MIT International Center for Air Transportation

Investigation of the Scalability of Air Transportation Networks

Philippe Bonnefoy
bonnefoy@mit.edu

R. John Hansman
rjhans@mit.edu

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Motivation & Approach

- **Scalability: the ability of a system, a network or a process to change its scale in order to meet growing volumes of demand**

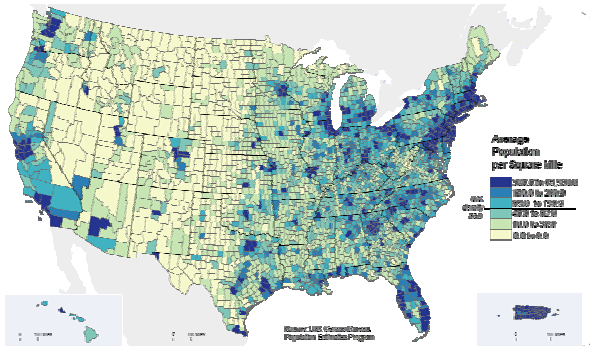
- **Relevance to the air transportation system**
  - Growing demand for air transportation
    - *FAA forecast growth rate: 2005-2017 forecast (enplanements air carrier: +3.1% per year, regional carriers: +4.3%, general aviation turbojet operations: +6.0%)*
  - Key constraints of the current air transportation system
    - *Infrastructure (i.e. airport & airspace capacity)*
  - Challenges and implications of not meeting demand
    - *Generation and propagation of delays throughout the system*
    - *Economic impacts (time loss for travelers, operational inefficiencies for airlines, environmental cost through excess fuel burn)*

- **Need to investigate ways to augment the scale of the air transportation system in order to meet future demand**

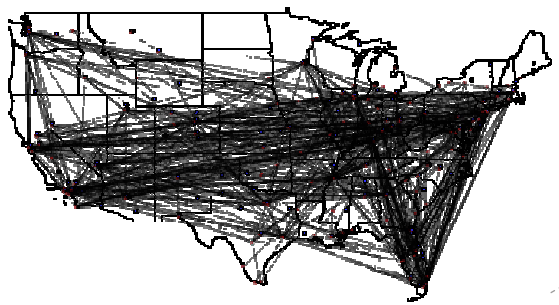
- **Approach**
  - Analysis of air transportation network topology and evolution
    - *Data: Enhanced Traffic Management System (ETMS) and TAF traffic data from October 1st 2004 to September 30th 2005 (20.5 million flights analyzed) & traffic from 1976 to 2005*
  - Application of scalable (scale free) network theory
  - Case study approach (23 case studies of regional airport systems)
  - Development of network evolutionary dynamic models

Introduction:
Network and System Dynamics Representation of the Air Transportation System

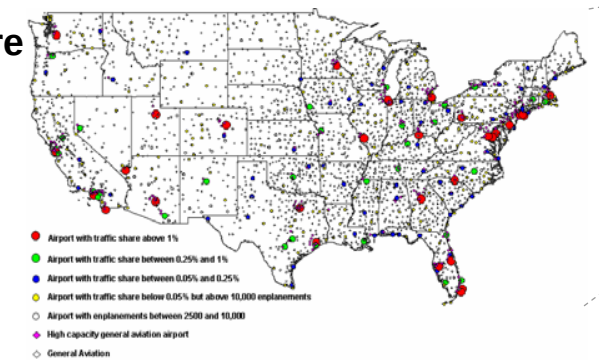
Demand
(Latent demand)



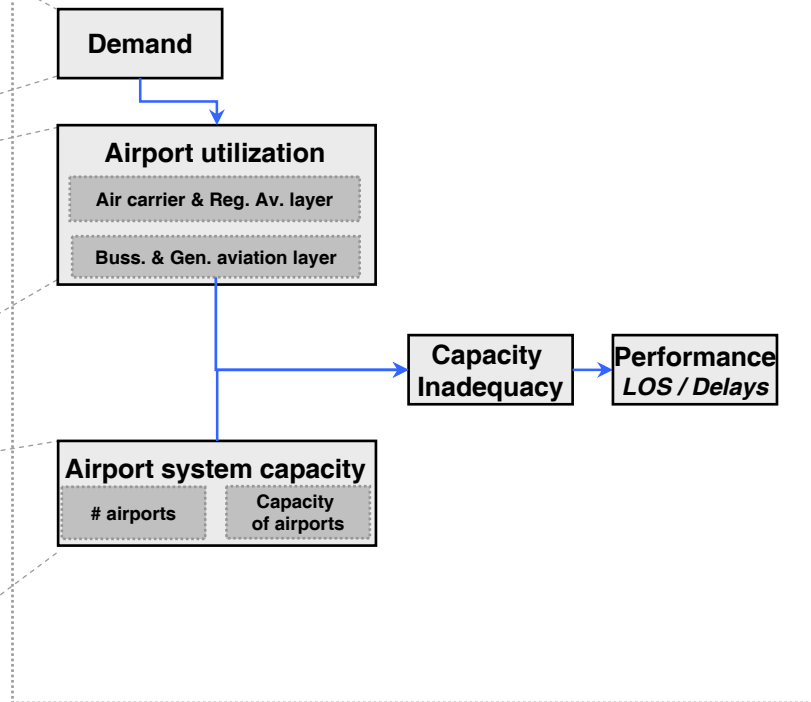
Transport Network



Infrastructure
(airport nodes)

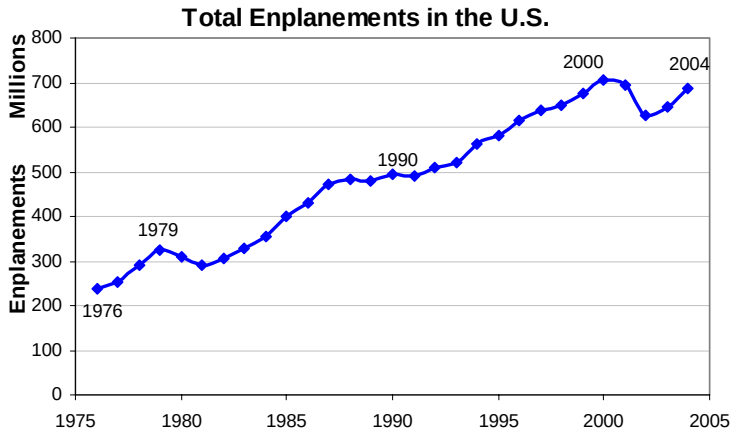


High Level System Dynamics Model



Evolution of Demand for Air Transportation

- **Historical and projected growth of demand (enplanements) for air transportation**



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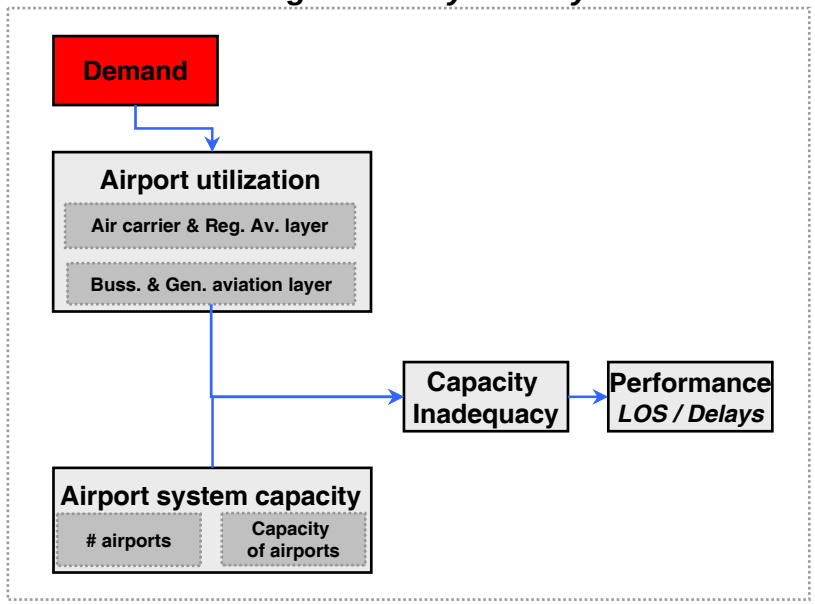


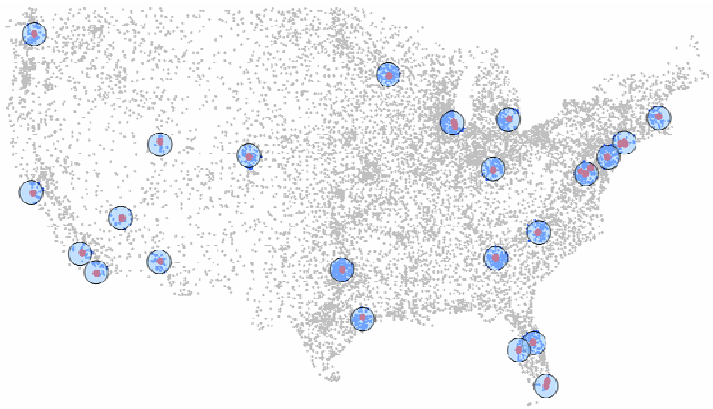
- **Greater number of operations are expected in the NAS in the upcoming years**

- **Factors amplifying the problem**
  - Decreasing size of aircraft: Influence of Regional Jets
  - Entry of small aircraft in the NAS in the upcoming years: VLJs, UAVs

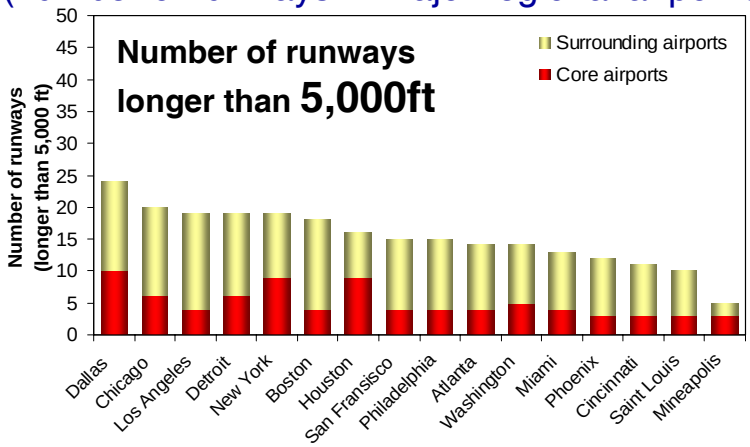
*** Graph represents realized demand**

Capacity the National Airport System

- **Capacity of the National Airport System**
  - Airports in the United States in 2006
    Total:19,847 airports
    5,261 public airports



  - Capacity also exist in high density metropolitan areas (number of runways in major regional airport systems)



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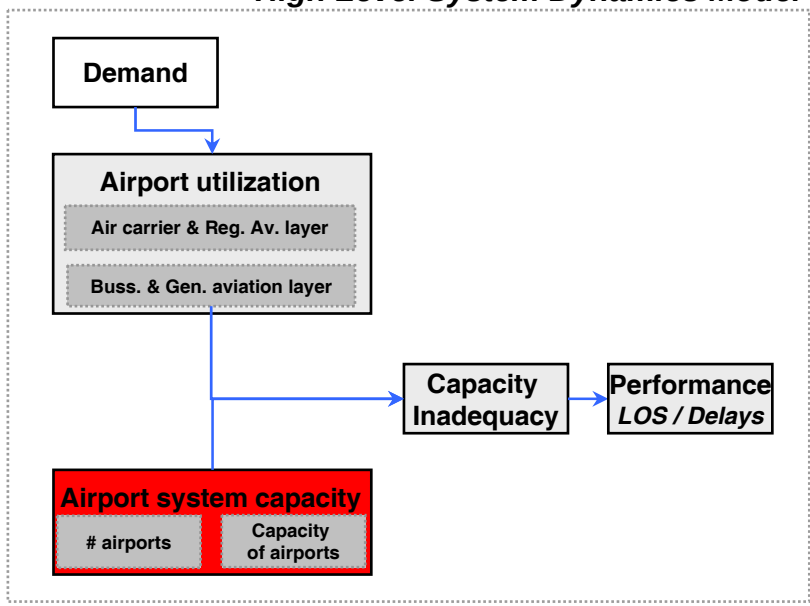
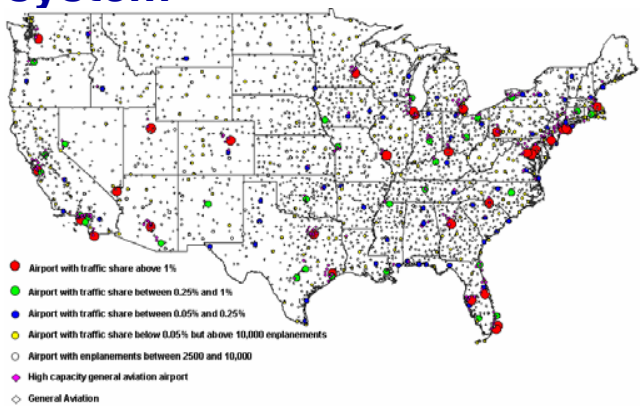
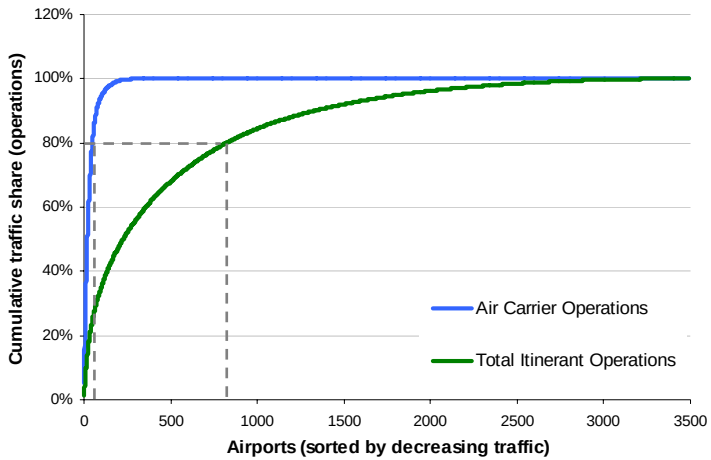


Airport Utilization in the United States

- **Concentration of traffic at key airports in the system**



  - 80% of the air carrier operations are handled at top 50 airports (4% of usable airports)
  - 80% of the total itinerant operations are handled at 820 airports (8% of usable airports)



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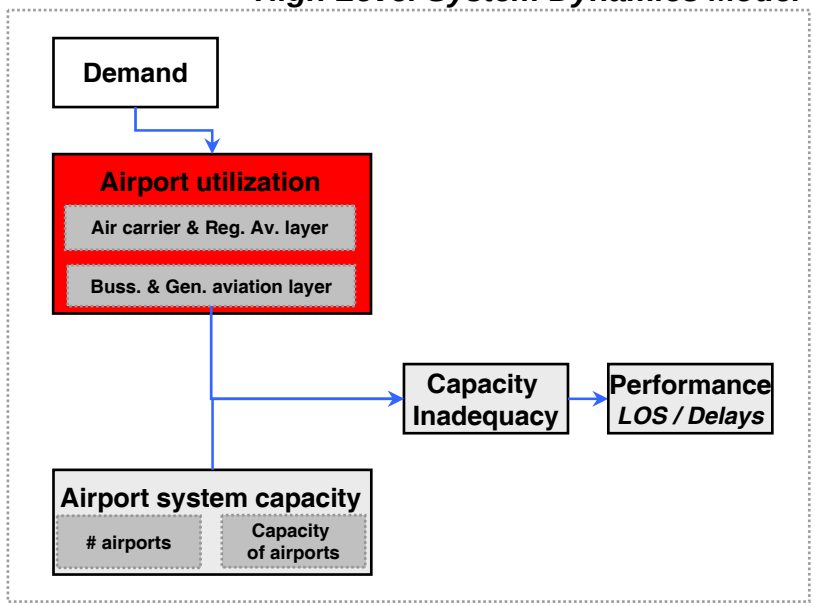
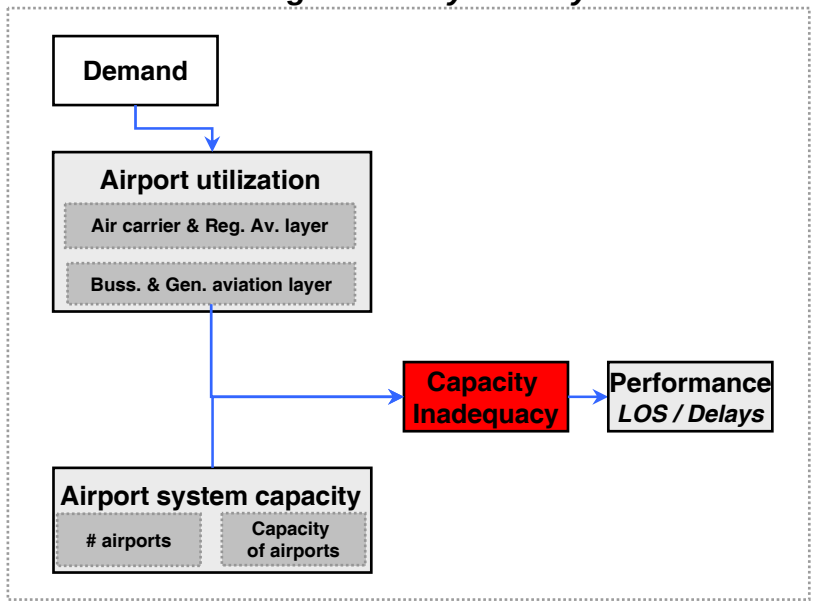
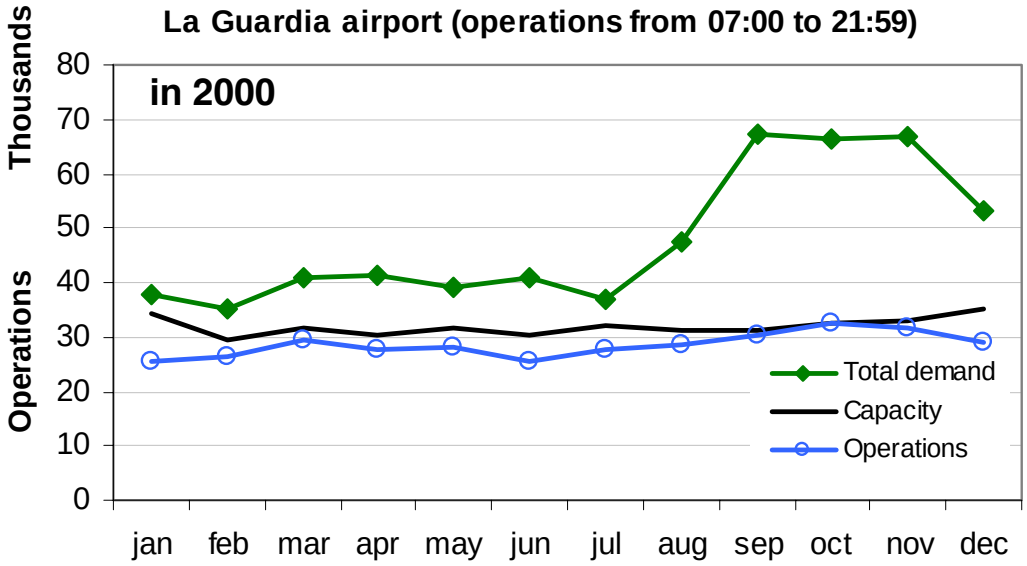


Inadequacy of Capacity at Key Points in the System

- **Demand-Supply Mismatch at key points in the system**
  - e.g. La Guardia (LGA) in 2000
    demand exceeded capacity by a factor of 2
  - e.g. Chicago O'Hare (ORD) in 2003
- **Demand growth is adding pressure on key airports**

High Level System Dynamics Model

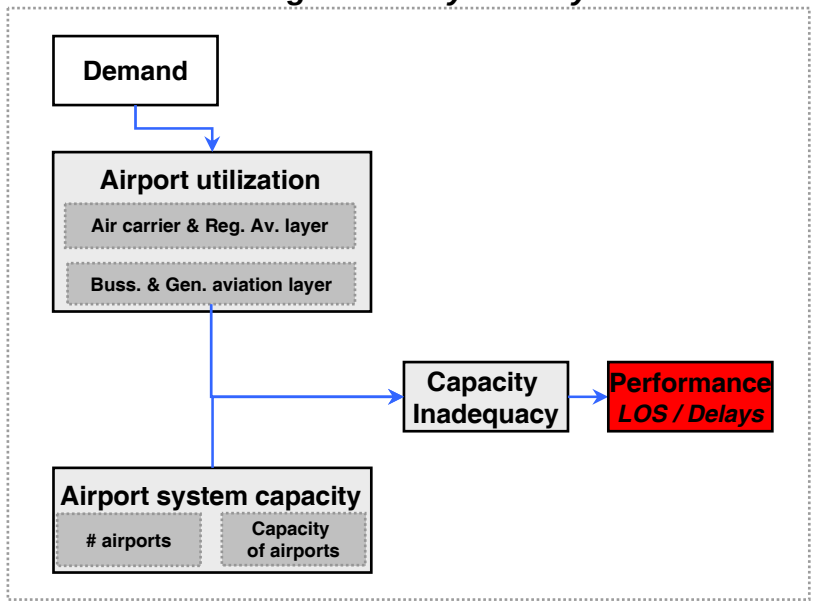


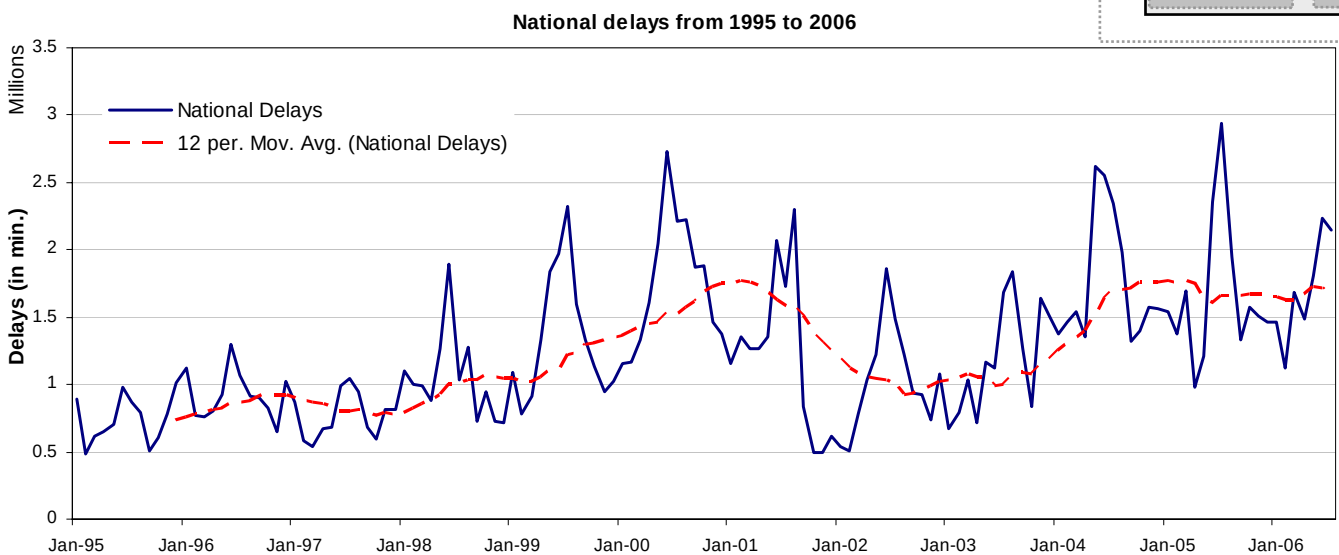


Delays as an Indicator of Airport Capacity Inadequacy

- **Implications of capacity inadequacy**
  - Generation of delays at key points in the system
    - *Peak of delays in 2000 due to the general growth of demand and the La Guardia problem that propagated throughout the system*
    - *Delays are back to 2000 levels and are stabilized*
  - Propagation of delays throughout the network

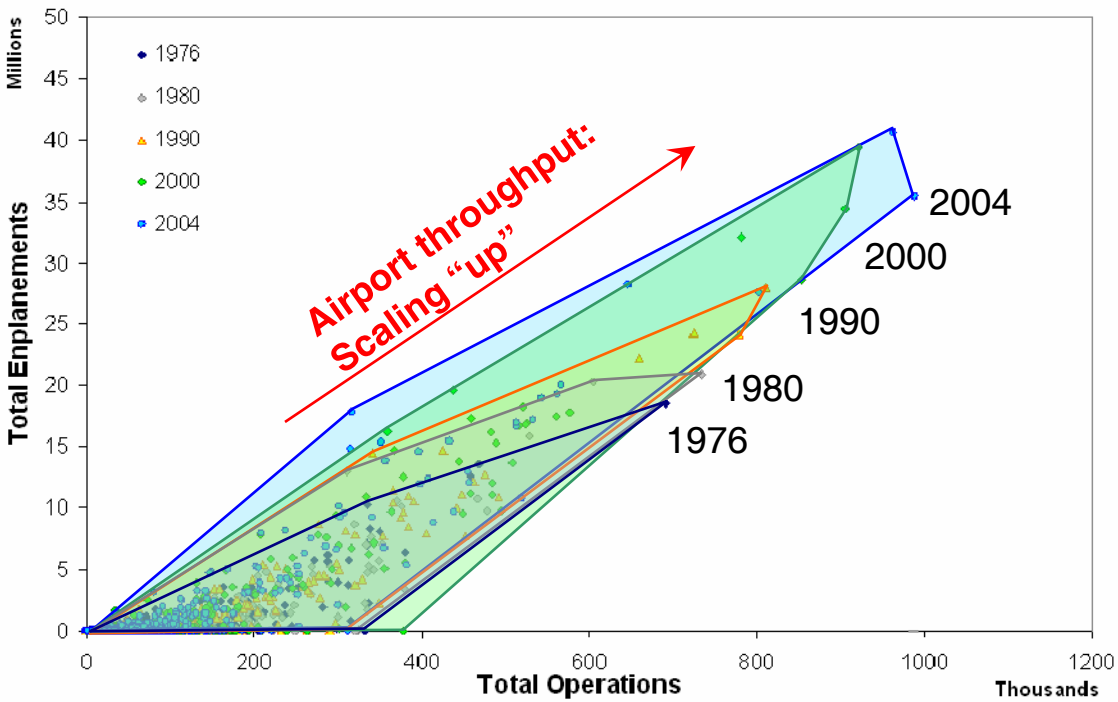
High Level System Dynamics Model





Scaling "Up" the Network: Adjustment of Capacity of Airports

- Evolution of throughput of airport (nodes) in the air transportation network between 1976 and 2004



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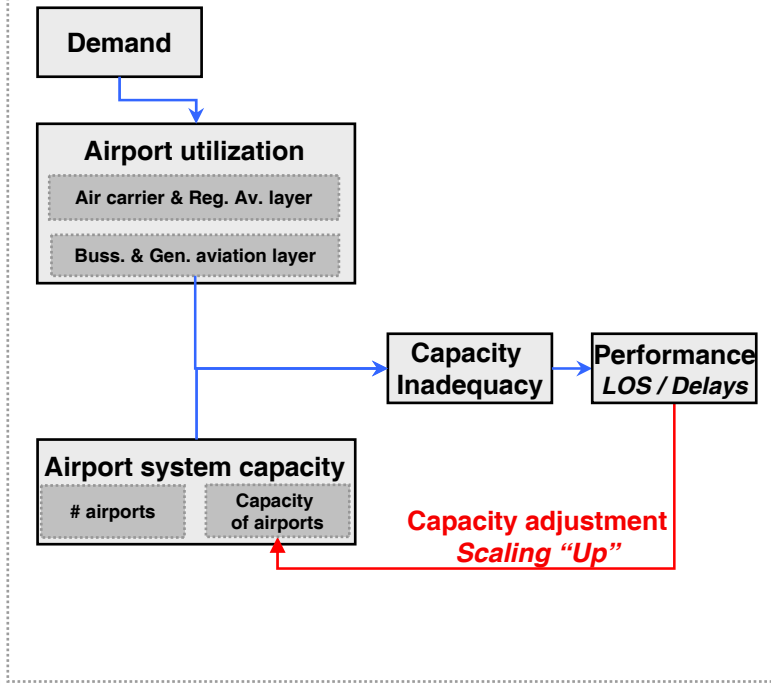
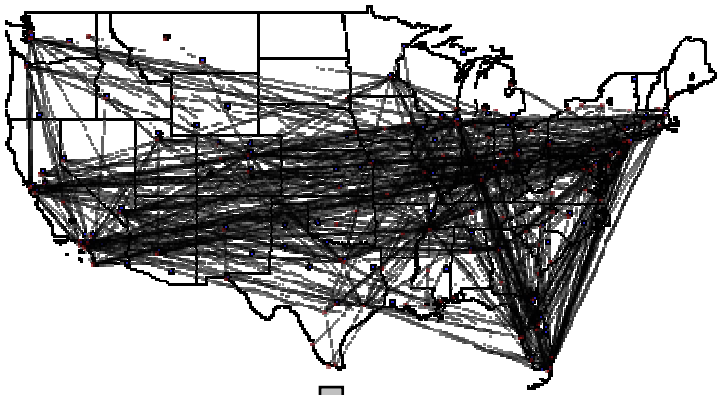


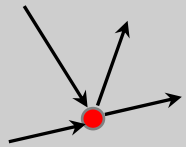
Scale Free (i.e. Scalable) Networks

Definition & Properties



Notations and basic network characterization concepts:

k: degree of a node = number of connections to other nodes

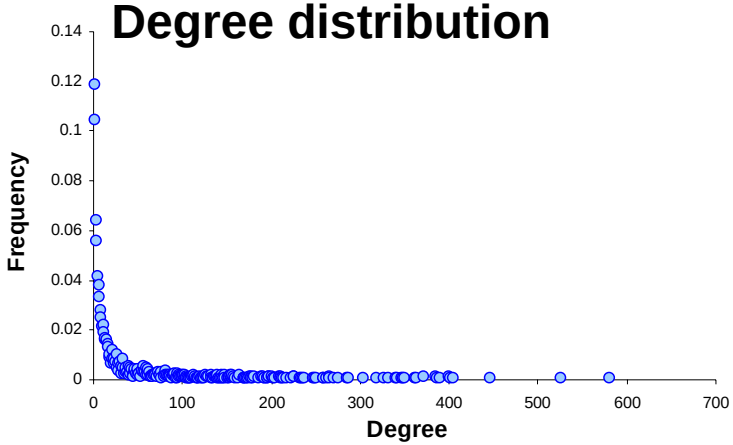


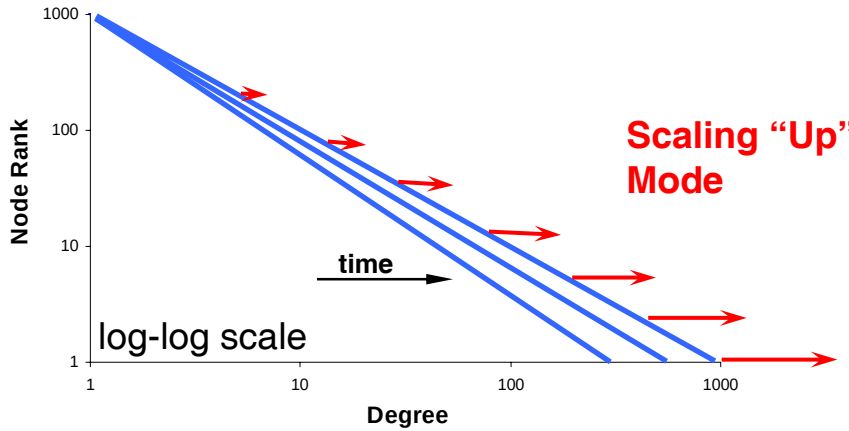
e.g. $k_{in} = 2$

$k_{out} = 2$

$k = 4$

Degree distribution





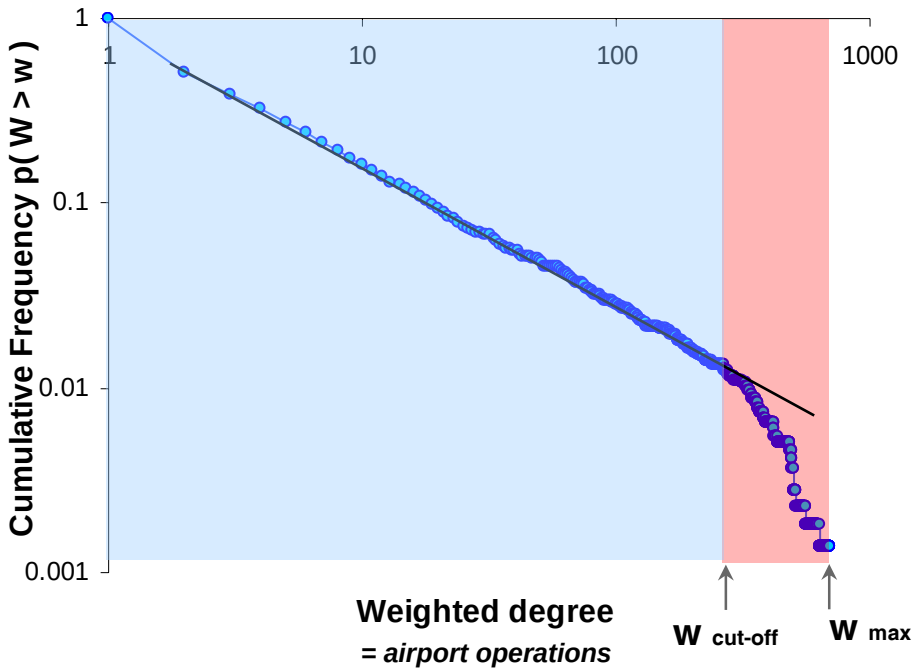
⇨ **Scale free networks exhibit power law degree distributions**

⇨ **i.e. A network with a power law degree distribution is represented by an affine function on a log–log scale graph**

⇨ **Scale free networks have the ability to change scale in order to meet any level of demand**

Flight Weighted Degree Distribution of the Air Transportation Network

- The air transportation network exhibits a partial power law distribution (scalable network)
- The cut-off is explained by nodal capacity constraints that limit the ability of the network to scale up



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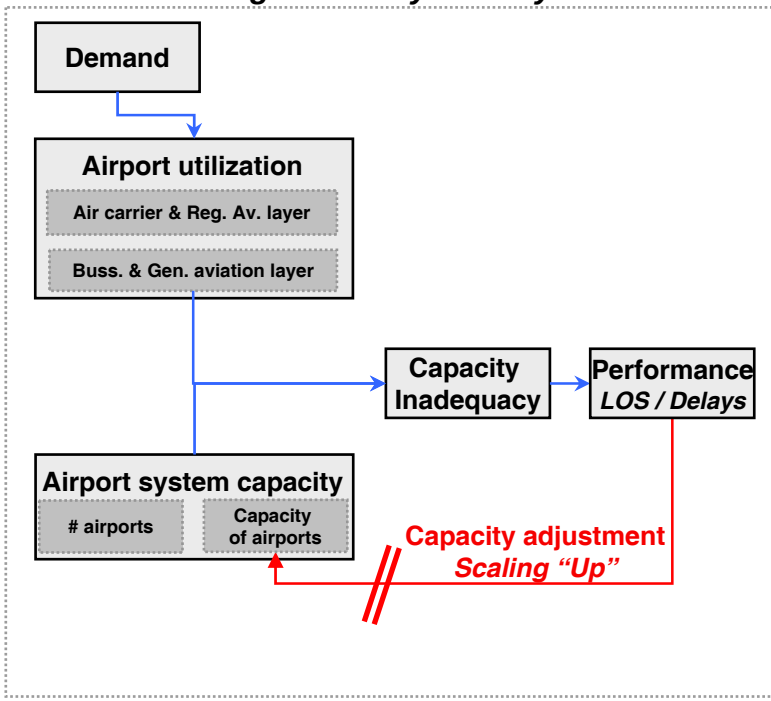
Delay/Impossibility of Adjusting the Capacity of Key Nodes in the Network

Airport code	Airport name	Percentage of operations delayed	OEP new runway project (date completion/ capacity benefit)
EWR	Newark	8.8%	
ATL	Atlanta	6.8%	2006 / + 33%
LGA	LaGuardia	6.7%	
ORD	Chicago	5.8%	?
PHL	Philadelphia	5.0%	2008 / ?
JFK	Kennedy	4.0%	
BOS	Boston	2.8%	2006 / ?
SFO	San Francisco	2.6%	
PHX	Phoenix	2.4%	
IAH	Houston	2.0%	
IAD	Dulles	1.9%	2008 / +12%
LAS	Las Vegas	1.5%	
CLT	Charlotte	0.9%	
DTW	Detroit	0.8%	
MSP	Minn./St. Paul	0.7%	
DCA	Reagan National	0.6%	
DFW	Dallas/Ft.Worth	0.6%	
CVG	Cincinnati	0.6%	
MIA	Miami	0.4%	
SAN	San Diego	0.4%	
BWI	Balt.-Wash. Intl	0.4%	
MEM	Memphis	0.3%	
SEA	Seattle	0.3%	2008 / + 46%
DEN	Denver	0.3%	
LAX	Los Angeles	0.3%	2008 / Not Avail.
MCO	Orlando	0.3%	
SLC	Salt Lake City	0.2%	
TPA	Tampa	0.2%	
STL	St. Louis	0.1%	2006 / + 48%
PIT	Pittsburgh	0.1%	

High Level System Dynamics Model

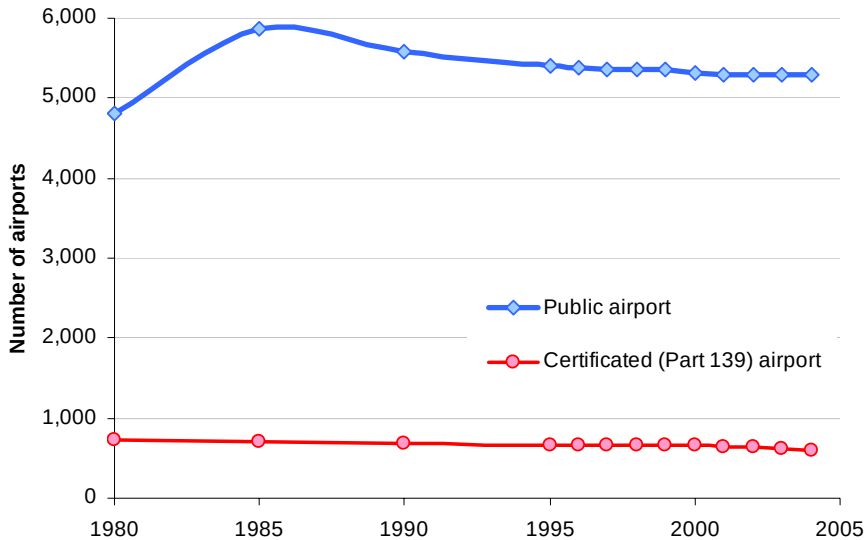


- **Factors limiting airport capacity adjustment:**
  - Constrained airport layout (limited ability to expand the footprint of the airport)
  - Layout of existing runways (legacy system)
  - Environmental constraints

Data source: [Delay data: FAA Operational Network, OPSNET], [Capacity improvement: FAA Operational Evolution Plan OEP] in 2005.

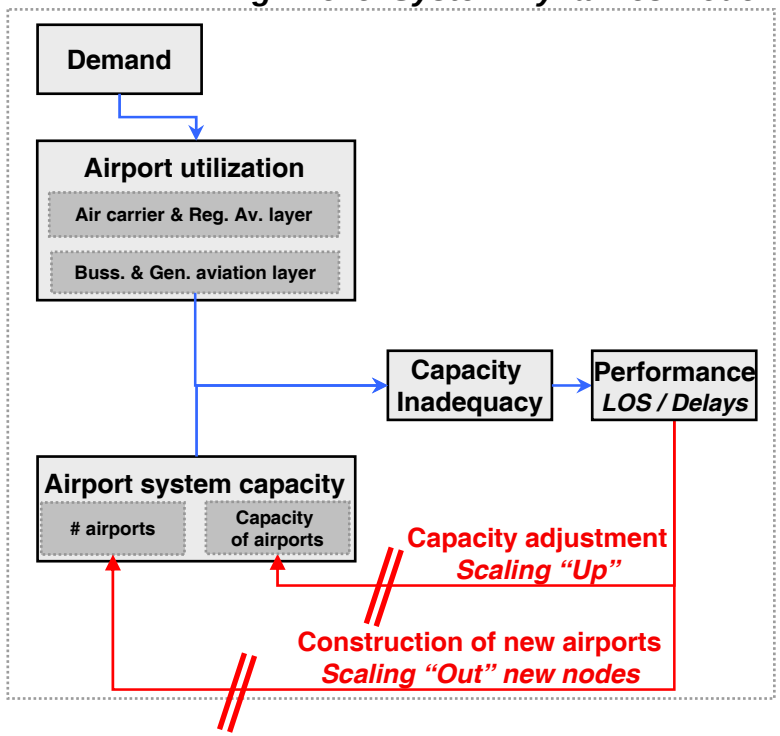
Scaling "Out" to new nodes: Construction of new airports

- **Limited ability to add new airports:**
  - Last major airport opening: DEN 1995
- **Evolution of the number of public airports in the United States from 1980 to 2005**
- **Average loss of airport from 1985 to 2004: 30 airports per year**



- **Factors influencing the inability to add new airport and close existing airports:**
  - Land availability (in areas of high demand for air transportation & high density of population)
  - Environmental constraints
  - Pressure from real estate development

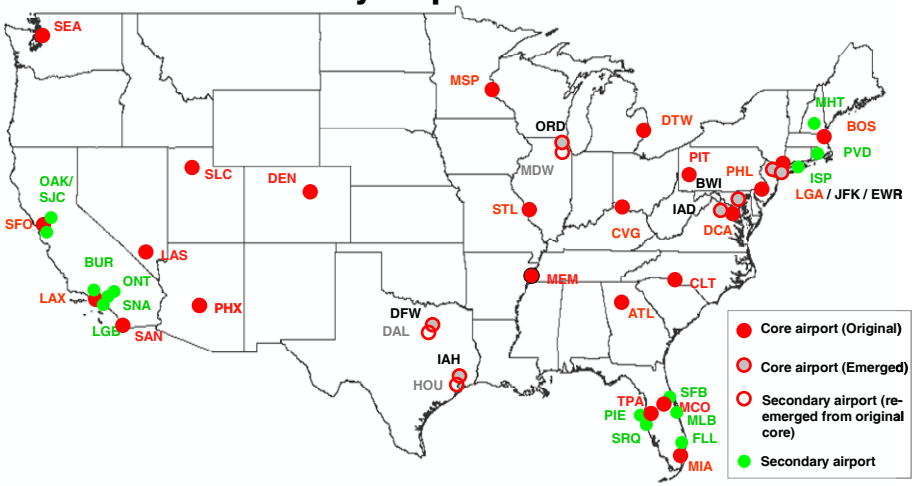
High Level System Dynamics Model



Scaling "Out" to Existing Nodes: Utilization of Existing Nodes in the Network

- **Scaling "out" to existing underutilized airports**
- **Emergence of secondary airports**
- **Average age of existing secondary airports (from opening): 73 years**
- **Future of secondary airports**
  - Use of secondary airports has been one of the key mechanisms by which demand was met in congested metropolitan areas
  - Strengthening role in the future
  - Key to the national plans for meeting future demand (e.g. NGATS Plan)

Core and secondary airports in the U.S.



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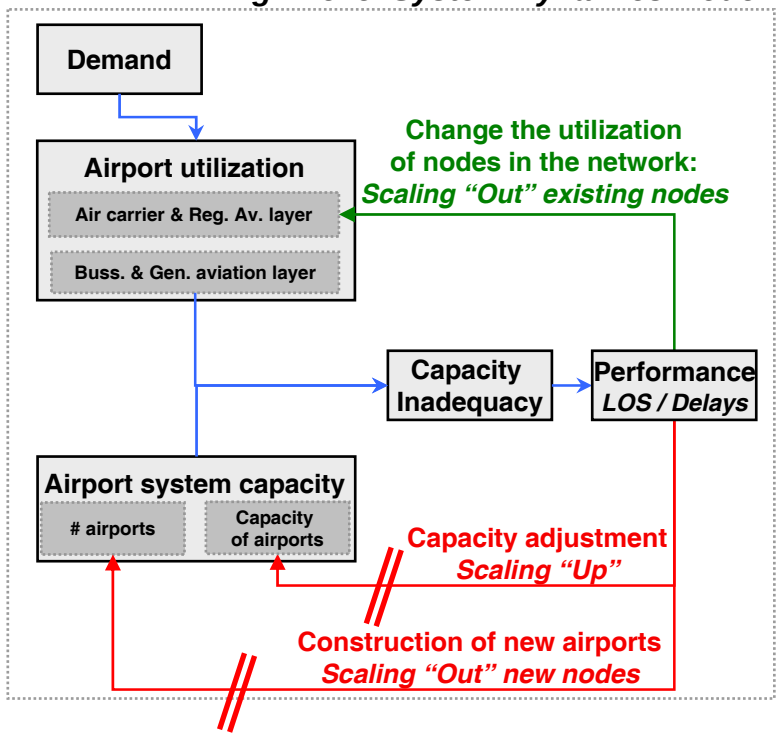
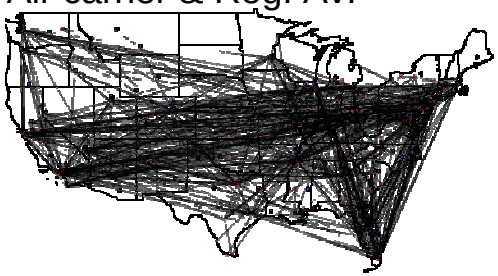


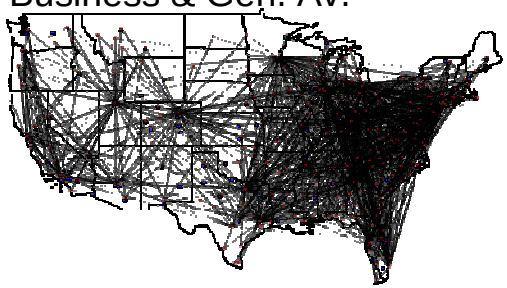
Scaling "Out" through Mode Shift: Utilization of small aircraft & small airports

- **Utilization of existing small airports (airports with 3000ft+ runways)**
- **Emergence of new services (i.e. on-demand air taxi) enabled by a "technology push" and a system "performance pull"**

Air carrier & Reg. Av.

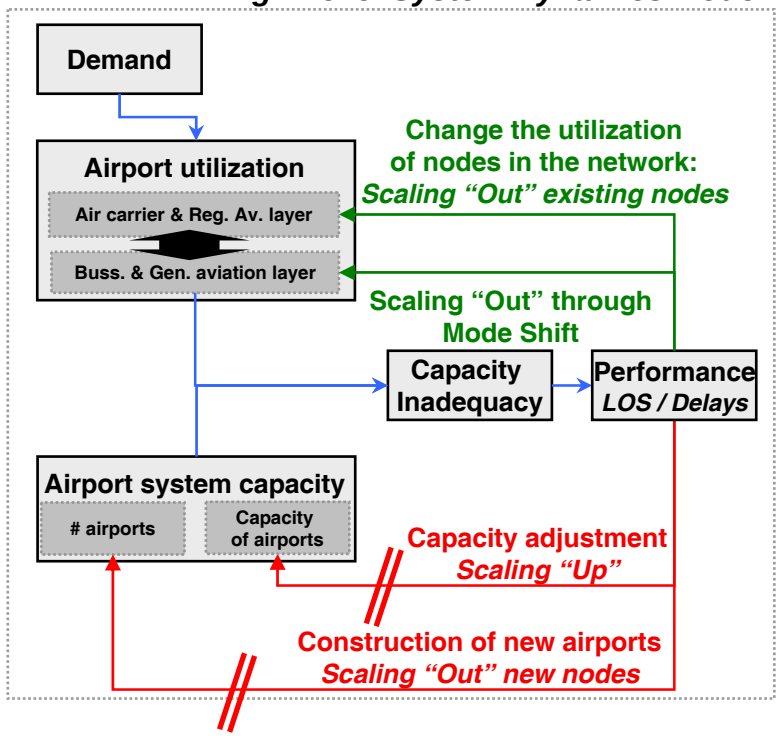


Business & Gen. Av.



Very Light Jets

High Level System Dynamics Model



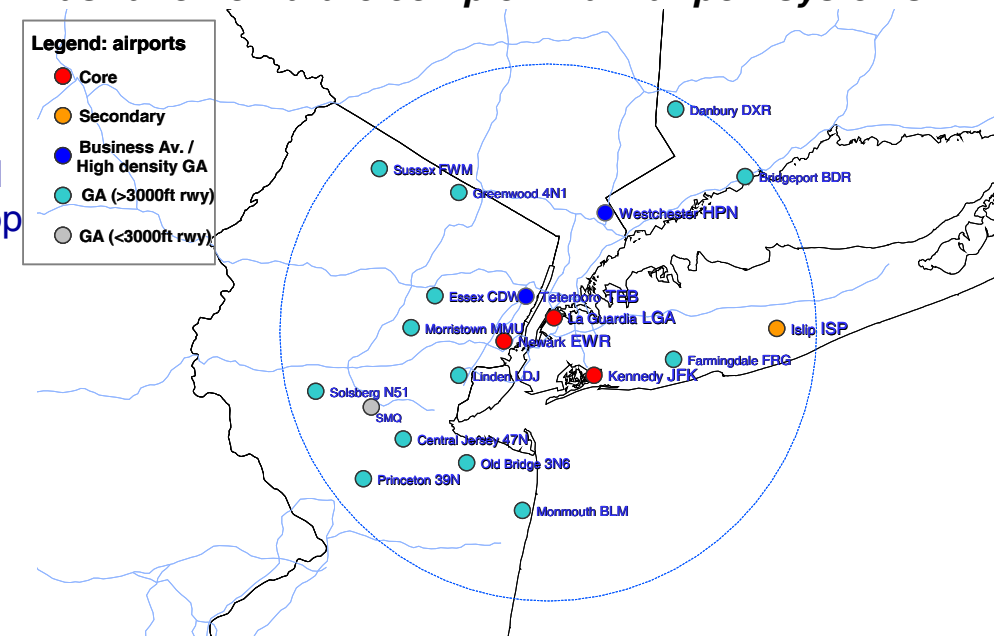
Implications for Air Traffic Control

- **Scaling "out" to new or existing nodes and trough mode shift impact terminal areas**
  - Concentration of traffic of light jet traffic as an indication of future concentration of traffic by VLJs
  - ETMS data analysis:
    64% of the flights performed by Light Jets had either their departure or arrival in one of the top 23 regional airport systems

- **Implications for ATC:**
  - Larger number of airports with significant volume of operations in the regional airport system
  - Emergence of interactions between airports (e.g. New York airport system: interactions between arrival and departure streams between LGA, TEB, EWR, JFK)

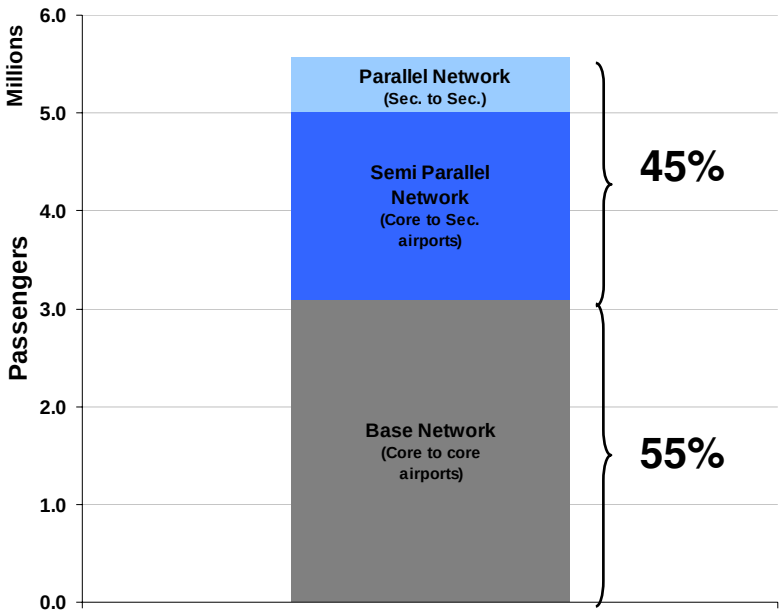
New York regional airport system

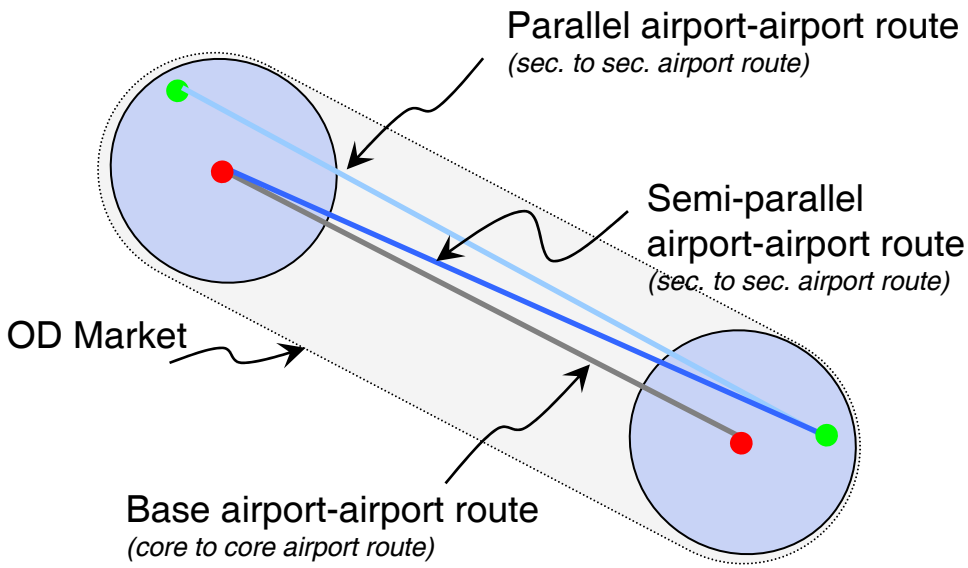
Illustration of future complex multi airport systems



Implications for Airlines: Emergence of Parallel Networks/Markets

- **Analysis**
  - 10 multi-airport regional airport systems
  - 30 airports
  - 445 airport-airport routes
    (out of a maximum of 870 feasible airport-airport routes)
- **Data**
  - Bureau of Transportation Statistics DB1 database segment data (March 2005)



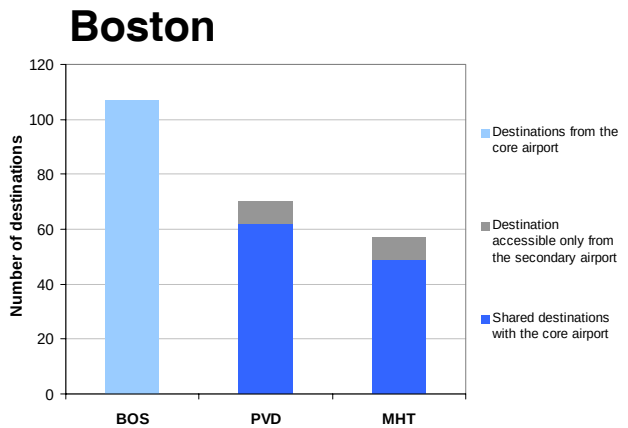


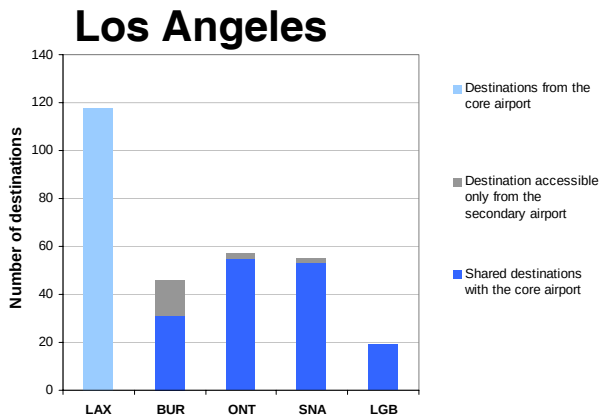
Legend
- Core airport
- Secondary airport

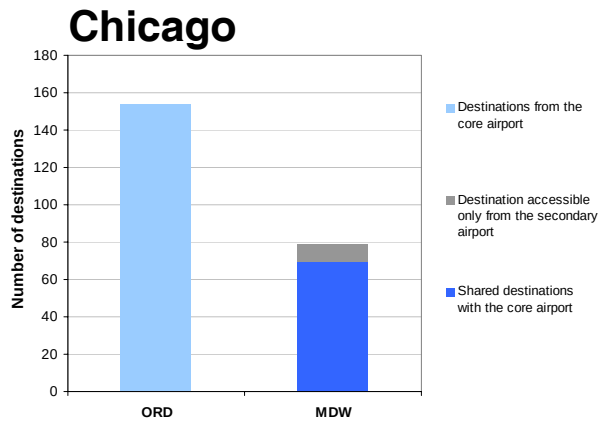
Reachable Destinations from Core and Secondary Airports

- **On average (for 10 regional airport systems), 38% of destinations reachable from the core airport are also reachable from secondary airports.**

- **Illustration with three regional airport systems:**







- **Implications of parallel networks for airlines:**
  - Competition between carriers operating airport-to-airport routes within the same OD market
  - Cost implications:
    - *Infrastructure cost (generally higher at core airports than secondary airports)*
    - *Higher reliability of operations at secondary airports due to lower average delays than at core airports*
    - *Dilution of operations for air carriers when operating at core and secondary airports simultaneously.*

Conclusions

- **Scaling modes of air transportation networks:**
  - Scaling “up” an existing network by adding resources
  - Scaling “out” to new nodes: construction of new airports
  - Scaling “out” to existing nodes: emergence of secondary airports
  - Scaling “out” through mode shift: emergence of air transportation services utilizing small airports and small aircraft
- **Limited potential of adding capacity at major airports and building new airports**
- **Increase the attractiveness of existing underutilized airports**
  - Existing secondary airports will gain more traffic
  - New secondary airports are going to emerge
  - General aviation & business aviation reliever airports will also become key to accommodating future demand growth
- **Implications**
  - Air traffic control: larger number of airports with significant volume of traffic and coupled operations
  - Airlines: emergence of parallel airport-airport routes within OD markets

Questions
&
Comments