Air Transportation System Architecture Analysis

Project Phase II

Advanced System Architecture

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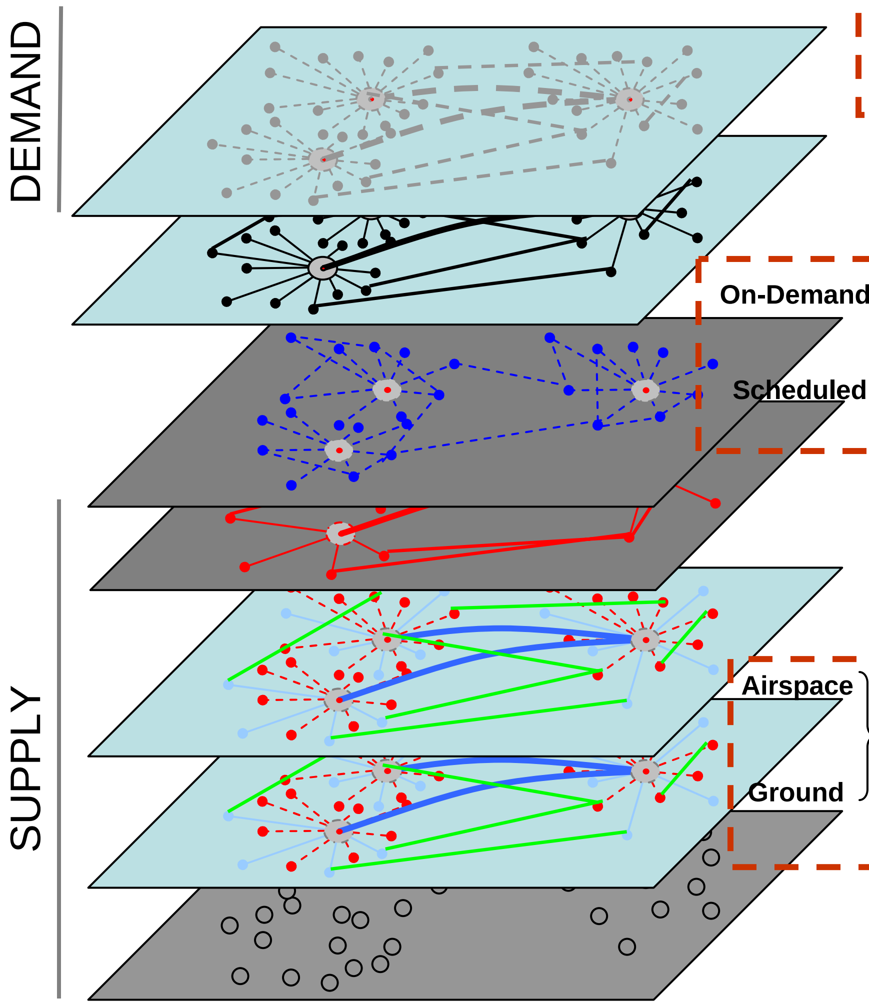
Motivation

- The air transportation system is facing and will continue to face significant challenges in terms of meeting demand for mobility
- Current multi-agency effort to establish a roadmap for the “Next Generation of Air Transportation System”
- Navigation in current system under most conditions requires use of fixed-location of current infrastructure to facilitate mobility
- Future (evolved) architecture of the system require understanding of the structure of the current system
- Lack of integrated quantitative analysis of structure of the current system

Objective of the project

- Better understand the architecture of the current system through network analyzes
- Understand
  - the network characteristics of individual system layers
  - Influence of constraints, desired properties (i.e. safety, capacity, etc.) in explanation of network characteristics
  - comparison of network characteristics across different layers, through coupling of infrastructure or comparison of different network characteristics across layers

Overview of the System



System layer	Layer attributes	Data sources
Demand layer	Population, income, location of businesses	ArcGIS, Census
Mobility layer	Movements of People and goods	DB1B database
Transport layer	Aircraft routes	ETMS, OAG
Operator layer	Crews & Pilots	
Infrastructure layer	National Airspace System (airports layout and airspace structure)	FAA Form 5010 airport database, airway

Infrastructure Layer Analysis

Navigation Infrastructure Analysis

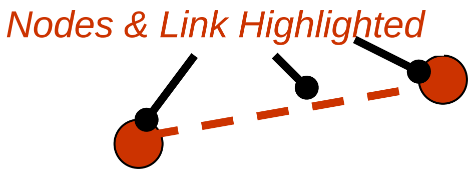


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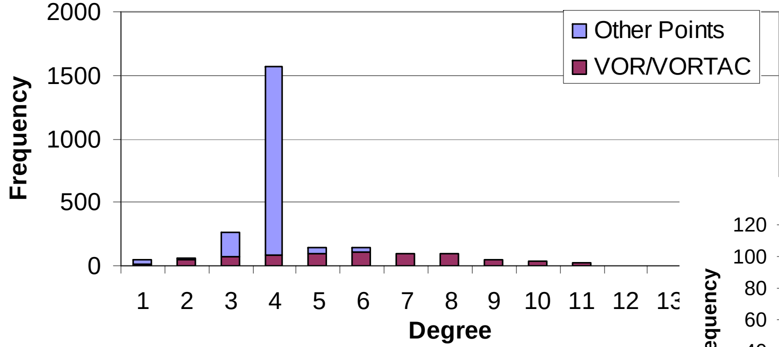
Chart of jet routes.

- Nodes: FAA-Defined Navigational Aids of Different Types
  - VORs, Reporting Points, etc
- Links: Air Routes Between Nodes
  - Victor (low alt) & Jet Routes (high alt)

- Network Metrics
  - Clustering Coefficient (Watts method) – Proxy for robustness of network
  - Correlation Coefficient
- Architecture Analyses
  - Shortest-Path Navigational vs. Direct Distance between Airports
  - Nodal Betweenness/Centrality

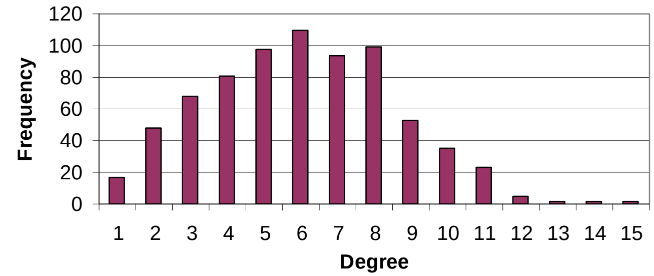
Degree Sequence

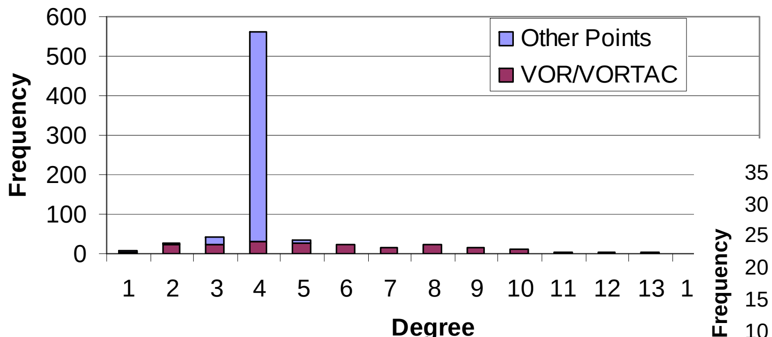


Victor Airways

-All Points (left)

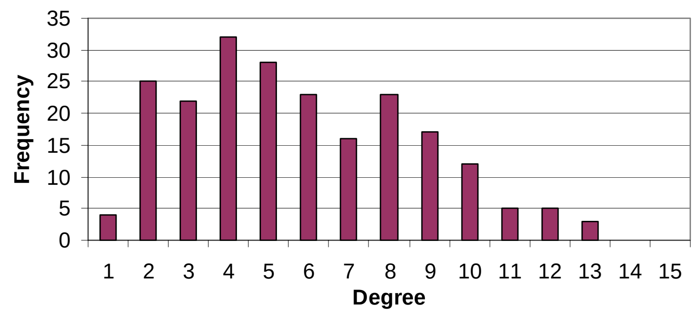
-VOR/VORTAC (below)





Jet Routes

-All Points (left), VOR/VORTAC (right)



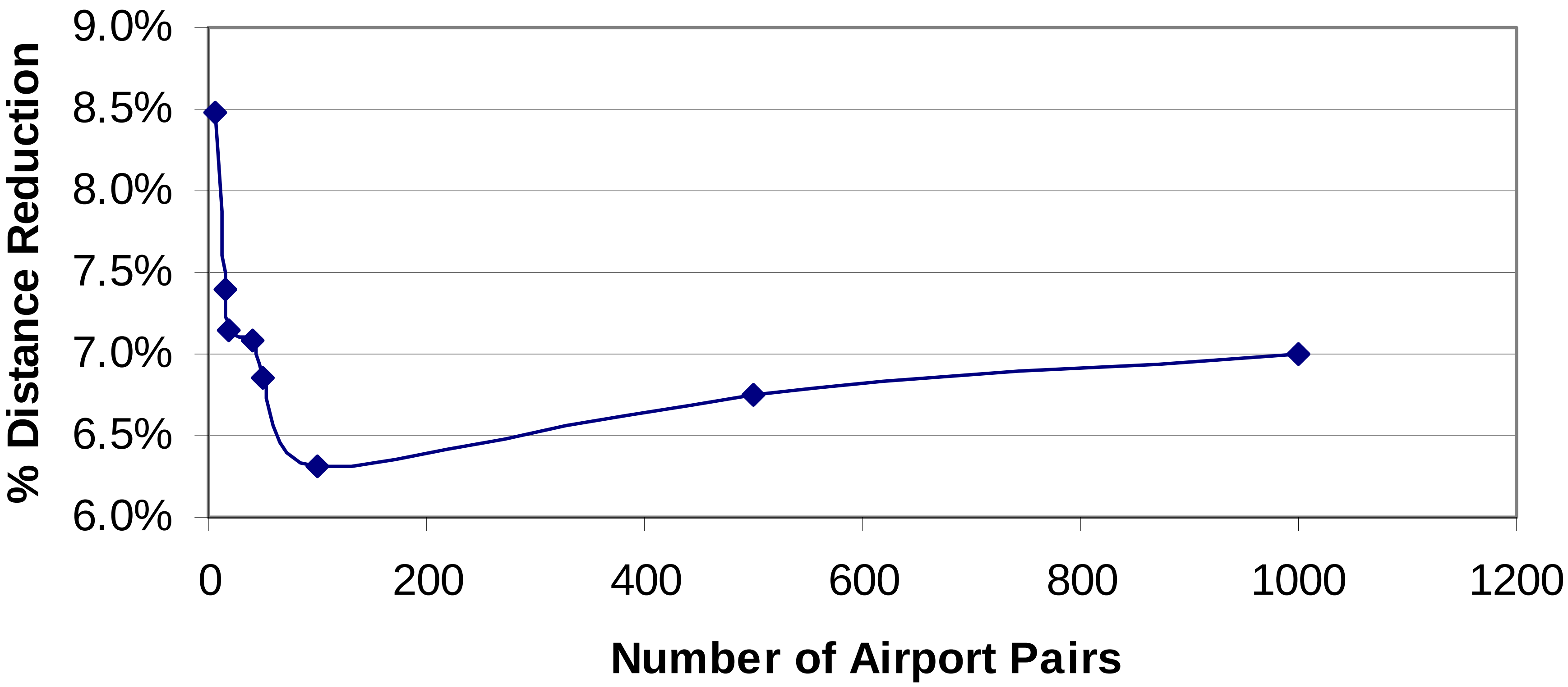
NavAid Network	n	m	C (Watts)	r
Jet Routes	1787	4444	0.1928	-0.0166
Victor Airways	2669	7635	0.2761	-0.0728

Navigation Architecture Analysis

- End Nodes: Navaids corresponding to published airports
- Geodesic (shortest path by navigational distance) computed between top 1,000 airport pairs
  - Airports ranked based on 2004 FAA traffic data
  - A-Star search algorithm implemented to find shortest distance along network
- Results – Dynamics Along Network
  - Navigational Distance Compared to Shortest Path Distance by Airport Ranking – Maximum “direct-to” efficiency
  - Betweenness centrality to be calculated for navigation nodes as measure of their utilization
    - Number of shortest-paths through nodes as a proportion to total shortest paths

Navigation Distance Results

$$\hat{d} = \sum_{i}^{n_{airports}} \sum_{j,j>i}^{n_{airports}} d_{ij} \qquad \%_{reduction} = 1 - \frac{\hat{d}}{d}$$



Transport Layer Analysis

Preliminary Analysis of the Wide-Body/Narrow Body &Regional Jet Flight Network

Wide Body Jets **Narrow Body Jets**

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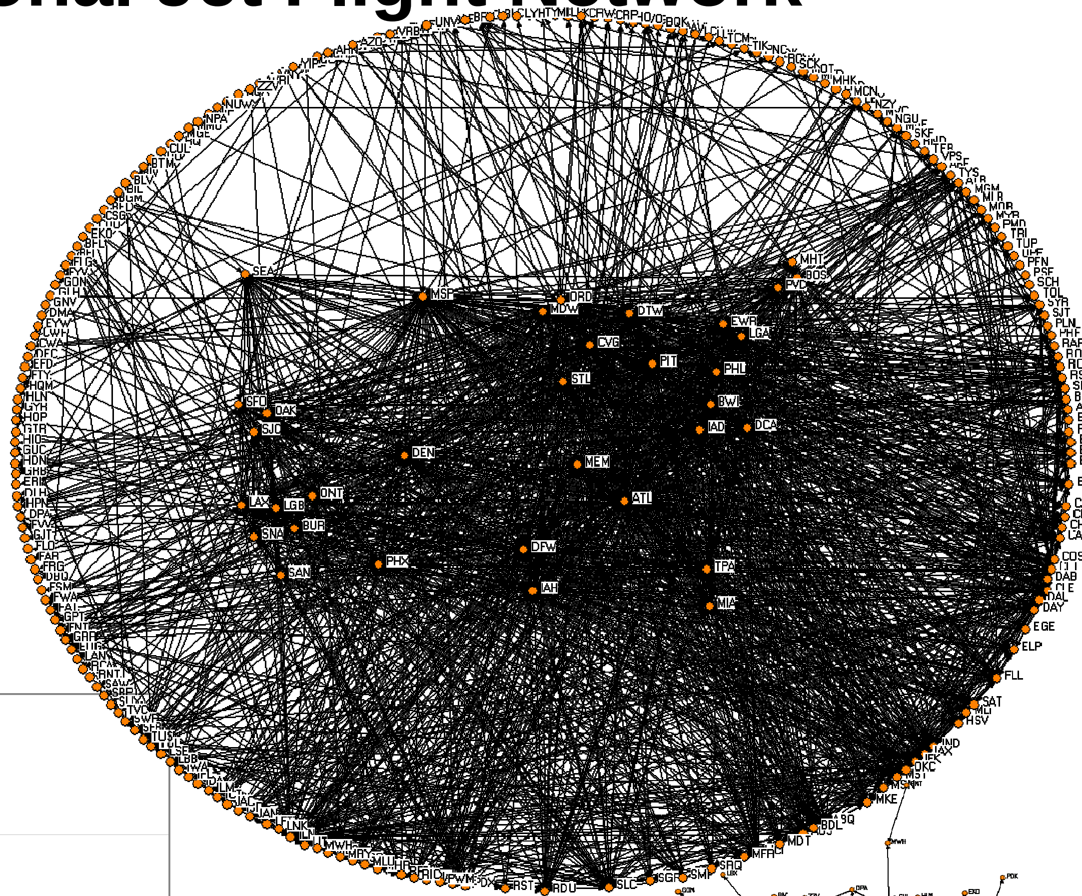
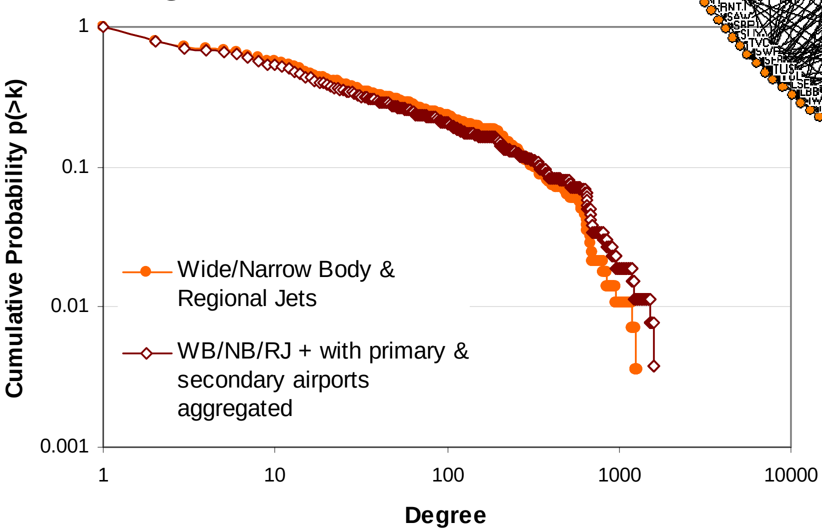
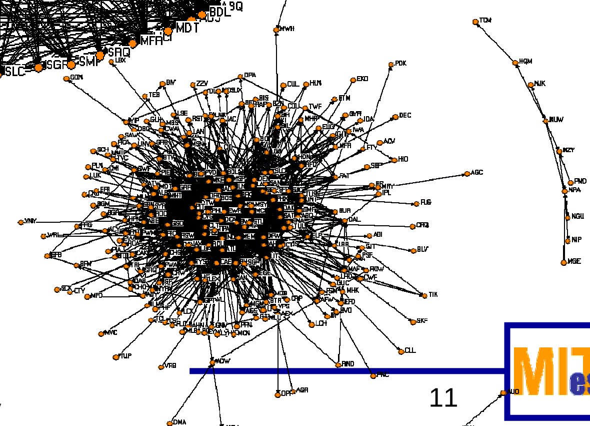
Regional Jets



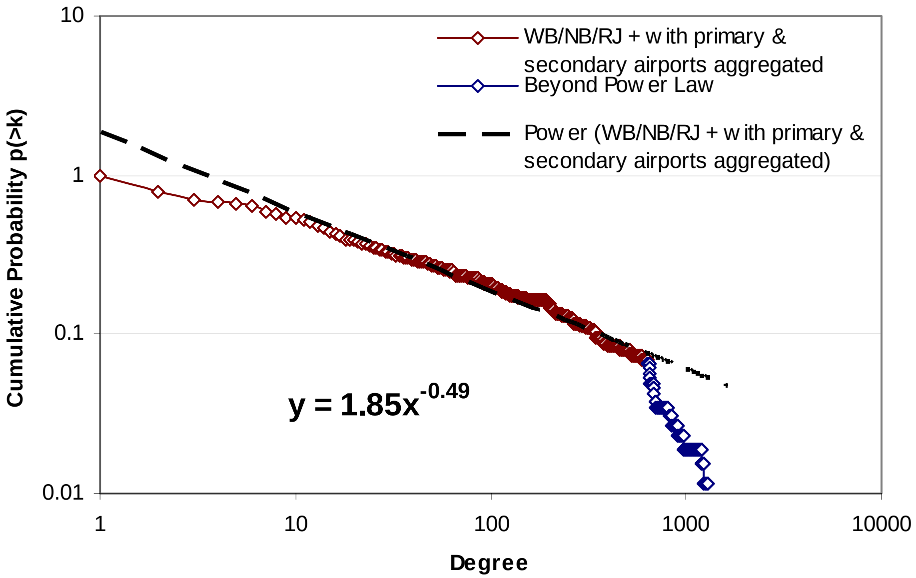
Degree Distribution





Analysis of the Wide-Body/Narrow Body & Regional Jet Route Network

Degree Distribution Analysis



Coefficient of the degree distribution power law function: $\gamma = 1.49$

Hypotheses for the exponential cut-off:

- Nodal capacity constraints
- Connectivity limitations between core and secondary airports
- Spatial constraints

Network Characteristics

Network	n	m	Density	Clustering coeff.	r	Centrality vs. connectivity
Scheduled transportation network	249	3389	0.052	0.64	-0.39	13/20 most central also part of the top 20 most connected

Preliminary Analysis of the Light Jet Route Network

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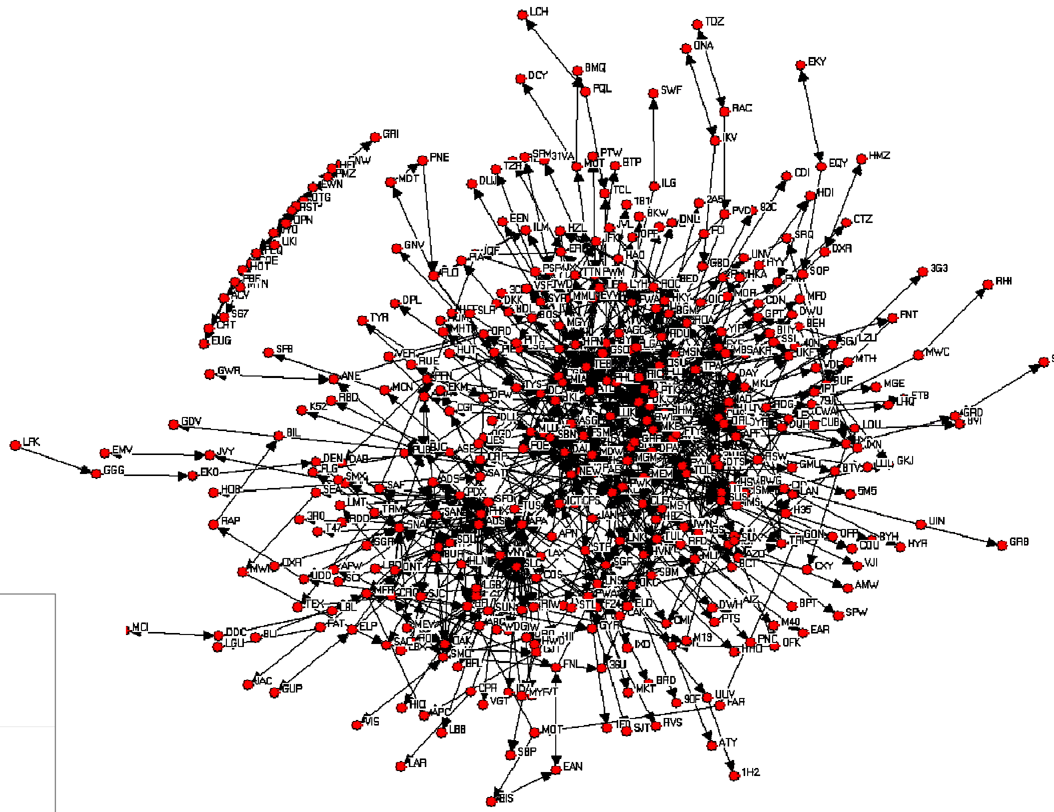
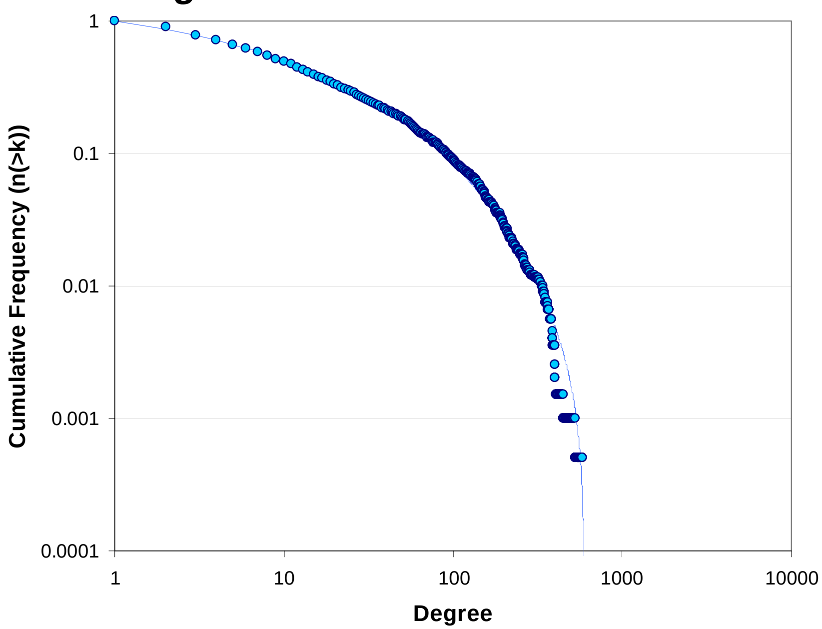
Light Jets

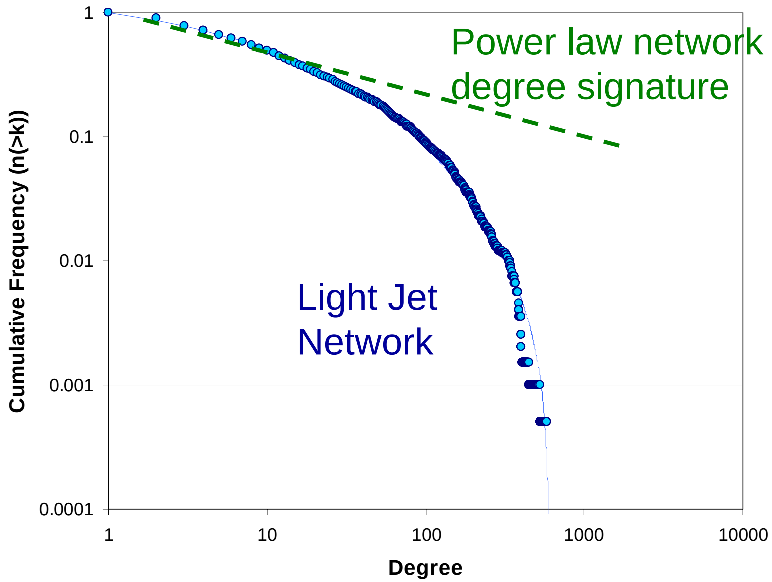


Degree Distribution



Analysis of the Light Jet Route Network

Degree Distribution Analysis



Degree distribution identified as resulting from **sub-linear preferential attachment**.

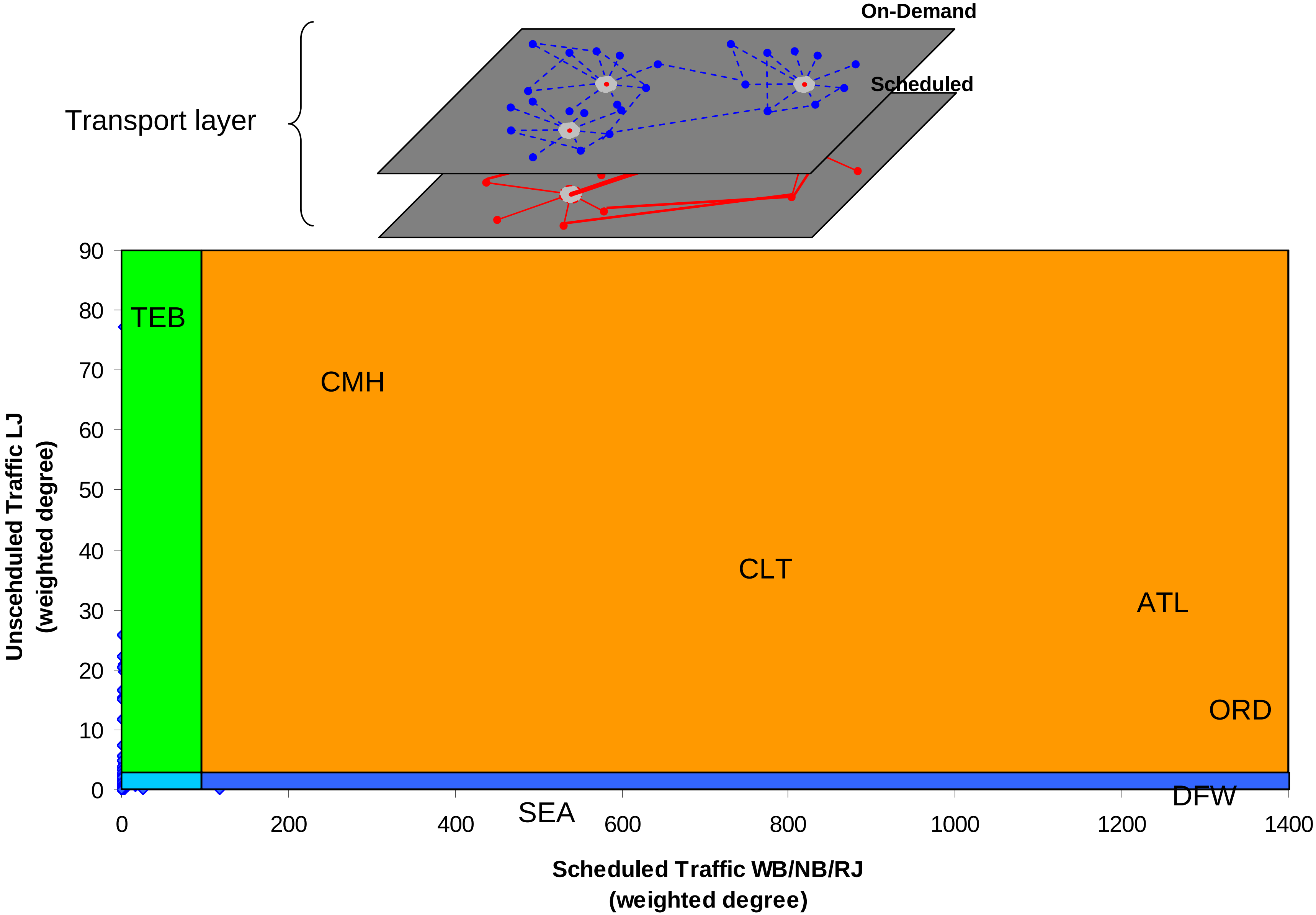
$$n_k = a.k^{-\gamma} \exp\left[-\mu\left(\frac{k^{1-\gamma} - 2^{1-\gamma}}{1-\gamma}\right)\right]$$

with: **γ = 0.57**
μ = 0.16
a = 0.13

Network Characteristics

Network	n	m	Density	Clustering coefficient	r
Light Jet Network *(Unscheduled)*	900	5384	0.005	0.12	0.0045

Interactions between Transport Layers



Demand Layer Analysis

Analysis of the Demand Layer

- **Single Layer Analysis**

  Population/Airport Gravity Model

$$b_i = \sum_{ct \in C_i} p_{ct} \quad s.t. \quad C_i = \left\{ ct \;\middle|\; d_{ct,i} = \min_j d_{ct,j} \right\}$$

based on 66,000 Census Track data

Notations:

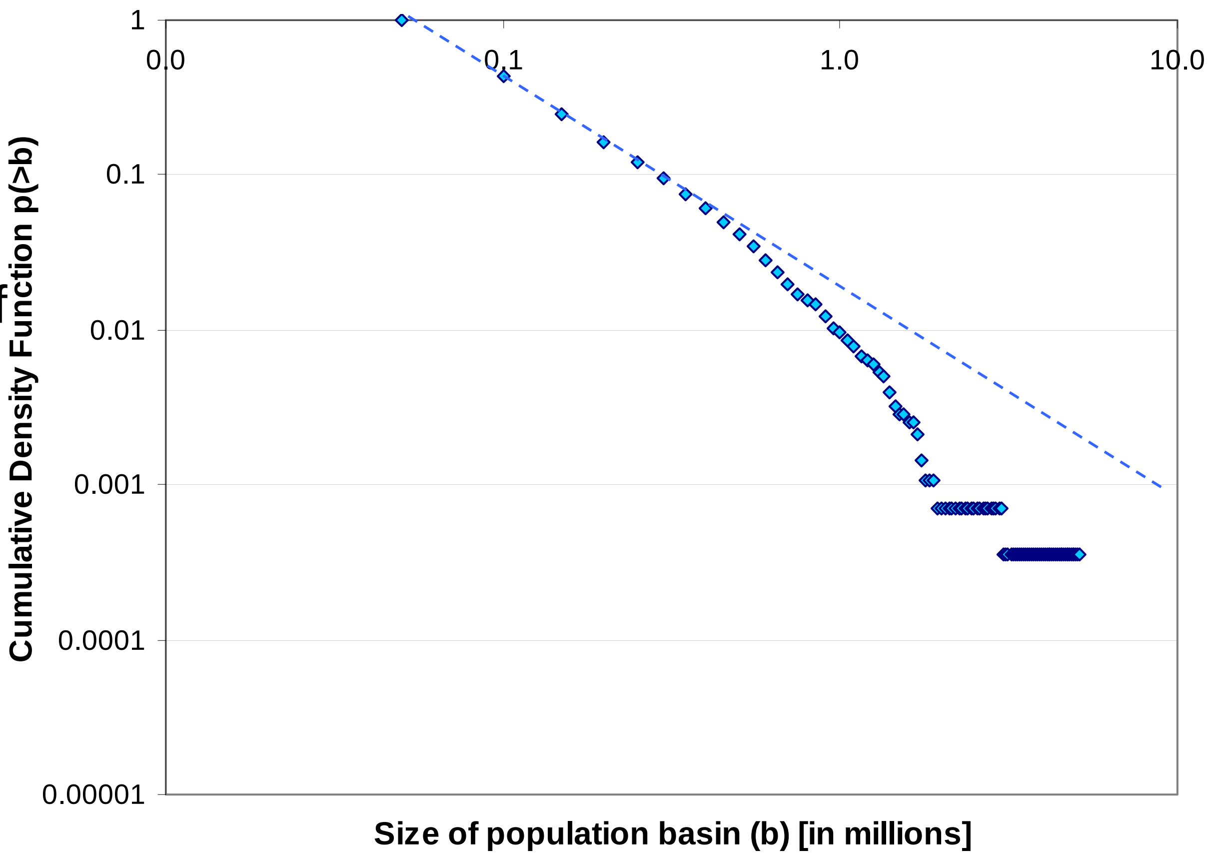
P_{ct}: population of census track ct

b_i: size of population basin around airport i

ct: census track

$d_{i,j}$: Euclidean distance

- Non scale free nature of distribution of population around airports



Questions & Comments

Thank you