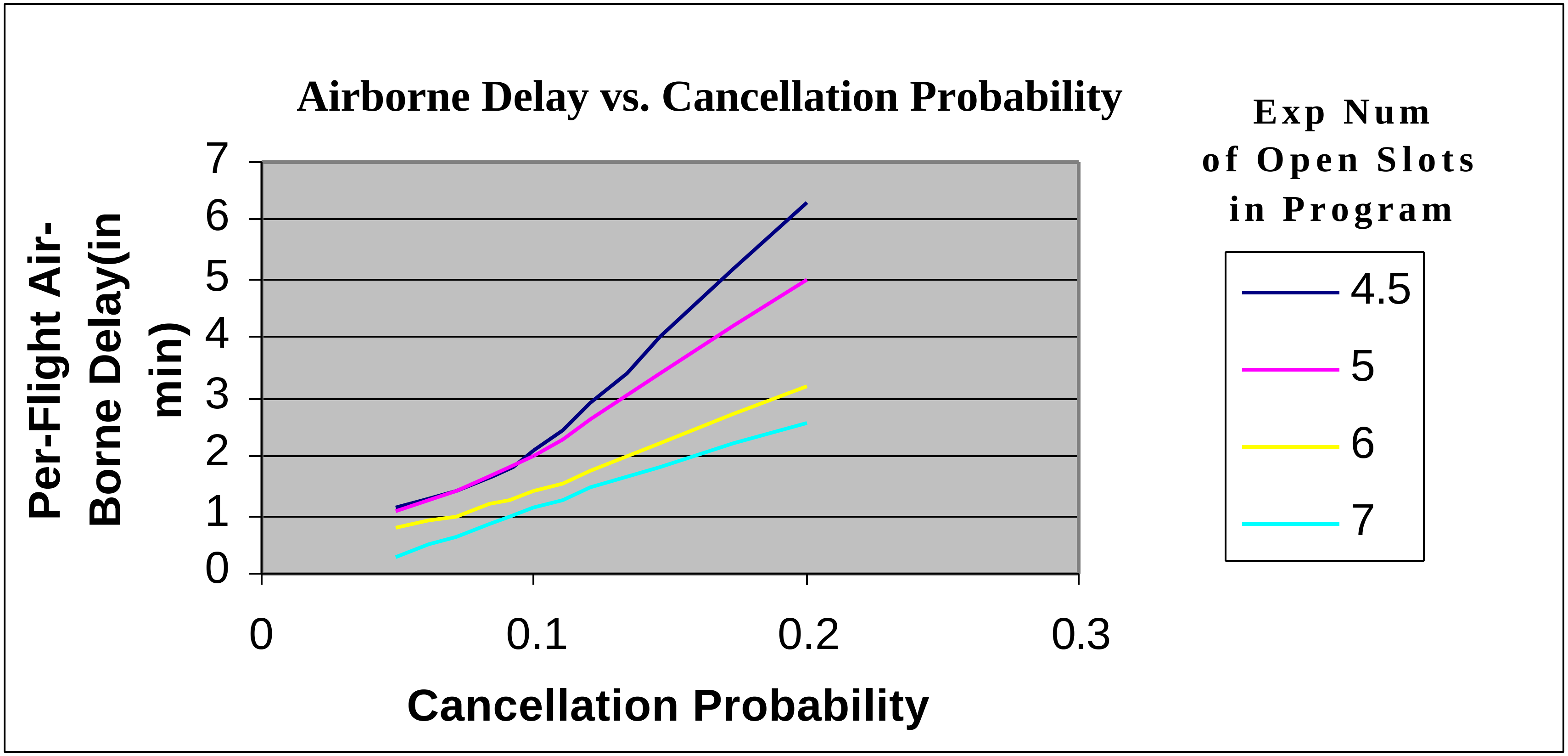

(Courtesy : Bob Hoffman)

# Results for SMIO Model

- ✈ Capacity Scenario : (30,30,30,30,30,30,30) on 05/01/98 SFO



# Results for SMIO Model (contd.)



# Results for Simulation Model

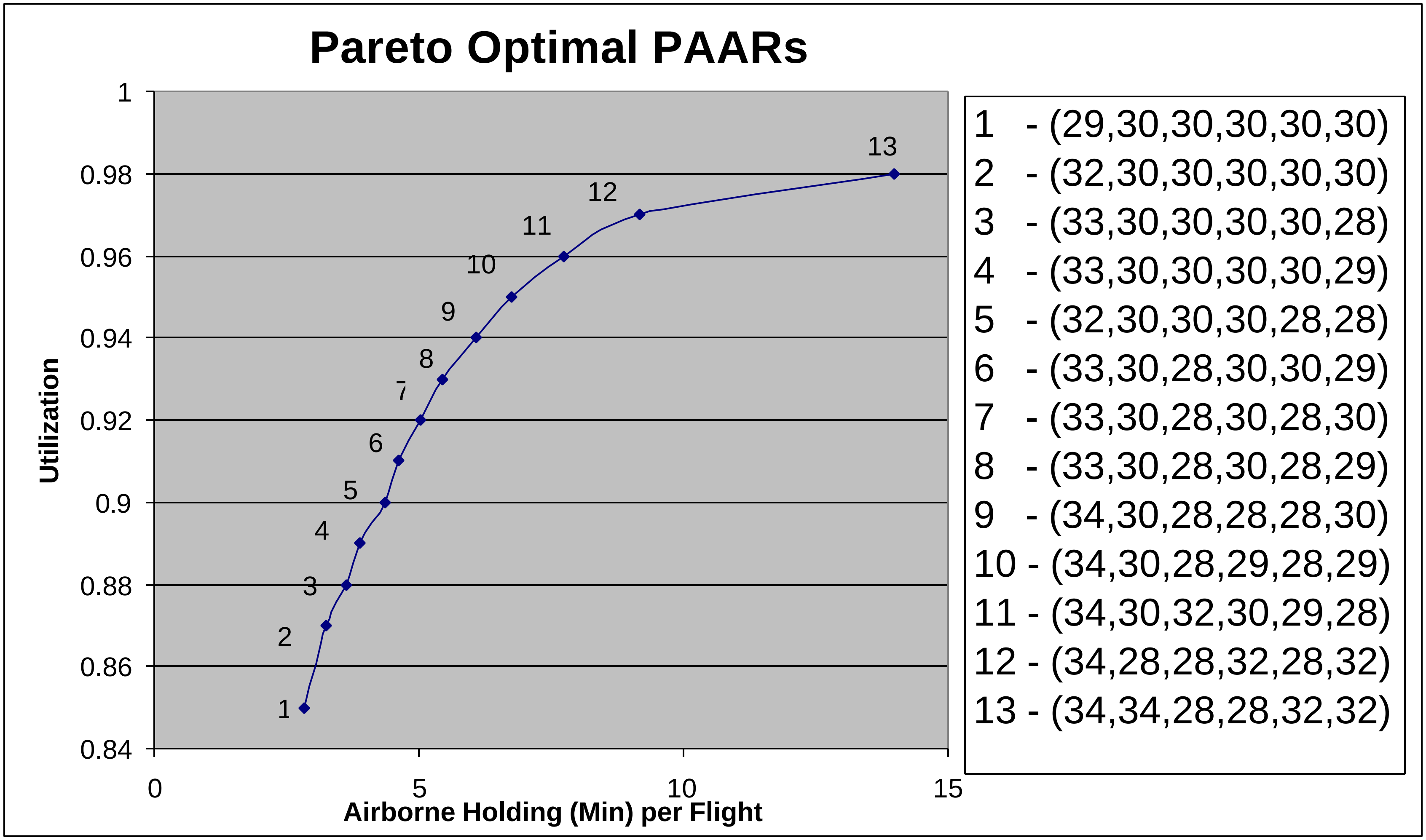
- Capacity Scenario : (30,30,30,30,30,30)
- Tested the scenarios for all PAARs in the interval [28 34]
- Used **Pareto Optimality** with Airborne Delay and Utilization as Objective functions

  - **Pareto Optimality**

    A state ***A*** (a set of parameters) is said to be Pareto optimal, if there is no other state ***B*** dominating the state with respect to a set of objective functions.

    A state ***A*** dominates a state ***B*** , if ***A*** is better than ***B*** in at least one objective function and not worse with respect to all other objective functions.

# Results for Simulation Model(contd.)



# Summary

- ✈ Significant stochasticity in airport arrival demand
- ✈ Demand Uncertainties lead to under-utilization, and excessive airborne holding
- ✈ Two models - SMIO and Simulation Model - are developed
- ✈ Models recommend policy changes in setting of PAARs - substituting *staggered patterns* for *flat patterns*