MIT International Center for Air Transportation

Scalability of Air Transportation Networks through the Development of Multi-Airport Systems: A Worldwide Perspective

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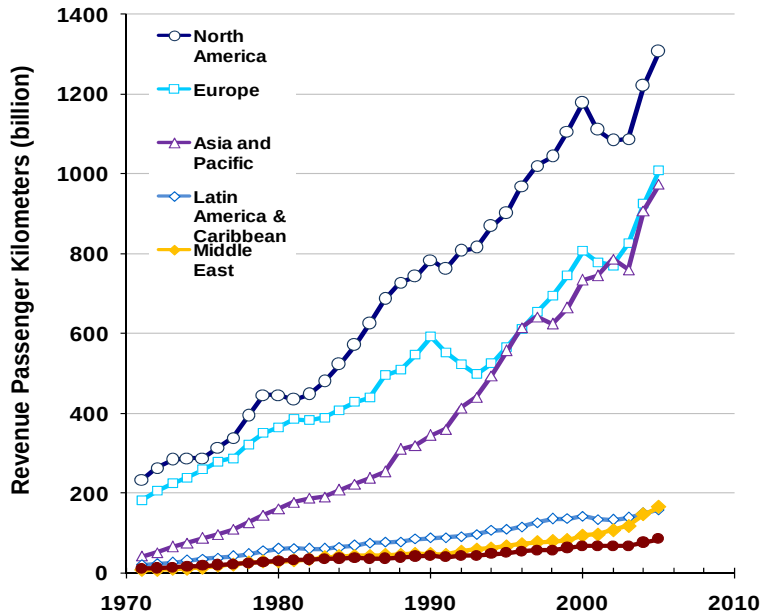
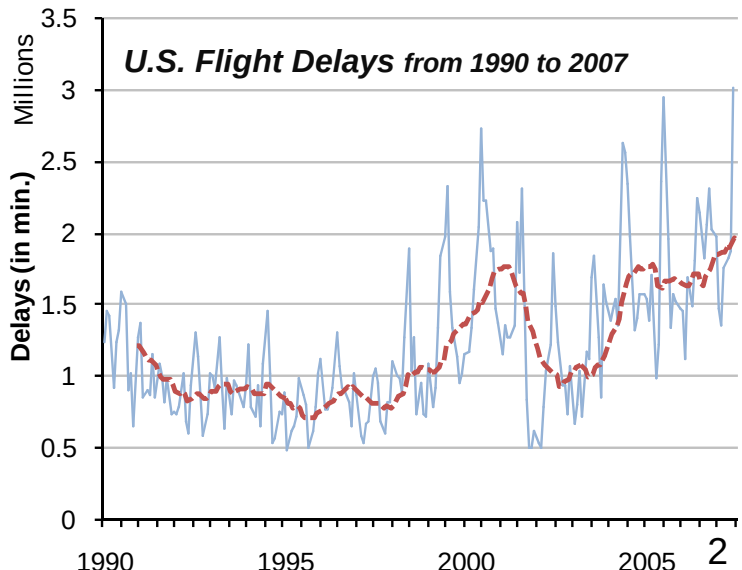
Air Transportation System Demand/Capacity Inadequacy Problem

- **Growth of 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%)
  - Factors adding pressure to the system:
    Entry of Very Light Jets and Unmanned Aerial Vehicles
- **Key infrastructure constraints in the air transportation system**
- **Demand/capacity inadequacy problem:**
  - leading to the generation and propagation of delays throughout the system
    Record of 22.1 million minutes of flight delays in 2006
- **Implications:**
  - Degradation of the quality of air service
  - Economic impacts
- **Need:**
  - Understand how the air transportation system evolved to meet demand in the past and how it will to so in the future



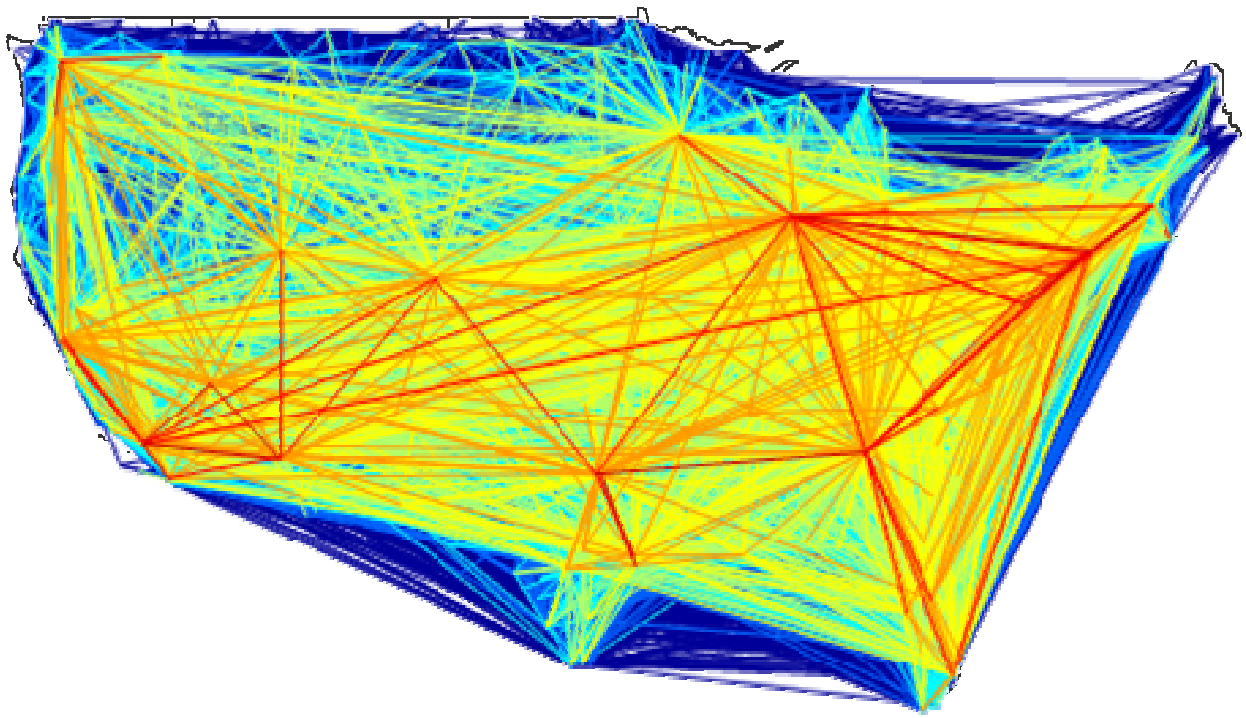


** Data source: ICAO traffic data & FAA OPSNET data*

Analysis of the U.S. Air Transportation Network

- **Air transportation system is fundamentally a network system**
- **Described and represented using network abstractions**
- **Use of tools from network theory**
  - Recent theories of scale free and scalable networks

U.S. Air Transportation Network in 2005



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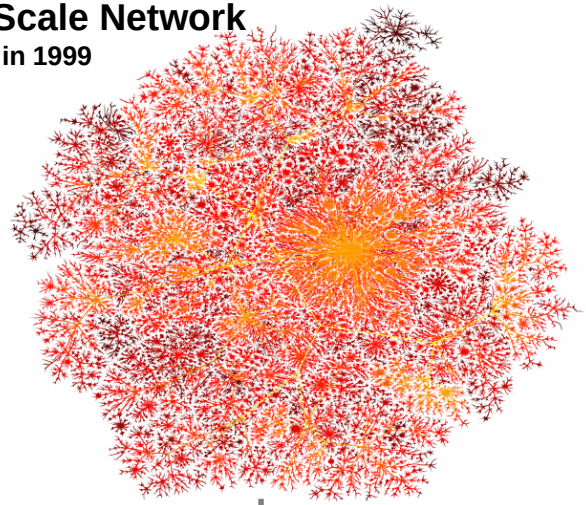
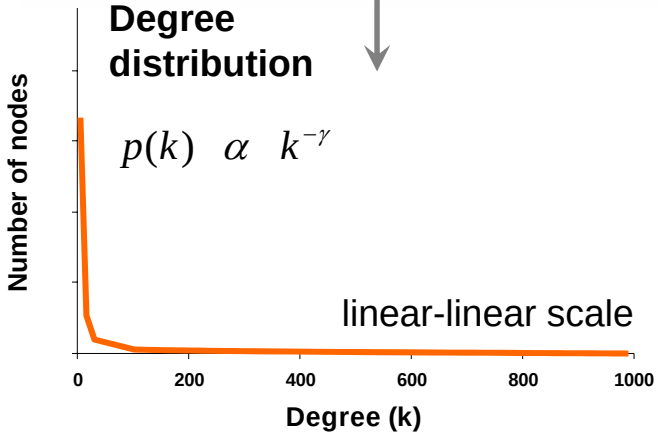
Scale Free & Scalable Networks: Definitions & Properties

Large Scale Network
e.g. www in 1999



Degree distribution

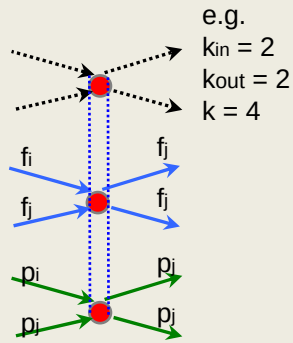
$$p(k) \;\; \alpha \;\; k^{-\gamma}$$



Notations and basic network characterization concepts:

Un-weighted networks:

Degree (k) = number of connections in and out of a node

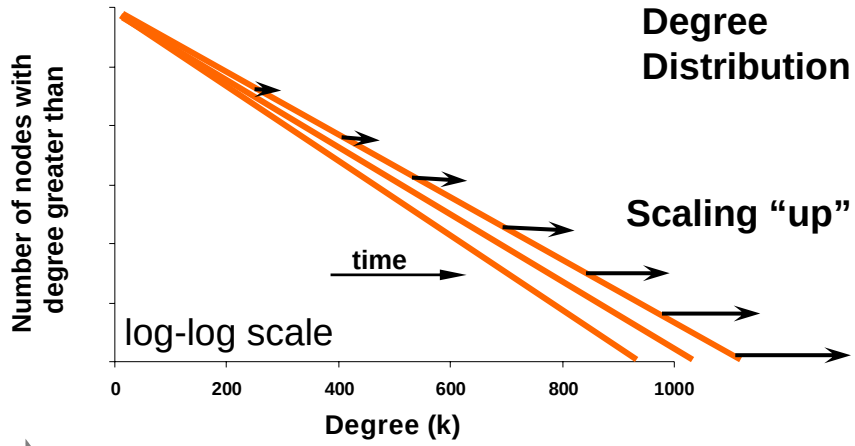


Weighted networks:

- **Flight Weighted degree** (weighted by the frequency of flights on each arc)

- **Passenger weighted degree** (weighted by the number of passenger traveling through each arc)

Degree Distribution



➡ **Networks that exhibit power law degree distribution are also called "scale free" networks**

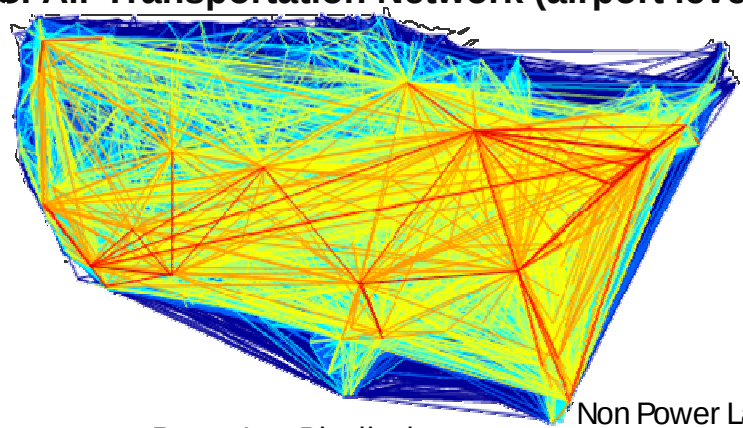
➡ **Scale free networks are represented by an affine function on a log–log scale**

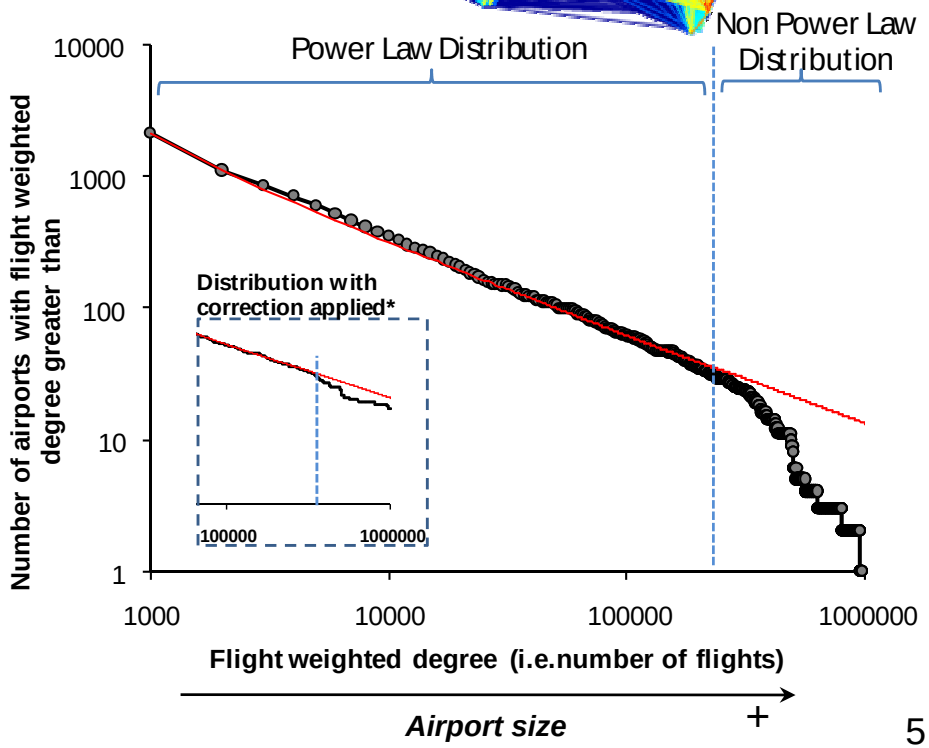
➡ **Networks that can grow without constraints are scalable (i.e. scale "up")**

Analysis of the U.S. Air Transportation Network: *(Airport Level)*

- **The air transportation network exhibits a partial power law distribution**
  - Power law distribution for small and medium size nodes
  - Non power law distribution (between 250,000 and 970,000 flights)
- **Limits to scale in this network and capacitated nodes (capacity constrained airports) are present in the non-power law part of the distribution**

U.S. Air Transportation Network (airport level)





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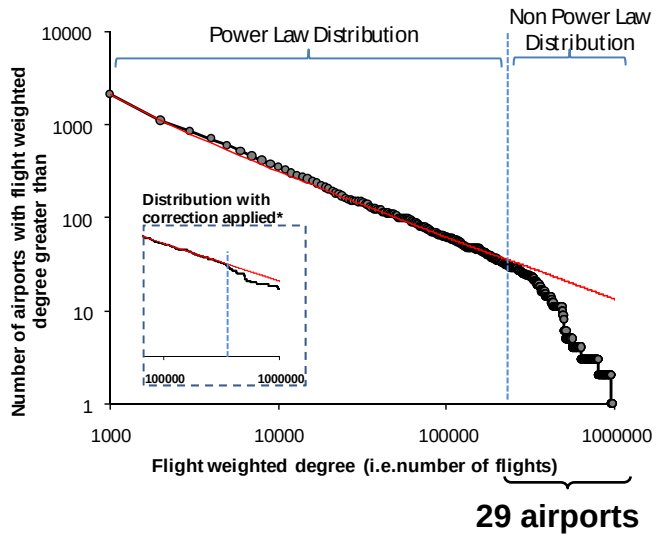
Analysis of the U.S. Air Transportation Network: *(Airport Level)*

- **Airports in the non power law part of the distribution: 29 airports**
- **Some of these nodes are clearly constrained by capacity:**
  - Slot restricted airports (i.e. ORD, LGA, DCA)
  - Airports that exhibit high level of delays that are indicative of congestion and capacity constraints (i.e. J.F. Kennedy JFK, Newark EWR, Philadelphia PHL, Boston Logan BOS and San Francisco SFO).

Flight weighted degree distribution



29 airports in the non power law part of the distribution

Airport code	Flight weighted degree (i.e. annual number of operations)	Airport code	Flight weighted degree (i.e. annual number of operations)
ORD	964360	LGA	386589
ATL	949708	BOS	381064
DFW	795974	MIA	366561
LAX	629735	IAD	361754
DEN	556178	SEA	354658
CVG	512830	MEM	343970
MSP	498523	SLC	339080
DTW	498053	SFO	331498
IAH	494410	PIT	324287
LAS	490290	JFK	311827
PHX	484252	MCO	292520
PHL	430218	MDW	280940
EWR	420197	STL	274770
CLT	417485	BWI	266166
		DCA	264784

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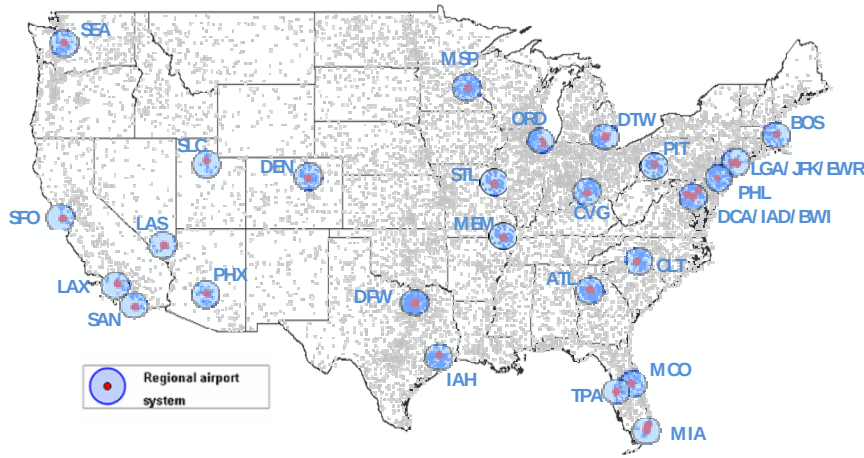
Regional Airport System Analysis

- **Hypothesis: Emergence of secondary airports in the vicinity of primary airports, leading to the development multi-airport systems, allows the network to scale**
- **Need to shift the focus from an airport level perspective to a regional airport system perspective**
- **29 airports in the non-power law part of the distribution: basis for a case study analysis of regional airport systems.**

Regional airport systems in the U.S.



- **Definitions:**
  - **Regional airport system:** all airports within 50 miles of one of the identified airports.
  - **Primary airport**: airport serving between 20% and 100% of the traffic in the region
  - **Secondary airport:** airport were defined as serving between 1% and 20% of traffic
  - **Other airport:** serving less than 1%

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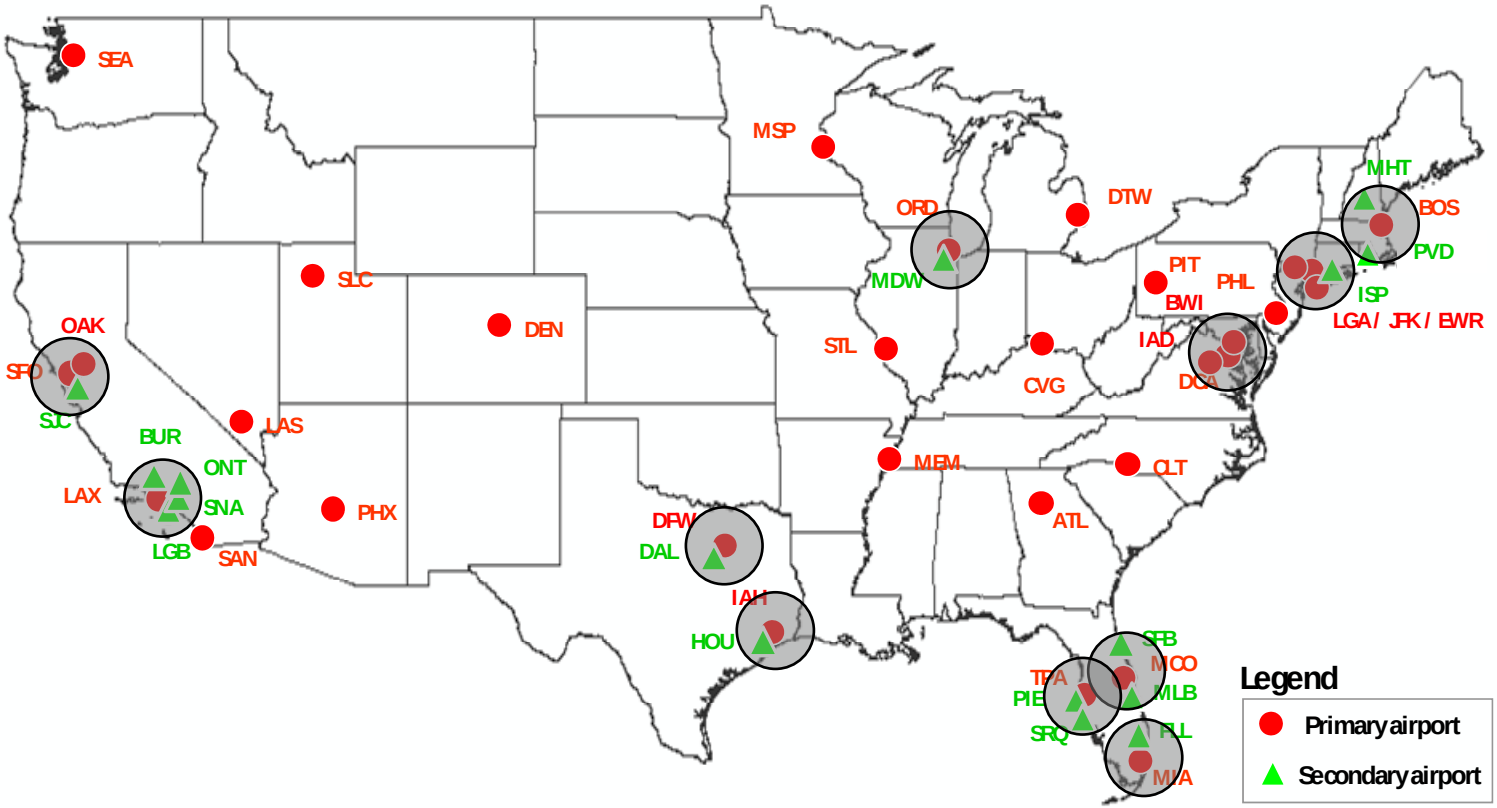
Primary & Secondary Airports in the United States

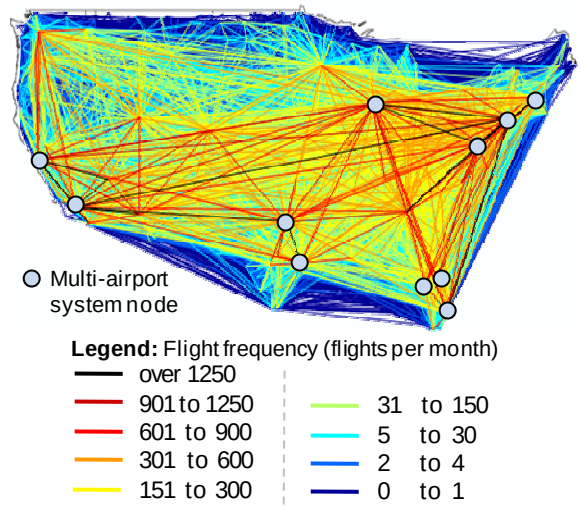
- Total of 16 primary and 16 secondary airports were found in the 11 multi-airport systems in the United States,
- 14 remaining regional airports systems were single airport systems.

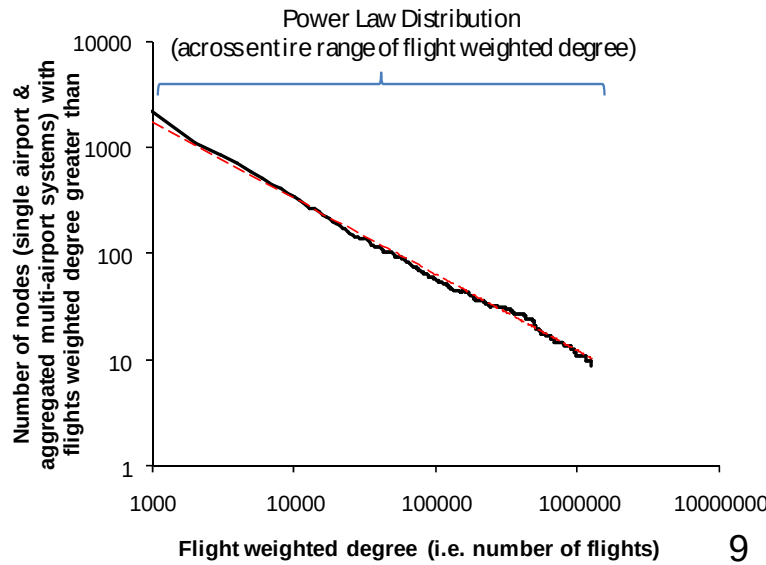


Analysis of the U.S. Air Transportation Network: *(Regional Level)*

- **Primary and secondary airports in each of the regional airport system serve the demand for air transportation within the region**
- **Airports part of multi-airport systems are aggregated into single nodes**
- **New network composed of 11 multi-airport nodes and 2159 single airport nodes**
- **Power law flight weighted degree distribution across the entire range of flight weighted degree.**
- **Mechanisms by which airports emerged in a region are key to the ability of the system to scale and to meet demand.**

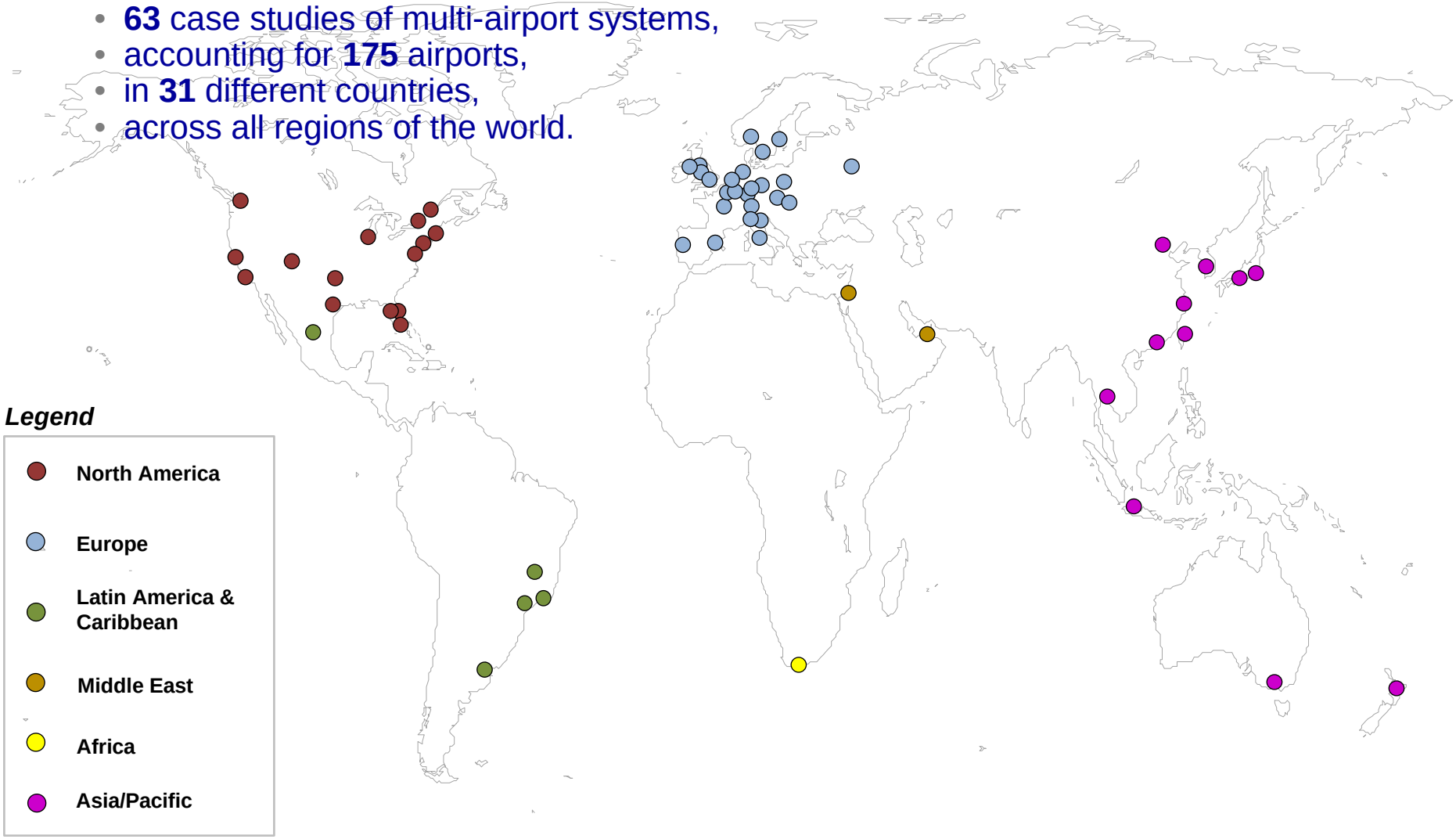
U.S. Air Transportation Network (Airport level)





Extension of the Case Studies to other Regions of the World

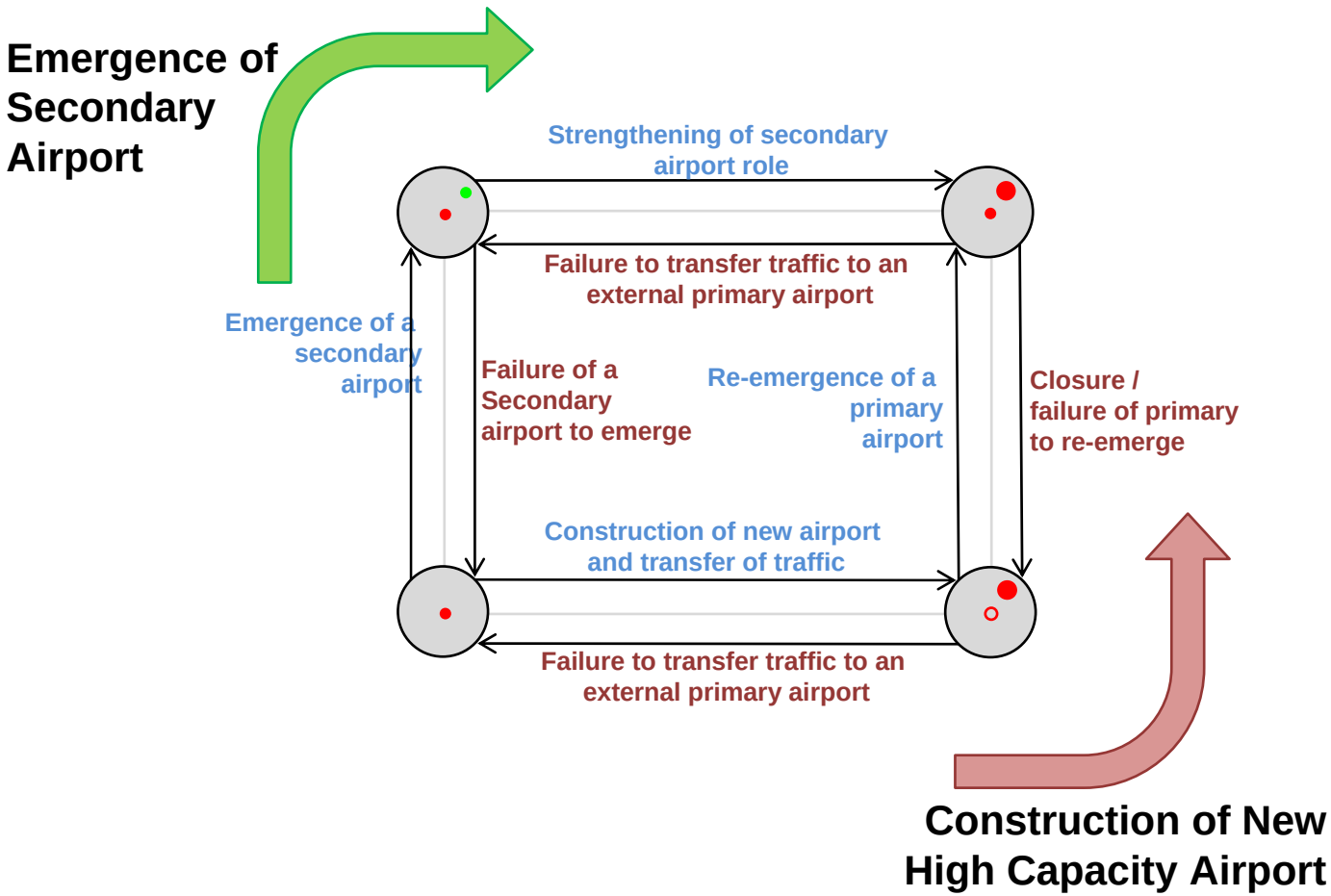
- **Overall analysis of multi-airport systems covers:**
  - **63** case studies of multi-airport systems,
  - accounting for **175** airports,
  - in **31** different countries,
  - across all regions of the world.



*** World regions defined based on the IATA statistics regions**

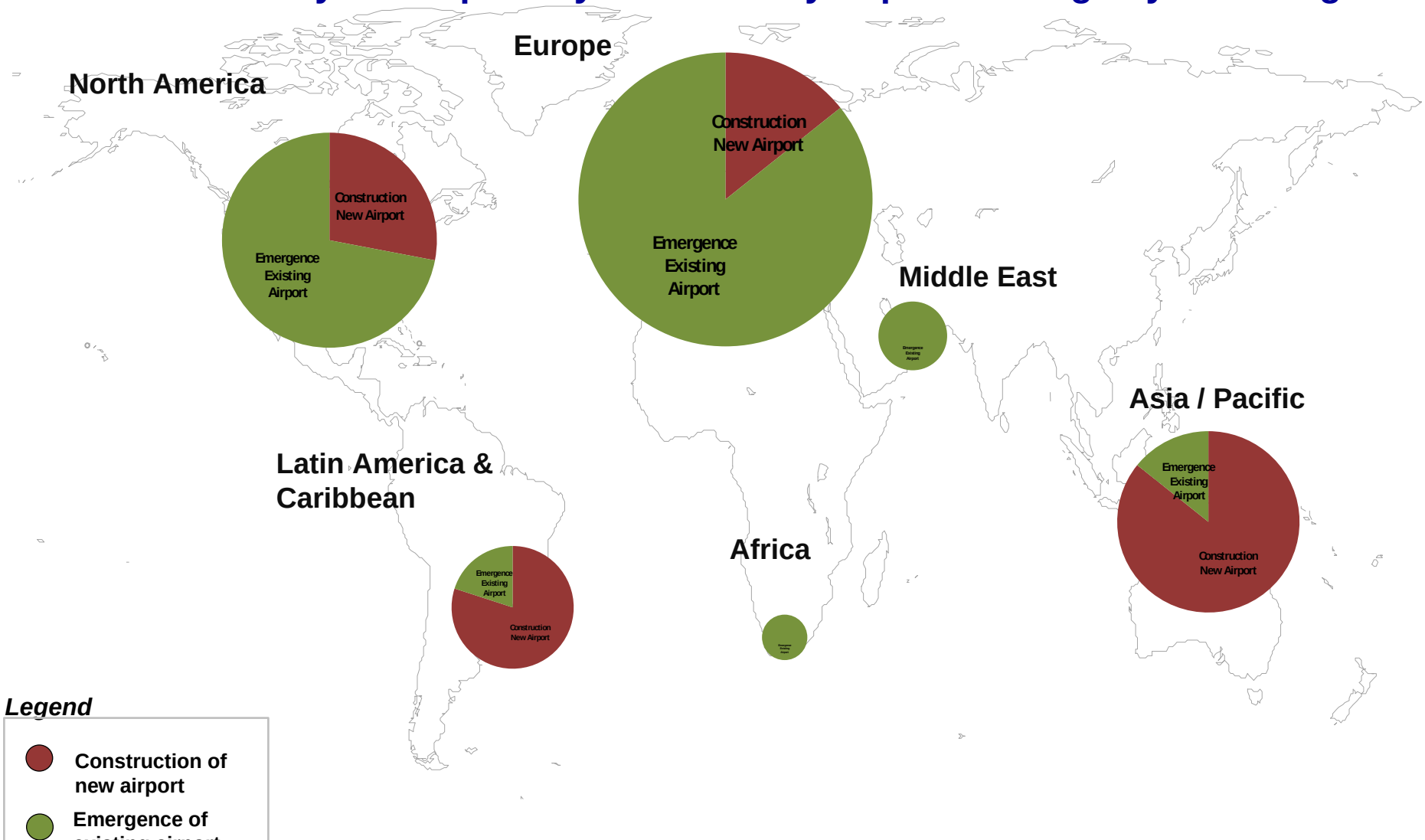
Fundamental Regional Level Scaling Mechanisms

- **Multi-airport systems evolve according to two fundamental mechanisms;**
  - **Construction of new high capacity airports**
  - **Emergence of secondary airports**

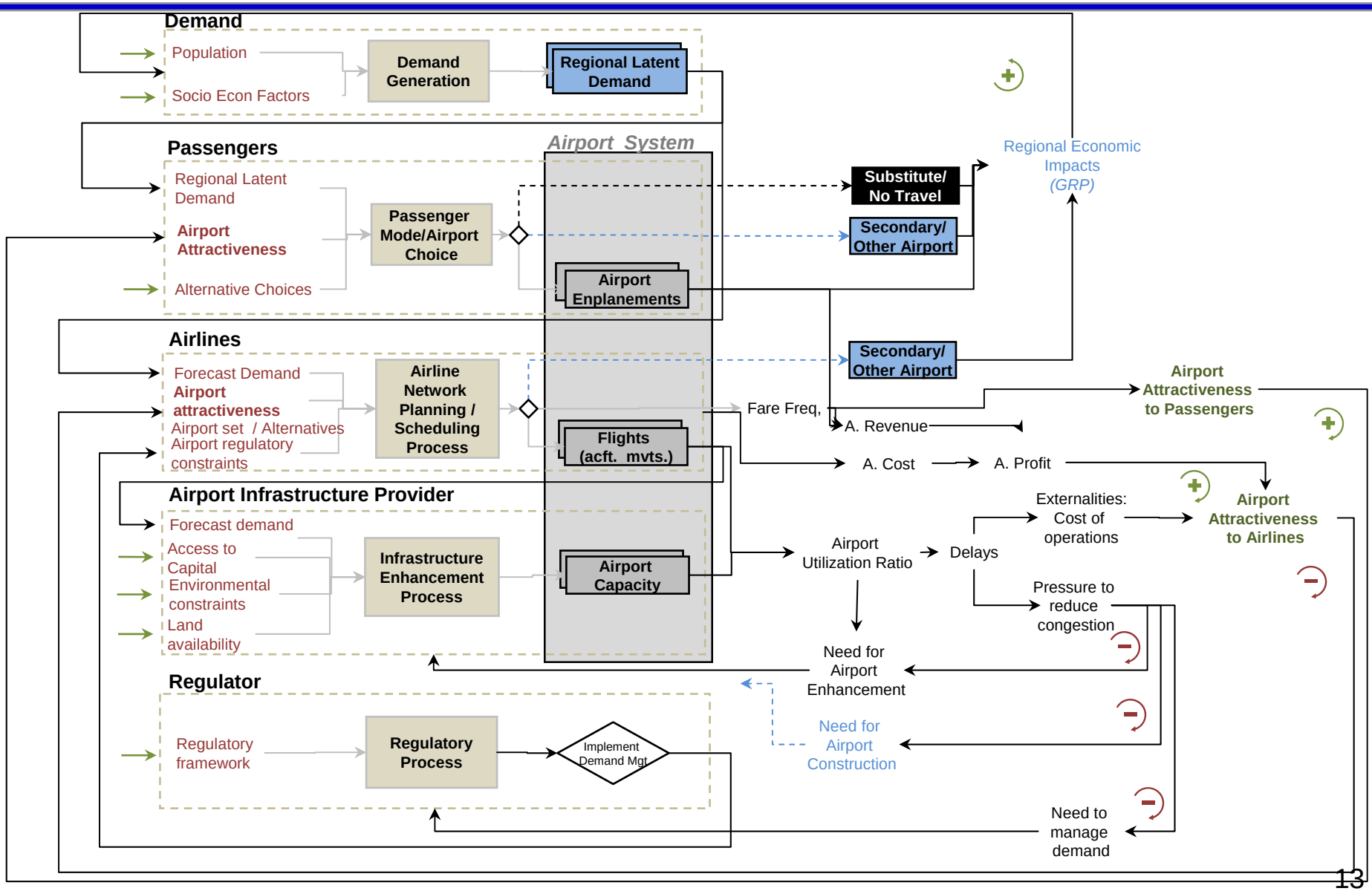


Mechanisms by which Airports Emerge in Multi-Airport Systems

- Mechanisms by which primary & secondary airports emerge by world regions:



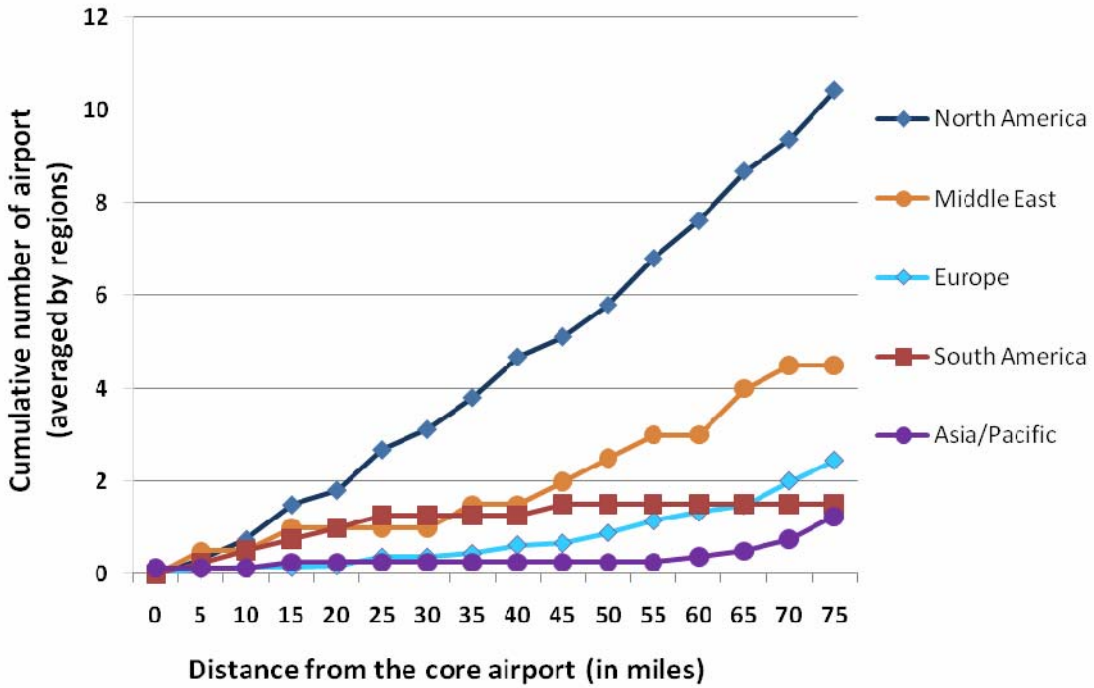
Model of Scaling Dynamics in the Air Transportation System



Availability of Existing Airport Infrastructure

- **Analysis of regional airport system capacity coverage charts:**
  (active civil and jointly operated airports with at least one runway longer than 5000ft)

- **United States:** Extensive set of existing under-utilized airport infrastructure
- **Europe:**
  - Limited existing under-utilized civil airport resources (presence of military airfields)
  - Explaining the conversion of existing military airfields into secondary airports
- **Asia:** Very limited existing under-utilized civil airport resources

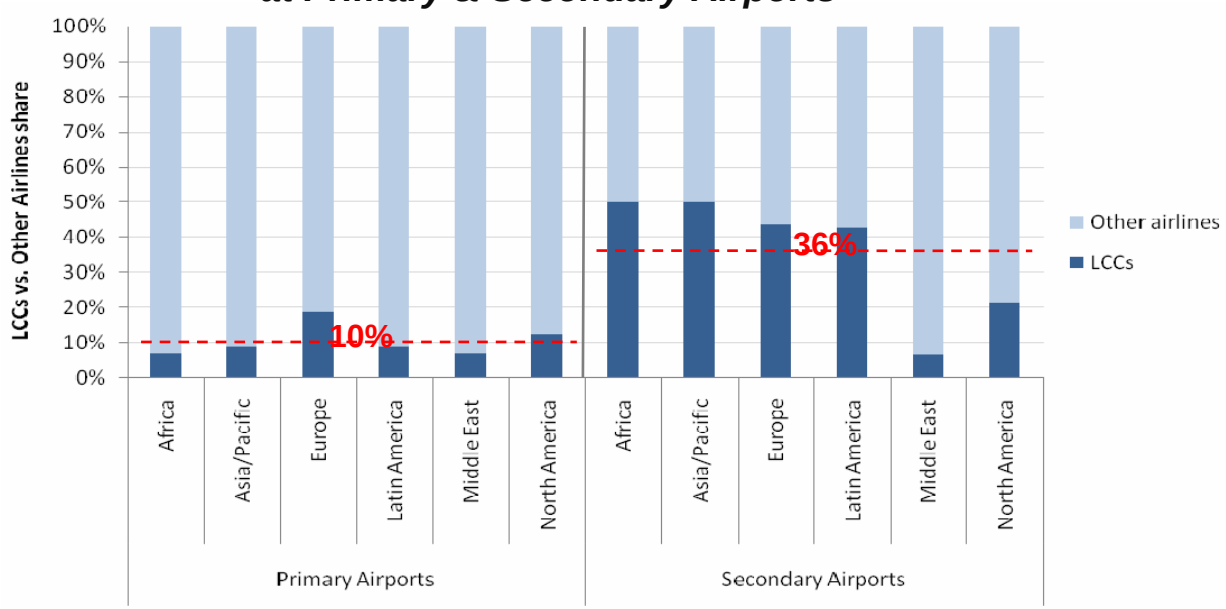


Data source: DAFIF (Category A & B airports) excluding existing primary & secondary airports

Entry of Low Cost Carriers at Secondary Airports

- **Low Cost Carriers (LCCs) generally concentrate at secondary airports**
- **Entry of low-cost carriers changes the dynamics at the airport and regional level:**
  - Entry of one LCC, followed by of entries of both LCCs and other airlines
  - Increased competition at the airport and regional level
  - Yield decrease followed by stimulation of demand and traffic shifts

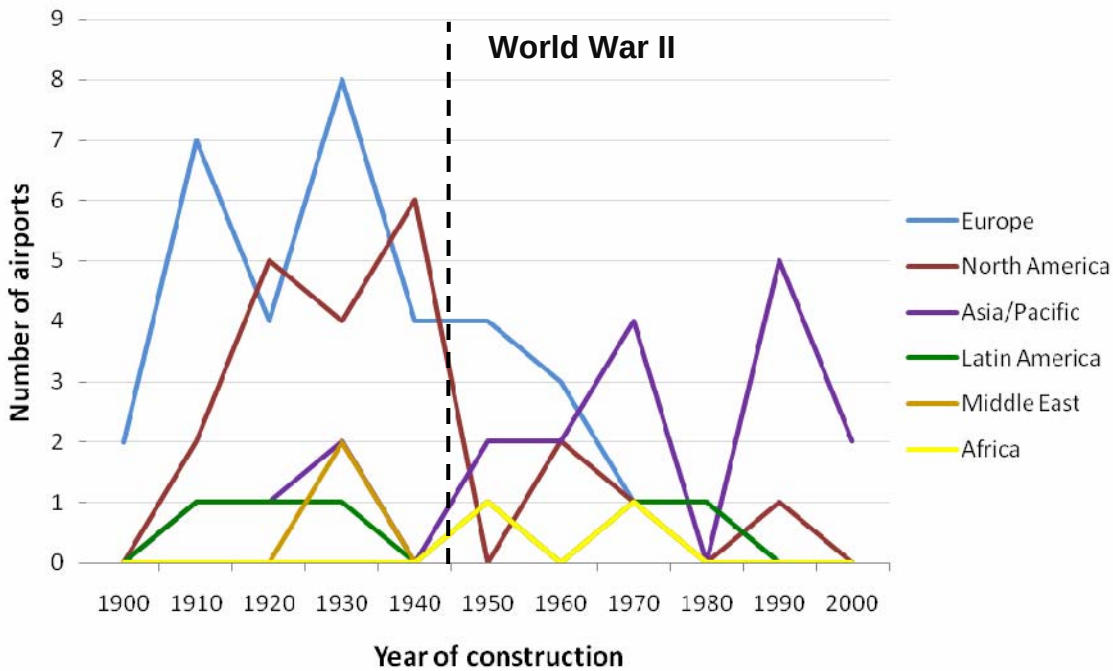
Presence of Low Cost Carriers vs. Other Airlines at Primary & Secondary Airports



** Data source: Airport websites*

Construction of Airports: Drivers & Constraints

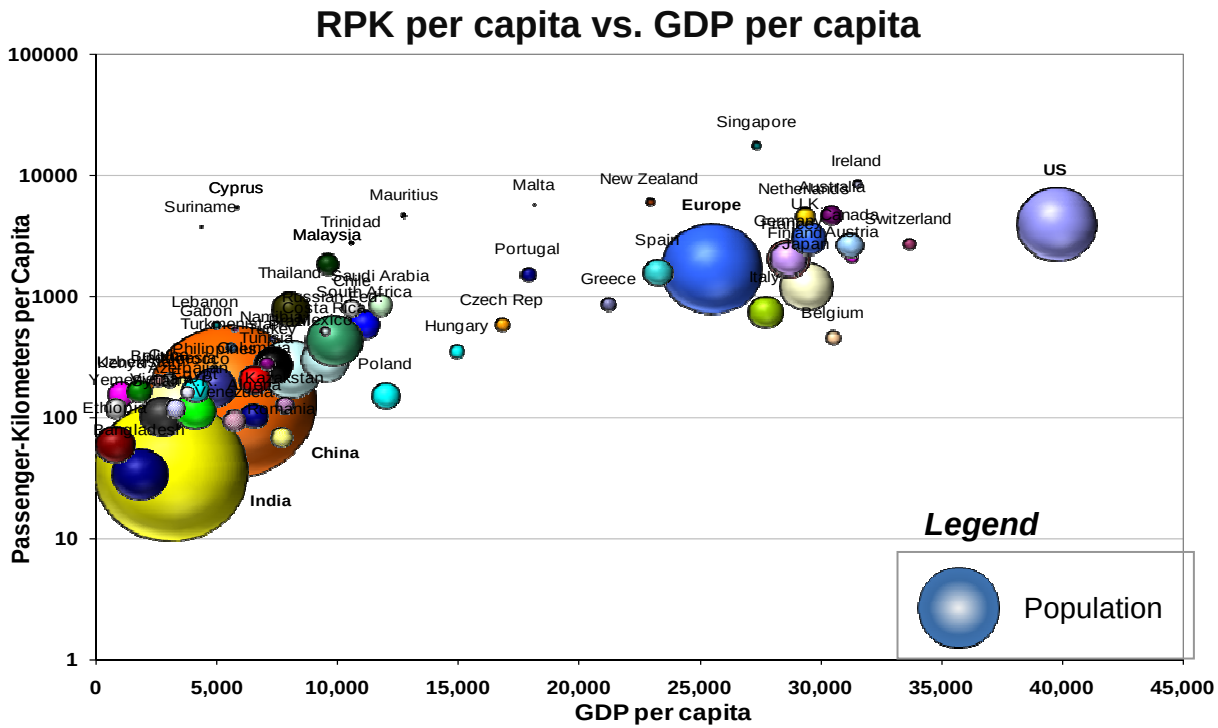
- **Historically, airports in Europe and the United States were built prior to or during World War II in Europe & North America.**
  - Meet the needs of military activity and growing demand for commercial traffic
  - Environmental constraints limiting the construction of new airports in the three decades
- **In Asia, phase of construction of primary airports in Asia is more recent (1970s and 1990s/2000s)**
  - Demand forecasts (double digit growth rates)
  - Weaker environmental constraints (than in Europe and United States)



** Data source: Airport websites and other sources*

Projected Rate of Growth of Demand for Air Transportation

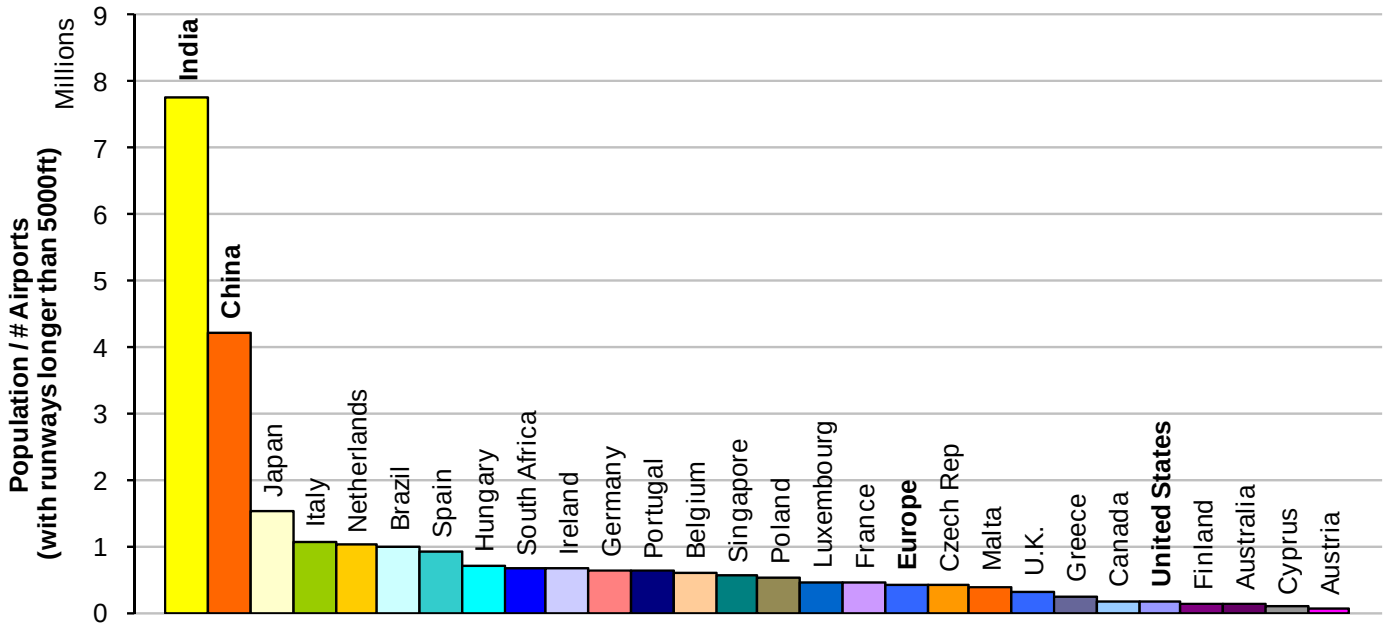
- **GDP driving air transportation activity (and conversely)**
- **Projected rate of growth of RPKs related to type and capacity of airport infrastructure developed**
  - **Secondary airports** (small incremental capacity strategy) in Europe and United States (small to medium average annual rate of growth)
  - **New high capacity airports** in anticipation of medium to high average annual rate of growth



** Data source: ICAO traffic data & CIA World Fact book data*

Future Needs for Airport Infrastructure:
Projected Demand/Airport Capacity Adequacy

- **Analysis of future needs for airport infrastructure:**
  - Population / Number of airports used as a proxy for latent demand vs. existing infrastructure capabilities
- **China and India:**
  - high population/airport infrastructure ratios
  - will require significant future development of airport infrastructure
- **United States and Europe:**
  - Significant number of existing airports that can accommodate future growth
  - Future emergence of secondary airports



** Data source: CIA World Fact book*

Conclusions

- **Air transportation network**
  - is not entirely scalable at the airport level due to airport capacity constraints,
  - scales to meet demand through regional level mechanisms.
- **Fundamental regional level scaling dynamics;**
  - construction of new high capacity airports,
  - emergence of secondary airports.
- **Differences & similarities across the world**
  - United States & Europe
    - *Concentration of traffic at primary airports*
    - *Construction of new large airports: pre/during WWII*
    - *Significant limitations to the development of new large airports; environmental barriers & constraints*
    - *Emergence of secondary airports (Southwest effect) 1970s to 2000s*
    - *More recent trend in Europe, especially with the growth of LCCs after deregulation in the early 1990s*
  - Asia Pacific
    - *Construction of multi-primary airport systems due to lack of existing infrastructure and projected demand*
- **Future Evolution of the System and Needs**
  - Regional level scaling mechanisms will be key to meeting future demand
  - Need to protect exiting airport infrastructure (both civil and military airports) in the United States and in Europe
  - Need to develop a phased development approach for future primary airports in Asia taking advantage of the lessons learned in the United States and in Europe