Methodology for Estimating Airport Capacity and Performance Using PDARS Data

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Objectives

Use PDARS data to :

- Provide a methodology to measure airport arrival and departure capacity and throughput baseline
- Develop airport performance metric

Road Map

- Objectives
- Task 1:
  - Refining Statistical Models for Landing Time Interval (LTI)
- Task 2:
  - Modeling LTI with Comprehensive Single Fixed Effect Model
  - Developing Methodology for Establishing Throughput Baselines
- Future Work

Task 1: Refine statistical models for landing time interval (LTI)

- Statistical models and rationales
- Parameter estimation
- Comparison of empirical data with various models
- Discussions

NEXTOR

Statistical Models

- Normal :
  - A standard distribution assumption for a random variable affected by a large amount of factors
  - PDF: $$f_s(s) = \frac{1}{\sqrt{2\pi\sigma}} e^{(\frac{s-\mu}{\sigma})^2}$$
  - Parameters: $\mu, \quad \sigma$

Statistical Models (cont'd)

- Vandevenne
  - Observed landing time interval

$$S = D + \varepsilon + g$$

S: actually observed headway

D: constant controllers' target headway

ε : controllers' imprecision error, N(0, σ^2)

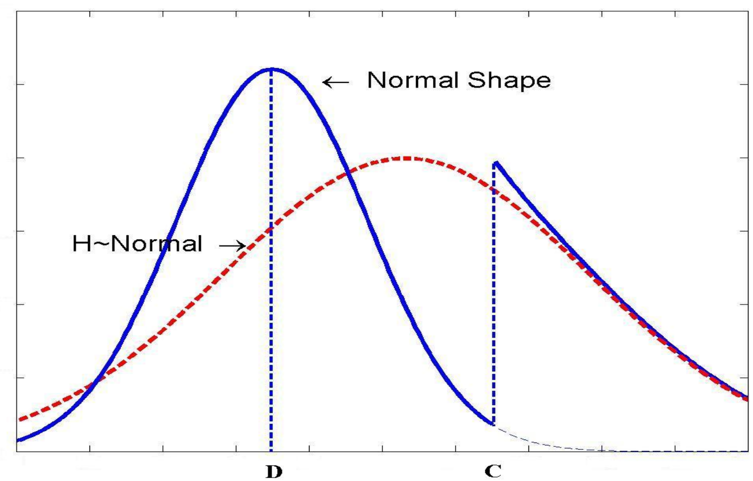
g: gap that can not be closed by control, exponential(λ)

  - PDF: $$f_S(s) = \lambda e^{[-\lambda(s - D - \frac{\lambda\sigma^2}{2})]} \Phi(\frac{s - D - \lambda\sigma^2}{\sigma})$$

  - Parameters: $D, \quad \sigma, \quad \lambda$

Statistical Models (cont'd)

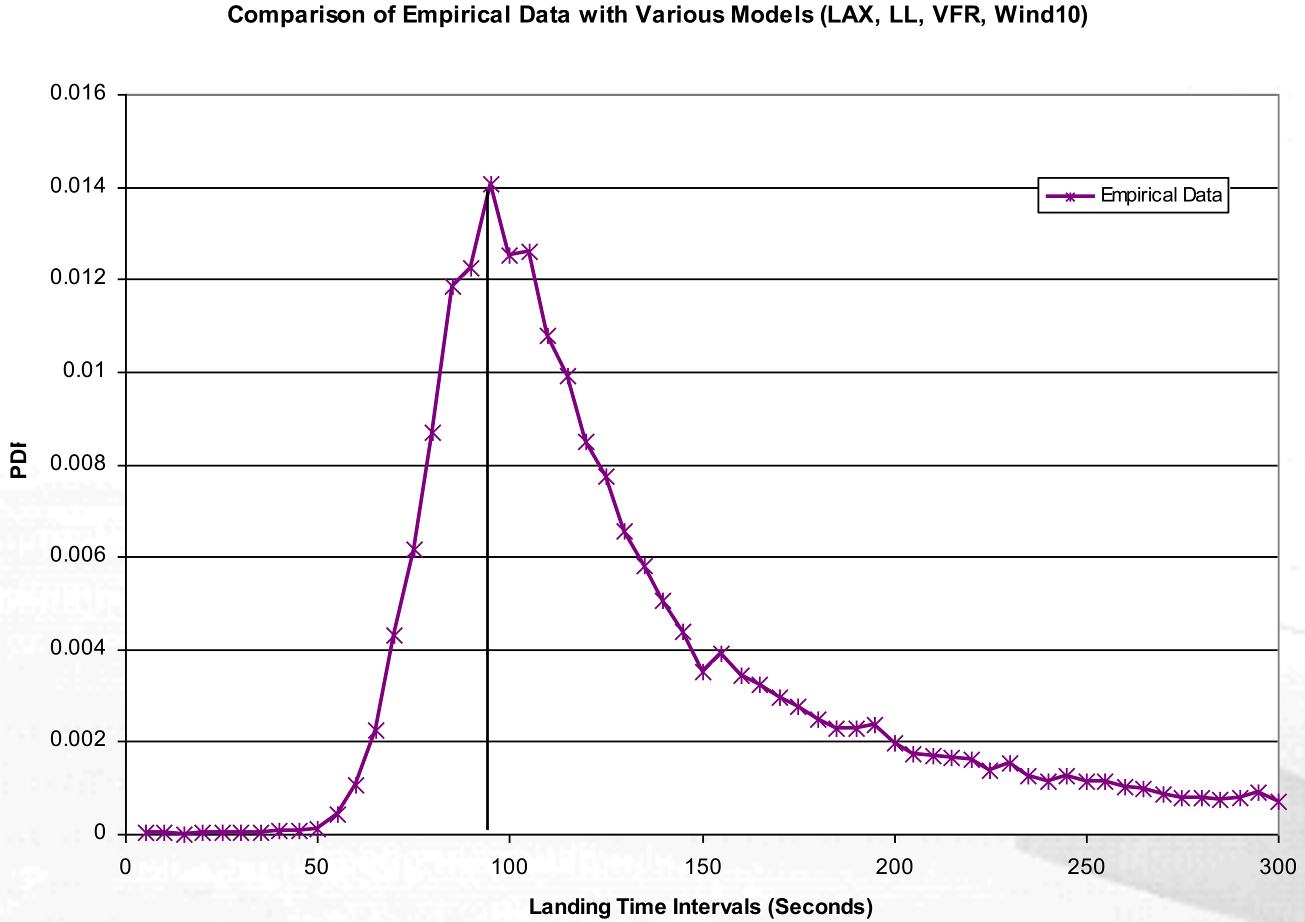
- Controlled-Normal
  - Natural headway follows normal distribution
  - Controllers take action if natural headway is less than threshold C
  - Controlled headway follows a new normal distribution



Statistical Models (cont'd)

- Controlled-Normal
  - PDF: $$f_S(s) = \begin{cases} \Phi_1(C) \times \phi_2(s) & \text{if } s \le C \\ \Phi_1(C) \times \phi_2(s) + \phi_1(s) & \text{otherwise} \end{cases}$$
    - $\Phi_1(C)$: CDF of the pre-controlled natural headway
    - $\varphi_1(s)$: PDF of the pre-controlled natural headway
    - $\varphi_2(s)$: PDF of $(D+\varepsilon)$
  - Parameters: $\mu_1, \quad \sigma_1, \quad \mu_2, \quad \sigma_2, \quad C$

Statistical Models (cont'd)



Statistical Models (cont'd)

- Normal-Lognormal
  - PDF:

$$f_S(s) = \begin{cases} \Phi(C) \times f(s) & \text{if } s \le C \\ \Phi(C) \times f(s) + \phi(s) & \text{otherwise} \end{cases}$$

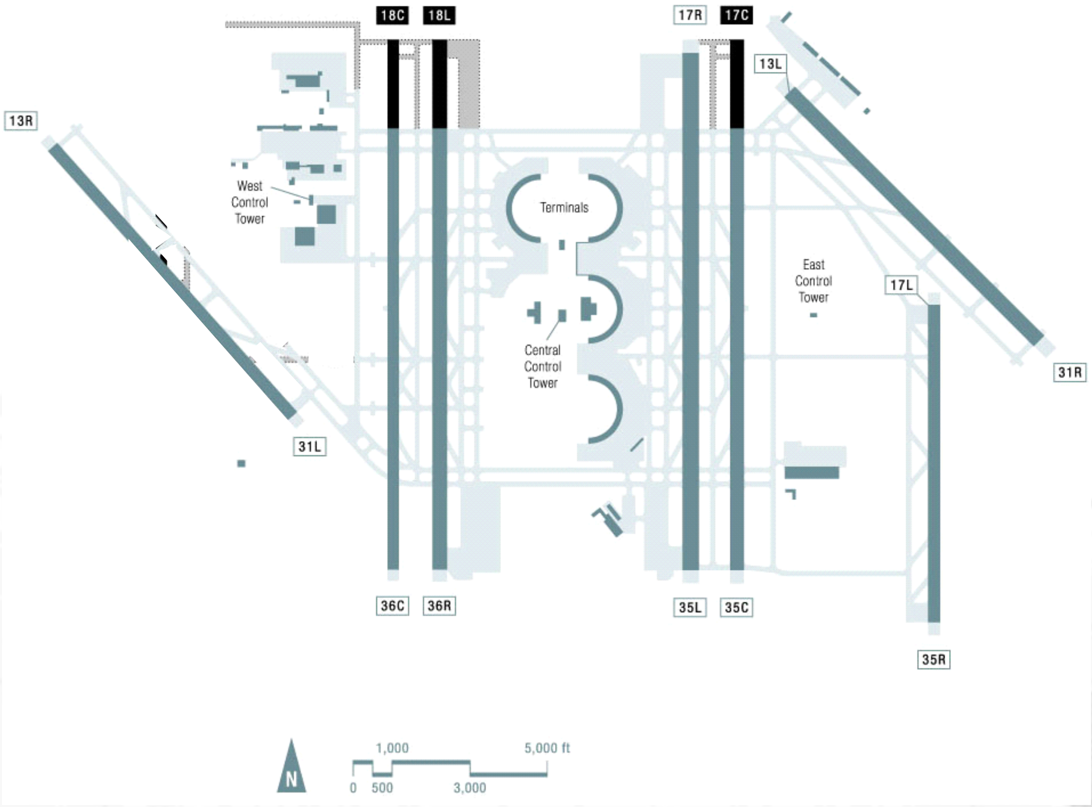
$$where: \quad f(s) = \begin{cases} \dfrac{\exp\left(-\dfrac{1}{2}\left(\dfrac{\log(s) - m}{t}\right)\right)}{st\sqrt{2\pi}} & s > 0 \\ 0 & otherwise \end{cases}$$

  - Parameters: $\mu, \quad \sigma, \quad m, \quad t, \quad C$

Data

- PDARS
  - Jan. 2005—Mar.2005
  - TRACON: D10, I90, NCT , P50, SCT
  - Major Airports: DFW, IAH, SFO, PHX, LAX
  - Other Airports: HOU, OAK, SAN, SJC
- ASPM
  - Jan. 2005—Mar.2005
  - Quarter hour data
  - Processed to include marginal VFR condition

Airport Layout of DFW



Parameter Estimation

Focus: Large-Large, VMC, Low wind speed

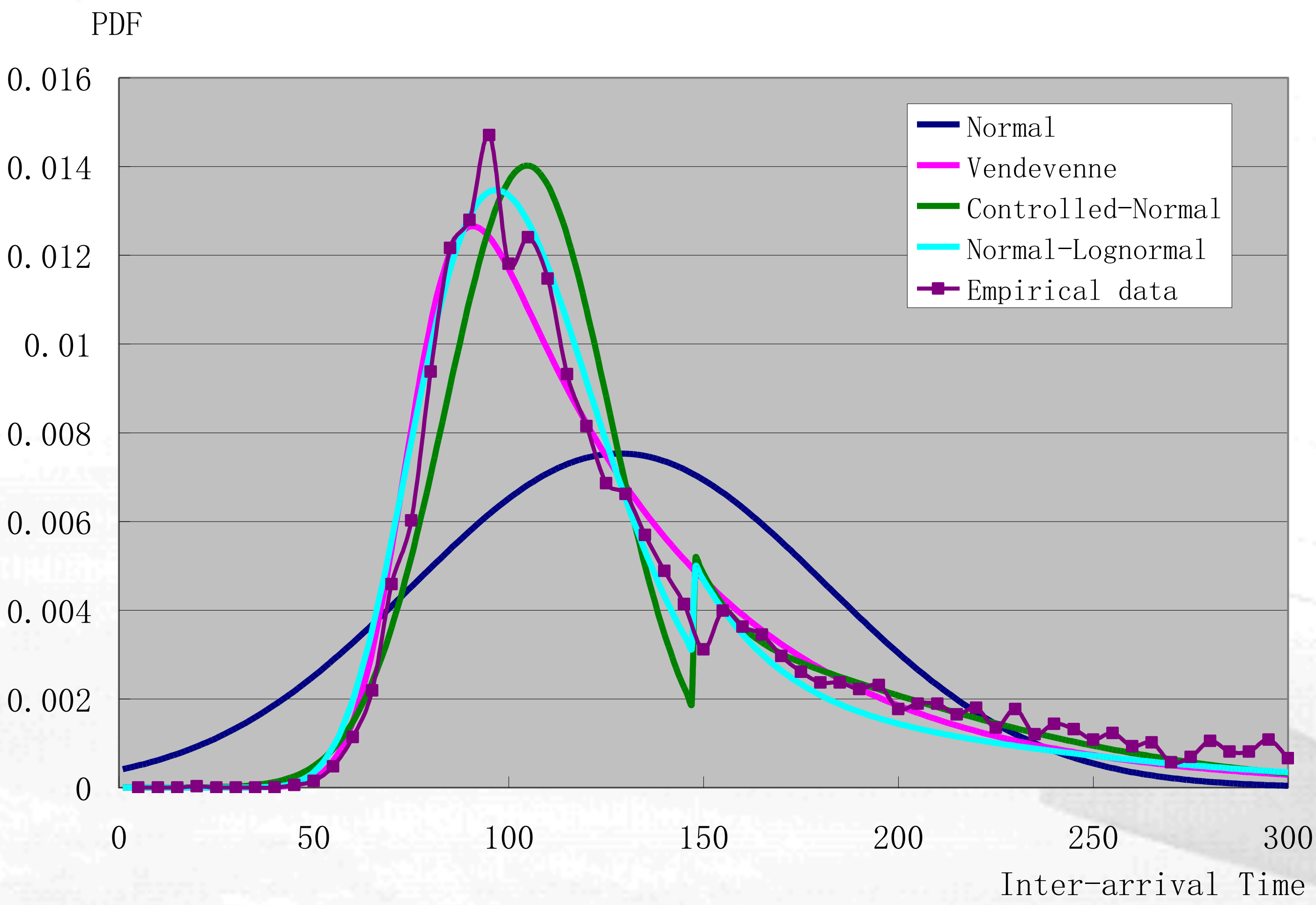
Method: Maximum Log Likelihood

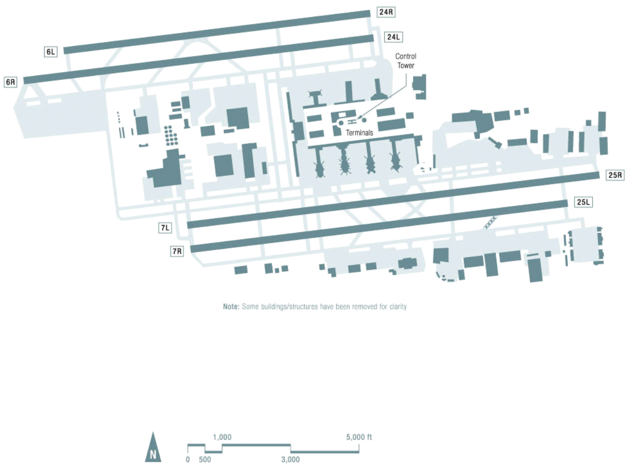
	u_1	δ_1	$u_2(D)$	δ_2	λ	δ	C	LL[1]	SIC[2]
Normal			129	53				**-35977**	**71958**
Vandevenne			77		0.02	10.93		**-34543**	**69092**
Controlled-Normal	88	93	105	21			148	**-34513**	**69036**
Normal-Lognormal	28	130	106	26			148	**-34476**	**68962**

1. Maximum Log Likelihood

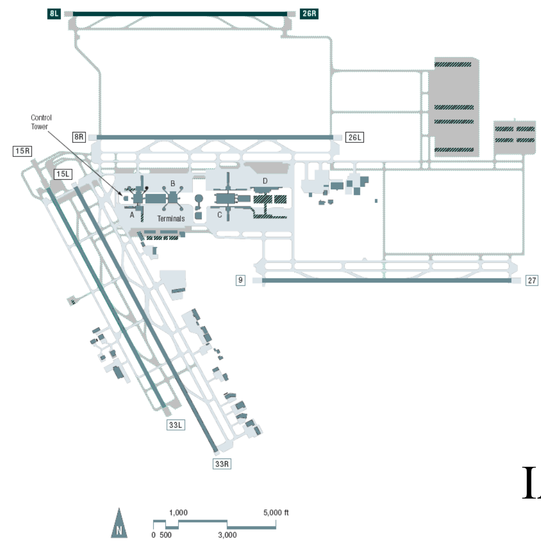
2. Schwarz Information Criterion

Comparison of Various Statistical Models

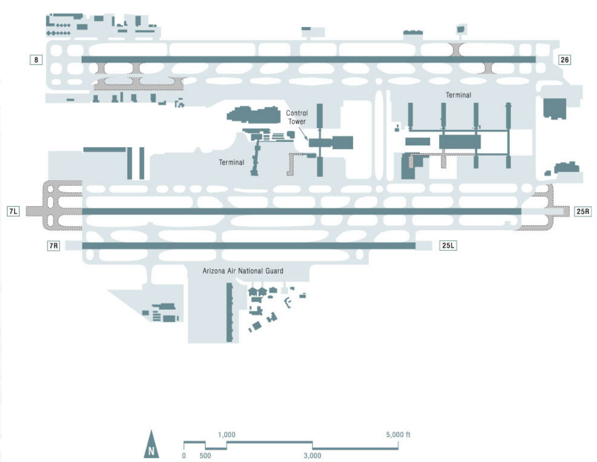




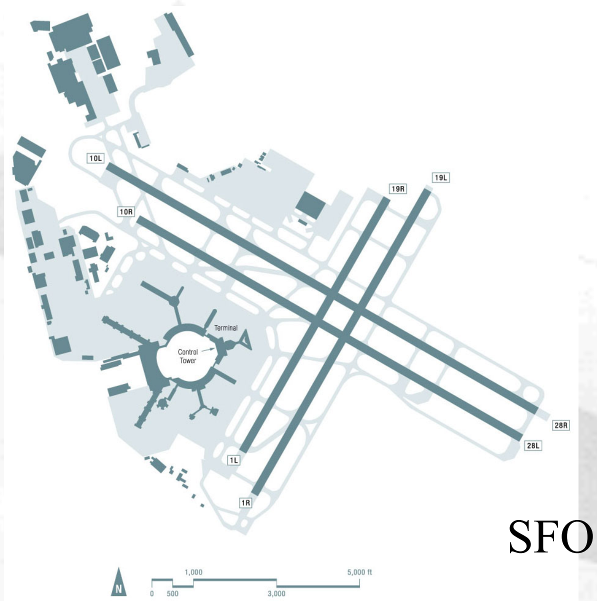
LAX



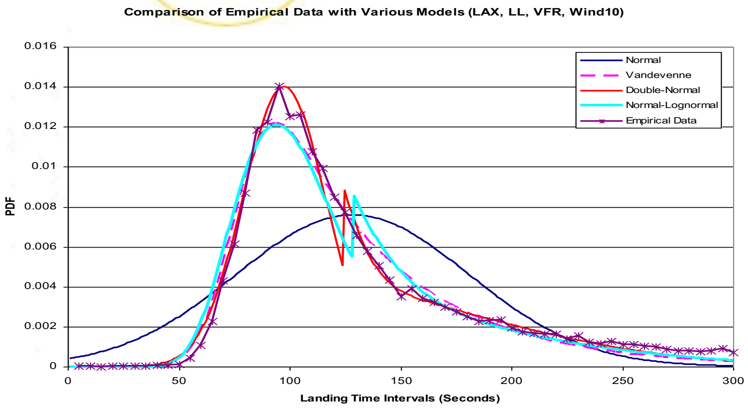
IAH



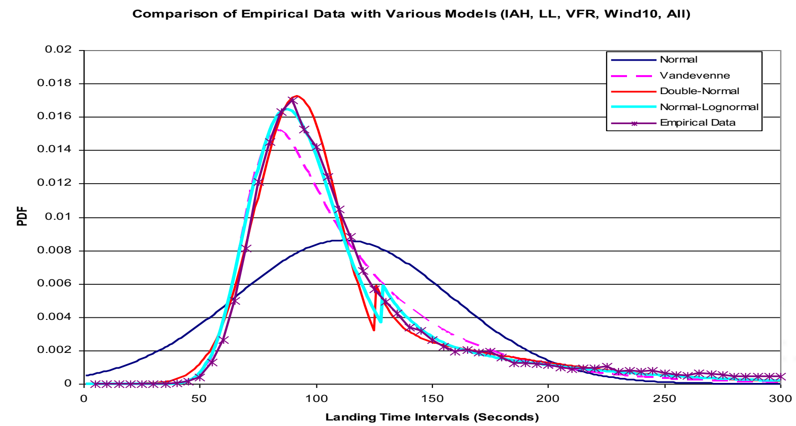
PHX



SFO



LAX



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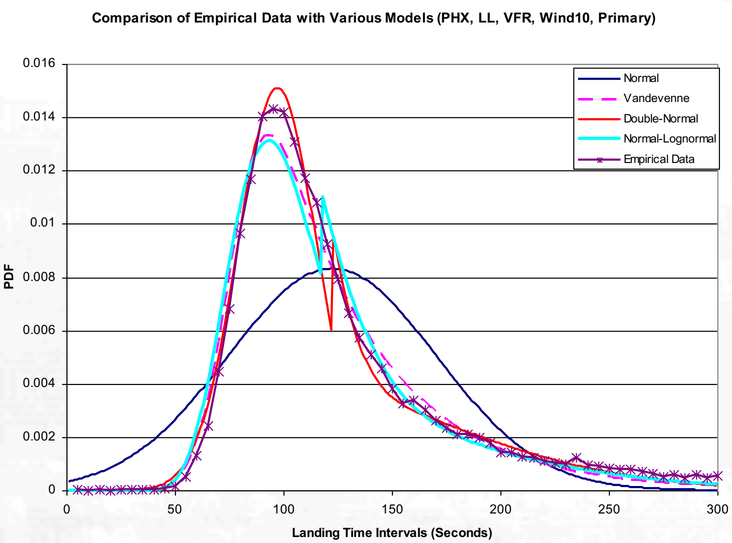
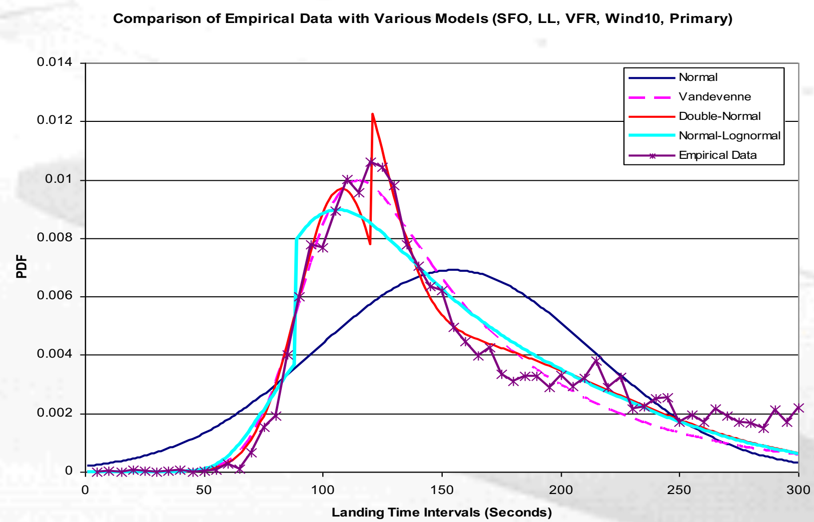


PHX



SFO

Discussions

- Proposed statistical models lead to slightly larger maximum log-likelihood value than Vendevenne model
- Vendevenne model obtains more degrees of freedom and has better converging performance under optimization environments

Discussions (cont'd)

- Physical meanings of D and λin Vendevenne model
  - D: a target time separation that a controller attempted to reach
  - λ : average arrival rate of flights

- Not constant but depends on
  - D: Runway configurations
  - λ : Arrival demand

Task 2: Establish throughput baselines using PDARS data

- Comprehensive Single fixed effect model of Landing Time Interval
  - Linear function of D: traffic mix, meteorological conditions, and runway configurations
  - Linear function ofλ:arrival demand and distribution logic to different runways

- Methodology for Establishing Throughput Baselines
  - Multi-dimension capacity estimation
  - Extension of dynamic capacity model

NEXTOR

Single Fixed Effect LTI Model

$$D = a + \gamma_1 \times MVFR + \gamma_2 \times IFR + \sum_{i=2}^{6} w_i \times Rwyconf_i$$

$$+ t_H \times TrailH + t_S \times TrailS + l_H \times LeadH + l_S \times LeadS$$

Meteorological conditions:

VFR	MVFR	IFR

Fleet mix

Trailing	L	H	S
Leading	L	H	S

Note: an M (B757) was taken as an H when it is leading and an L when it is trailing

Runway configurations:

Runway Configuration	ID
24R, 25L | 24L, 25R	1
24L, 24R, 25L, 25R | 24L, 24R, 25L, 25R	2
24L, 24R | 25L, 25R	3
6L, 7R | 6R, 7L	4
6L, 6R, 7L, 7R | 6L, 6R, 7L, 7R	5
6L, 6R | 7L, 7R	6

Single Fixed Effect LTI Model (cont'd)

λ : Arrival demand

Runway characteristics (Outside or Inside)

Runway configuration groups (Model 1)

Group 1: Runway configuration 1&4

Group 2: Runway configuration 2&5

Group 3: Runway configuration 3&6

$$\lambda = \sum_{i=1}^{3} \left((inside = 0) \times \beta_{i0} \times arrdemand + (inside = 1) \times \beta_{i1} \times arrdemand \right)$$

Specific runway configurations (Model 2)

$$\lambda = \sum_{i=1}^{6} \left((inside = 0) \times \beta_{i0} \times arrdemand + (inside = 1) \times \beta_{i1} \times arrdemand \right)$$

Key Findings

- For large-large, VMC, runway configuration 24R, 25L | 24L, 25R at LAX, the target LTI is 81 seconds.
  - For same meteorological condition and runway configuration, the target LTI with fleet mix

Trailing / Leading	L	H	S
L	81	77	84
H	103	99	106
S	76	72	78

  - For same condition, the target LTI increase 8.4 seconds under runway configuration 6L, 7R | 6R, 7L
  - For same runway configuration, headway increase 3.6 seconds under MVFR but only 2.5 seconds under IFR condition

Key Findings (cont'd)

	Estimated Landing Time Interval				Fleet Mix			
	Trailing							
Leading		L	H	S	L	H	S	
LAX	L	81	77	84	0.16	0.04	0.04	41
	H	103	99	106	0.28	0.06	0.08	
	S	76	72	78	0.23	0.04	0.07	
DFW	L	81	83	87	0.51	0.05	0.01	42
	H	102	104	108	0.24	0.02	0.01	
	S	80	83	86	0.12	0.01	0.02	
IAH	L	77	77	87	0.31	0.02	0.02	44
	H	102	102	111	0.21	0.01	0.01	
	S	74	74	84	0.36	0.02	0.04	
PHX	L	78	87	80	0.25	0.01	0.04	46
	H	93	102	95	0.05	0.00	0.01	
	S	76	85	78	0.49	0.04	0.11	
SFO	L	97	97	96	0.19	0.05	0.05	36
	H	106	107	105	0.19	0.05	0.06	
	S	93	94	93	0.25	0.05	0.09	

Key Findings (cont'd)

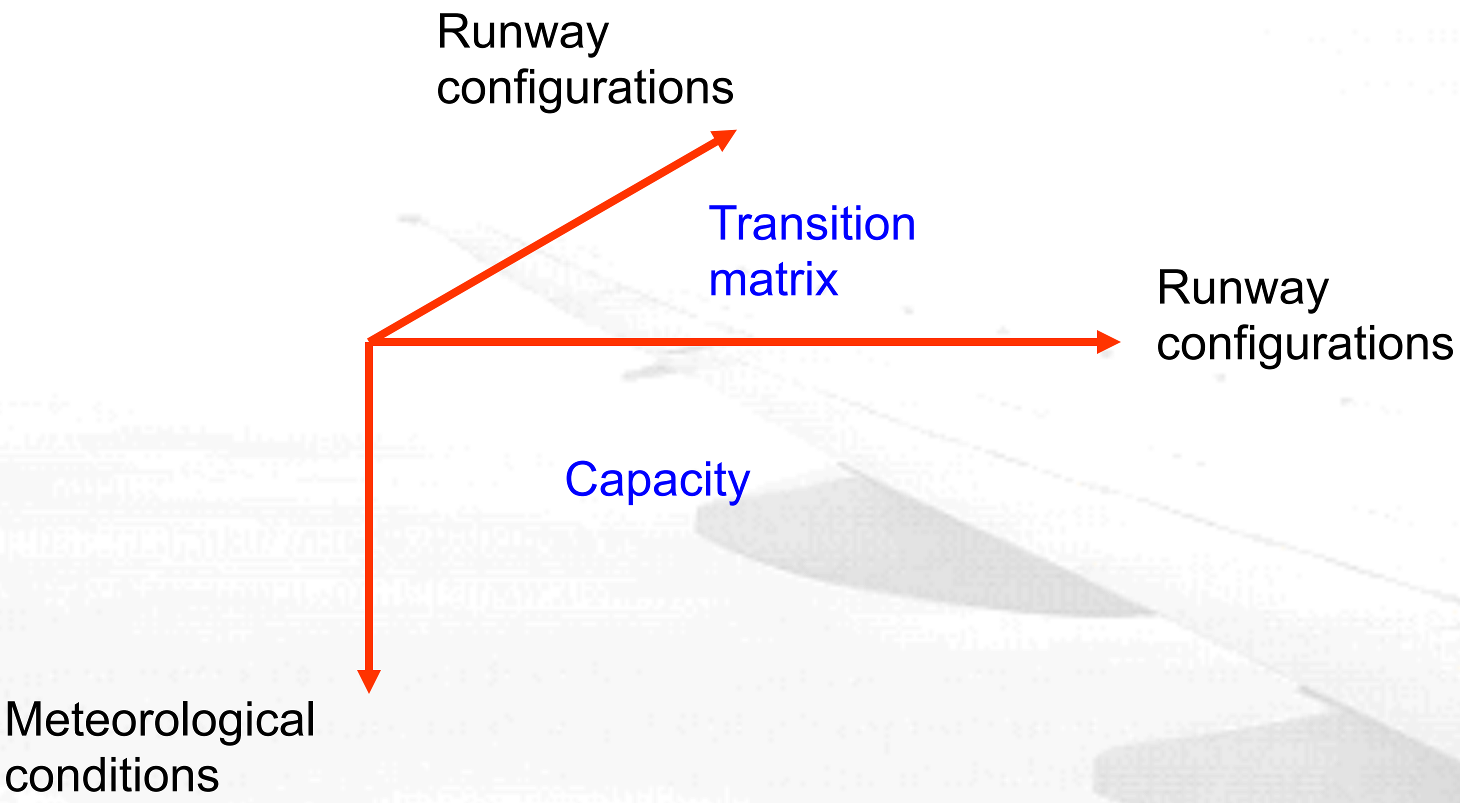
- Substantial variation in target LTI
  - LAX 16.9secs
  - DFW 14.5secs
  - IAH 12.0secs
  - PHX 18.7secs
  - SFO 20.2secs
- Fixed effect of meteorological conditions
  - LAX DFW
  - IAH SFO PHX

Methodology for Establish Throughput Baselines

	Rwy conf 1	Rwy conf 2	Rwy conf 3	Rwy conf
VFR	L H S L H S	L H S L H S	L H S L H S	L H L H S
MVFR	L H S L H S	L H S L H S	L H S L H S	L L H S
IFR	L H S L H S	L H S L H S	L H S L H S	L H S L H S

	L	H	S
L			
H			
S			

Extension of Dynamic Capacity Model



Future Work

- Further analysis of variation of target LTI
- Analysis of other PDARS airports and departure capacity
- Further study of dynamic capacity model
- Impact of equipment outages on airport performance, using MMS and OPSNET data

Thank you!

Back up Slides

Contributions

- Exploit accuracy and precision of PDARS
- Explicitly consider traffic mix
- Consider the impact of meteorological conditions
- Account for the effects of demand level
- Aggregate
  - micro aircraft landing data
  - runway level
  - airport configuration level
  - airport level

LTI as a Random Variable

- Landing time interval—time between when two successive flights arriving on the same runway crossing runway threshold or passing the outer marker
- The headway has intrinsic variation because of
  - Human factors
  - Meteorological factors
  - Other factors
- We treat headway as a random variable
  - Can take different values
  - Probability of taking different values determined by probability density function (PDF)

Extension to Dynamic Capacity Model (Cont'd)

- Historical Transition Matrix of Runway Configurations

PHX	25L, 26｜25R	25R｜25L, 26	7L, 7R｜7L, 8	7R, 8｜7L
25L, 26｜25R	0. 982	0. 000	0. 000	0. 017
25R｜25L, 26	0. 250	0. 750	0. 000	0. 000
7L, 7R｜7L, 8	0. 050	0. 000	0. 875	0. 075
7R, 8｜7L	0. 019	0. 000	0. 001	0. 980