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Emerging Trends in Air Transportation:

Challenges & Opportunities for Guidance & Control Research

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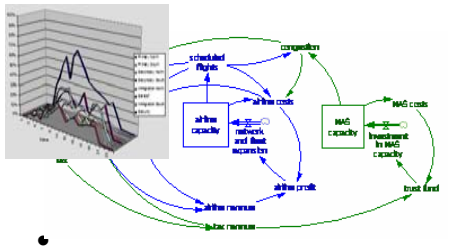
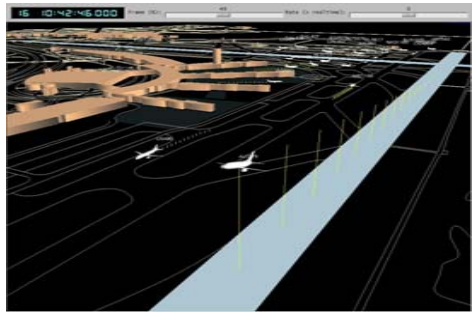
Systems Engineering and Operations Research Department

STRATEGIC PLANNING/ INDUSTRY ANALYSIS	AIRPORT & AIRSPACE SIMULATION	SYSTEM/SAFETY ANALYSIS	EDUCATION
• **Industry Dynamical System Models**  • •Cost/Benefit Analysis • Airline Revenue Management • Airline IT/Enterprise Architecture Design	• Airport & Airspace System Performance Analysis •Airspace Design •Stochastic Analysis & Simulation  •Passenger & Baggage Flow Simulations •Airport Security	• Probabilistic Risk Assessment • Safety Monitoring System Design • Probabilistic Wake Vortex Models 	•Degree programs (Ph.D., M.Sc., B.Sc.) with concentrations and courses in Air Transportation. •Continuing Education •Seminars & Short-courses •Co-ops with Industry Partners

Summary

- U.S. Domestic Air Transportation System (ATS) is an amazing success story over last century
  - Economic engine of U.S. economy
- Sustainability of growth in question
  - Demand approaching Capacity of sub-systems (delays, cancellations, excess costs, salaries, staffing)
  - Scarce resource not being managed
- Dynamical System Model of ATS demonstrates that *Technology alone*, cannot solve problem
  - Systemic industry structure must be modified to included close-loop feedback to:
    - Manage fluctuations in demand in efficient manner
    - Incentivize adaptation and innovation

Organization

1. Air Transportation System (ATS)
   - Success and Sustainability?
2. Analysis of ATS
   - Dynamical System Model
3. Opportunities for Research

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Air Transportation System

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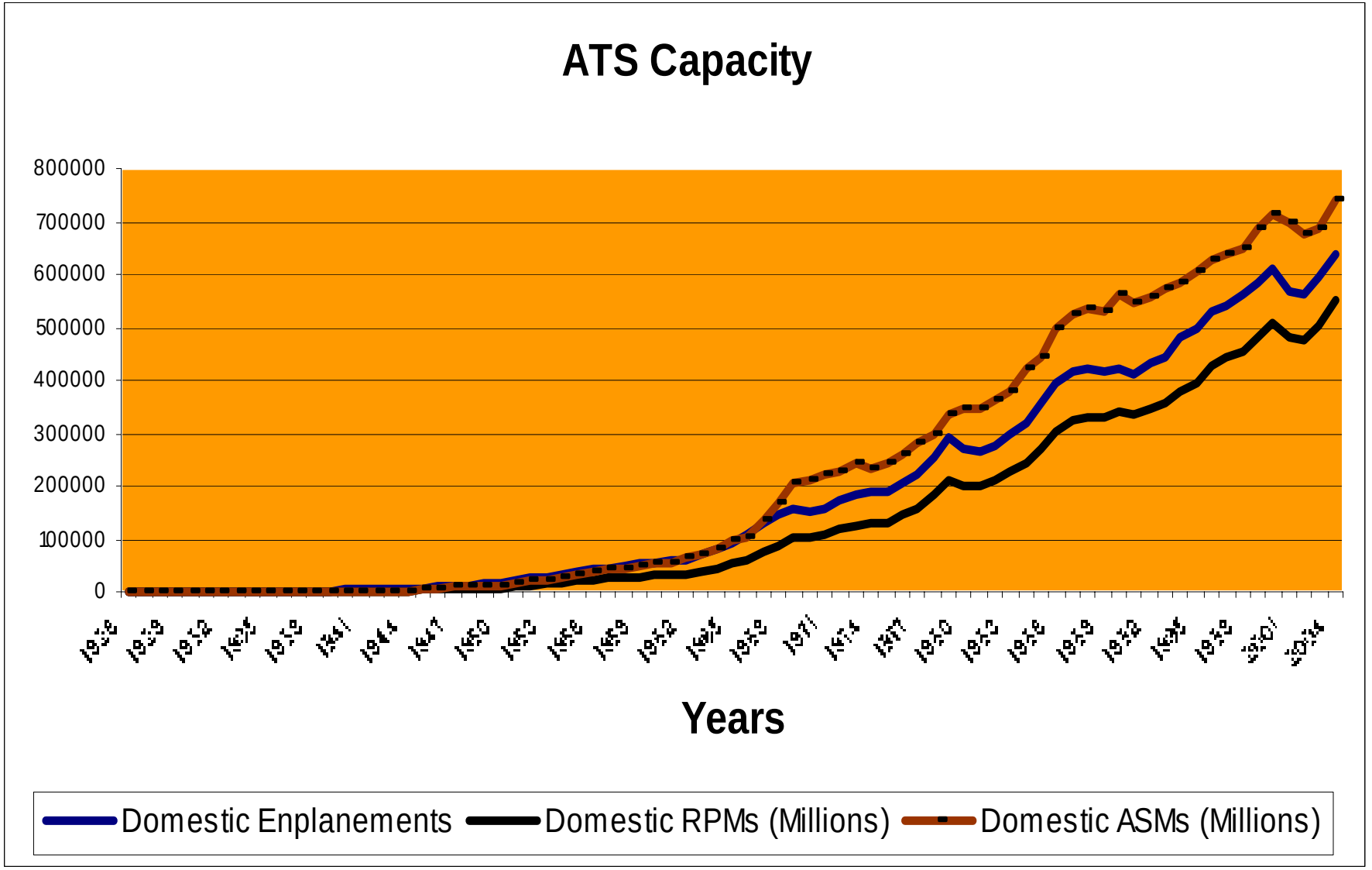
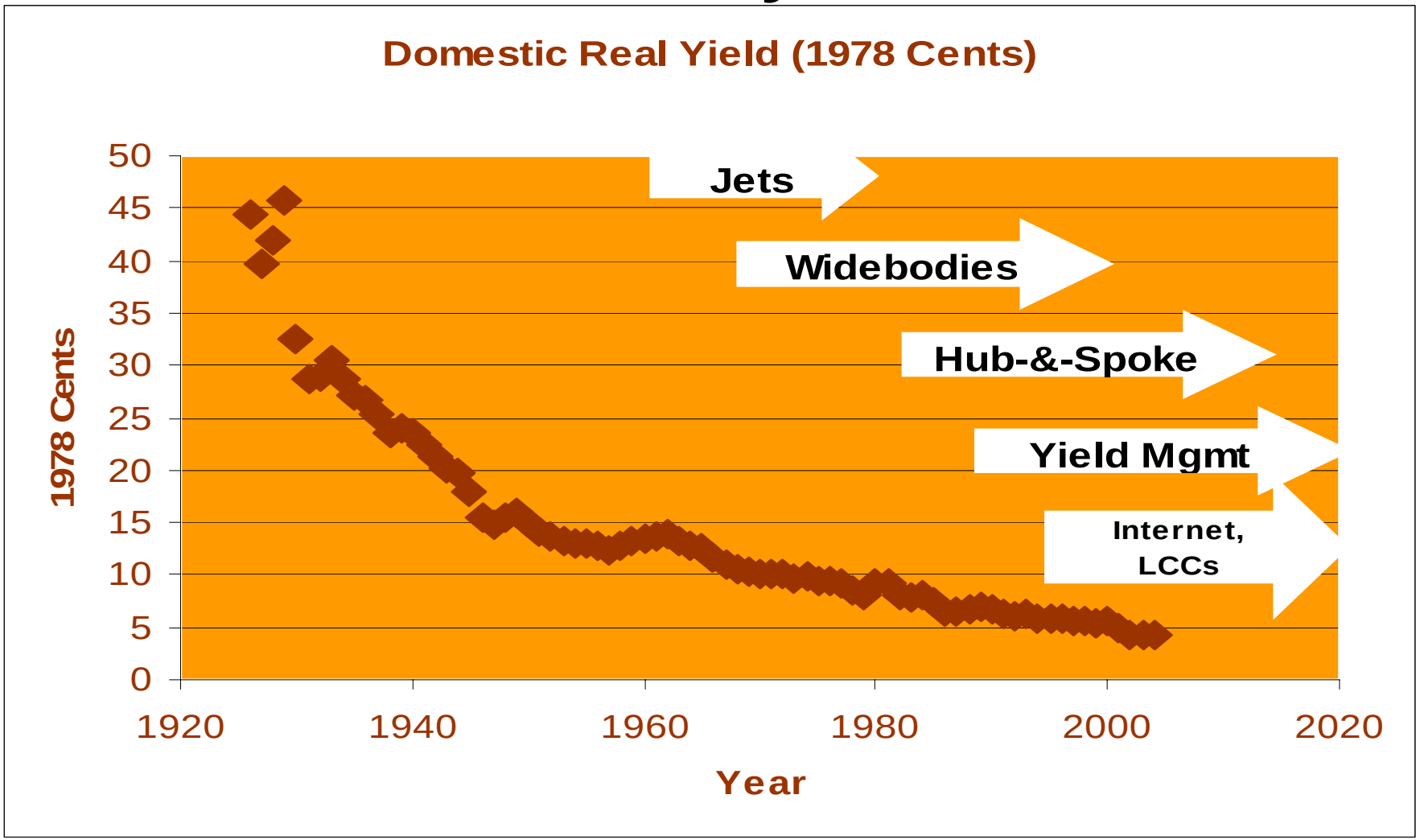
Air Transportation & Economy

- Air Transportation is a major determinant of the nations economic health
  - Growth in U.S. GDP corresponds to growth in air transportation
- Air Transportation is an “intermediate good”
    - Air transportation used to achieve other purpose
- Direct Contributions:
  - Air transportation directly contributes 1-2% to GDP
  - Employment, Airport economies
- Indirect Contributions:
  - supply chain, equipment suppliers
- Induced Contributions:
  - Hotels, rental cars, …

Success Story – Capacity



Success Story - Airfares



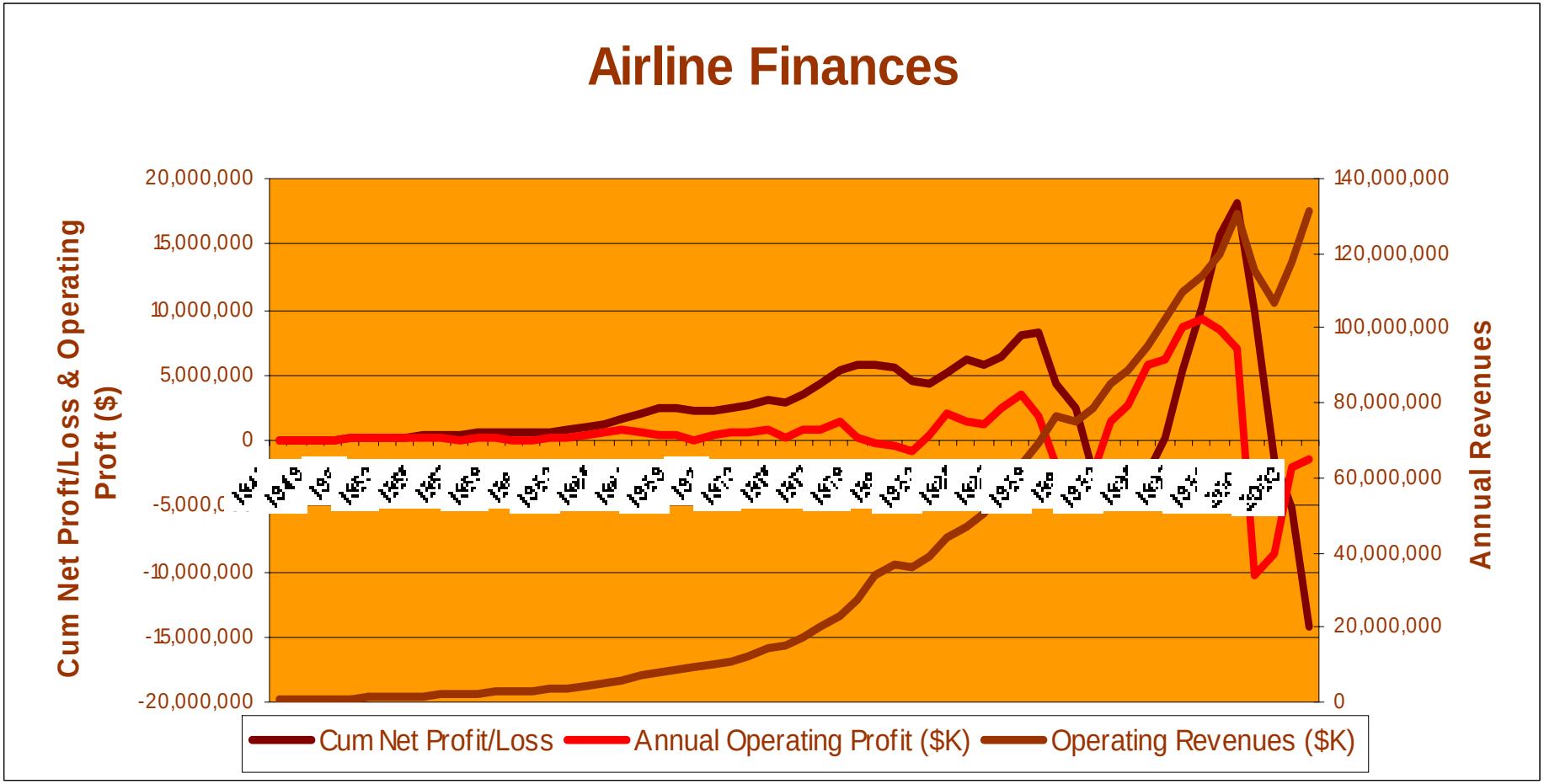
Source: ATA (2005)

Yield = Before Tax Revenue per Seat-Mile

Sustainability ?

1. **Airline Profit/Loss Cycles**
   - Finding economic equilibrium?
2. Eroding access from small communities
   - Essential Air Service subsidies growing?
3. **Congestion at hubs**:
   - delays and cancellations
   - Go-arounds/Wake Vortex encounters
4. Environmental issues (emmissions, noise)
5. **Airport & Airspace Trust Fund eroding**
6. Airport & Airspace innovation cycle is dormant
7. ATC innovation cycle is dormant
   - Modernization efforts effectively stalled
8. **ATC labor issues (salary, staffing)**

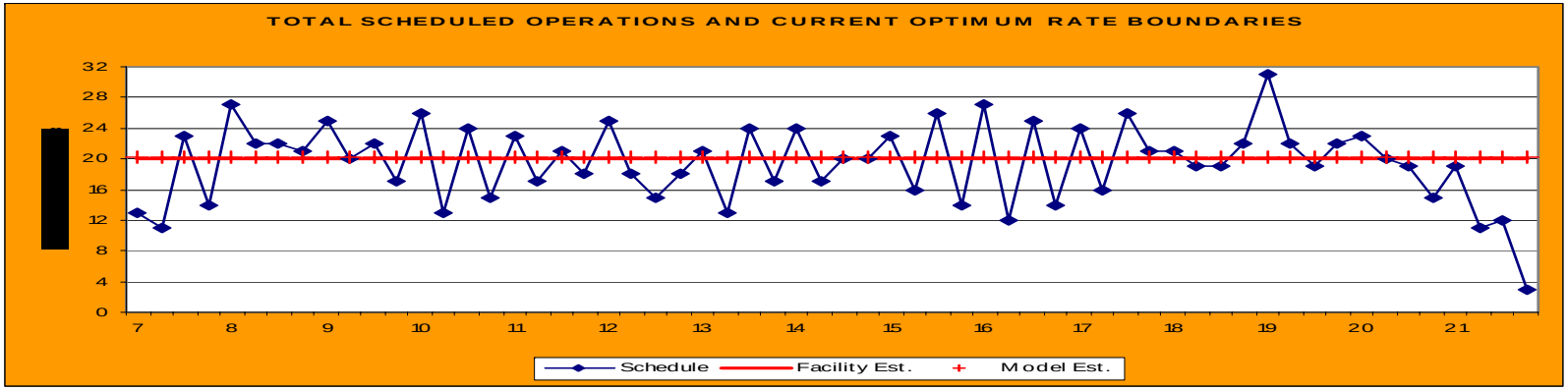
Sustainability ? – Airline Finances



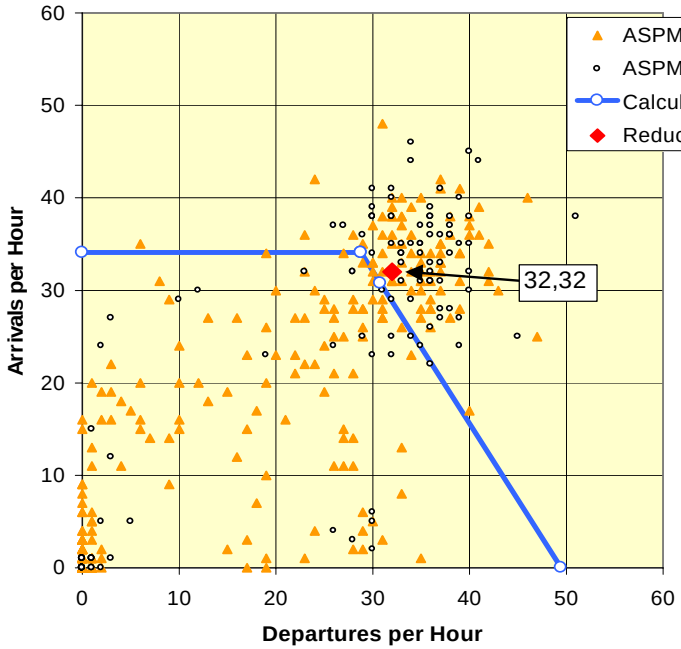
Source: ATA (2005)

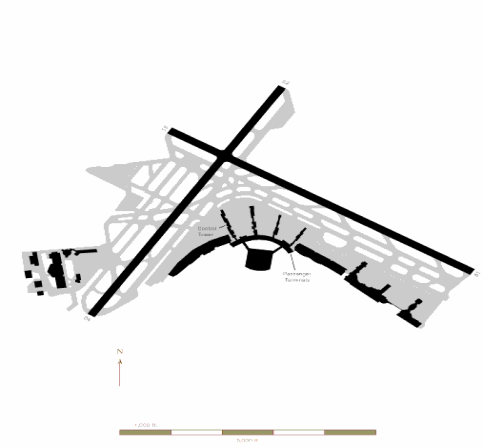
Symptom, not a cause

Sustainability ? - Congestion



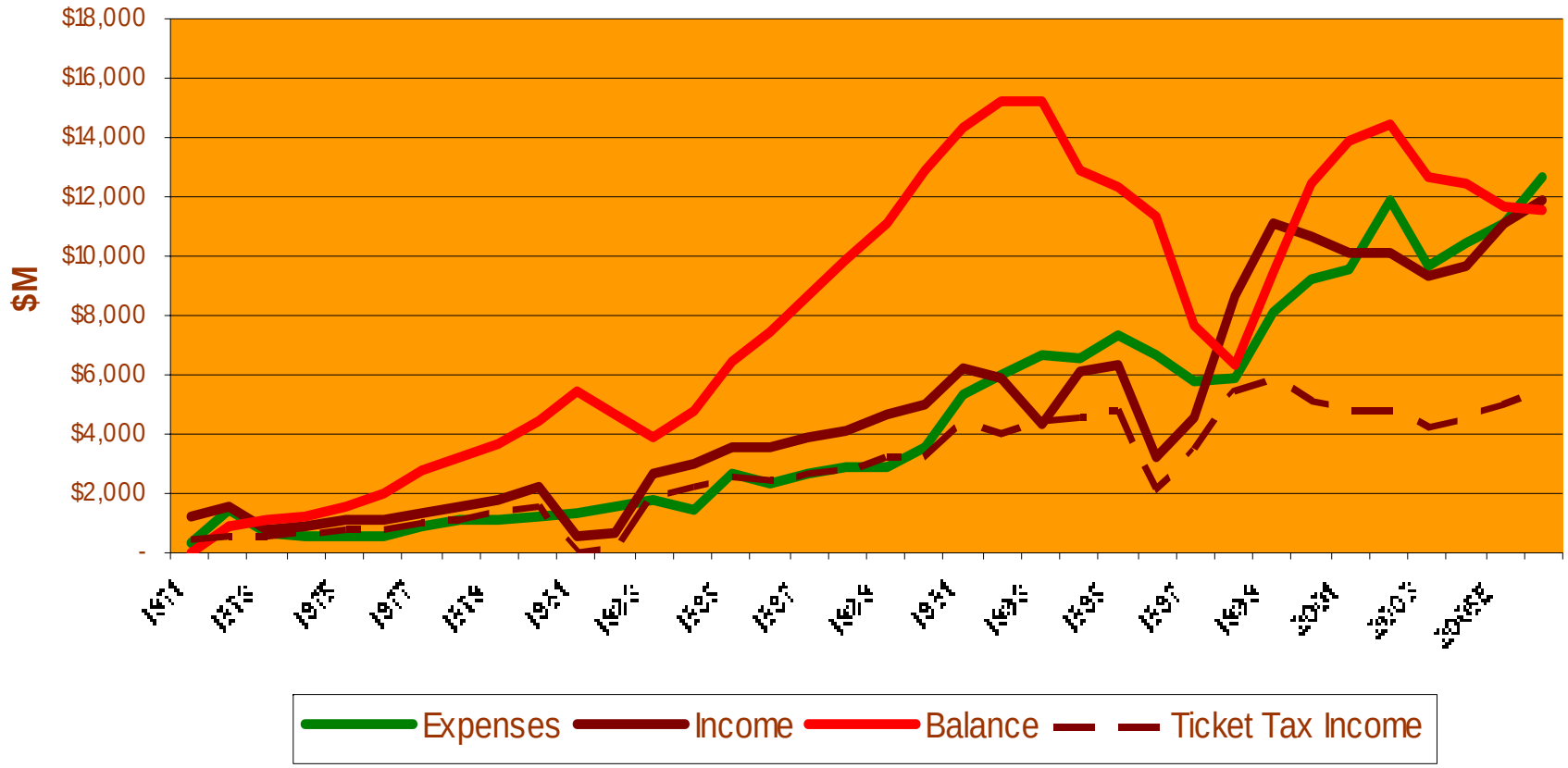
- 1 Arrival Runway
- 1 Departure Runway
- 45 Arrivals/Hr (Max)
- 80 Seconds Between Arrivals
- 11.3 minute Average Delay
- 77 Delays/1000 Operations
- 40 min./Delay





Sustainability ? – A&ATF

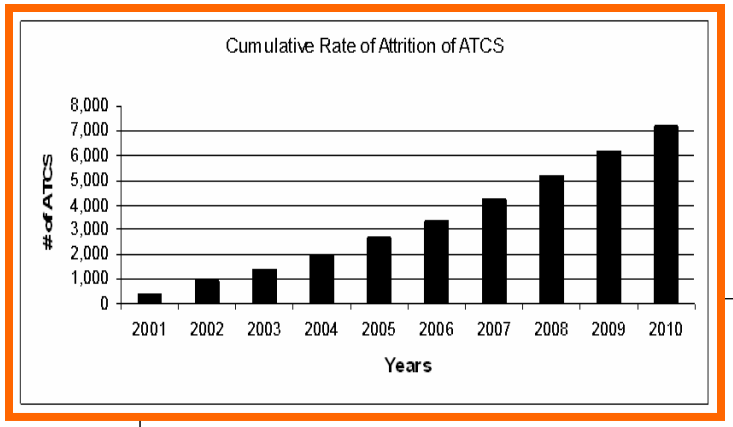
Airport & Airway Trust Fund



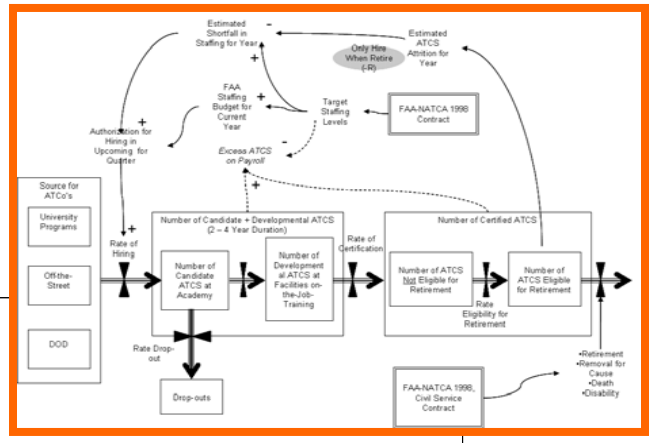
Source: ATA (2005)

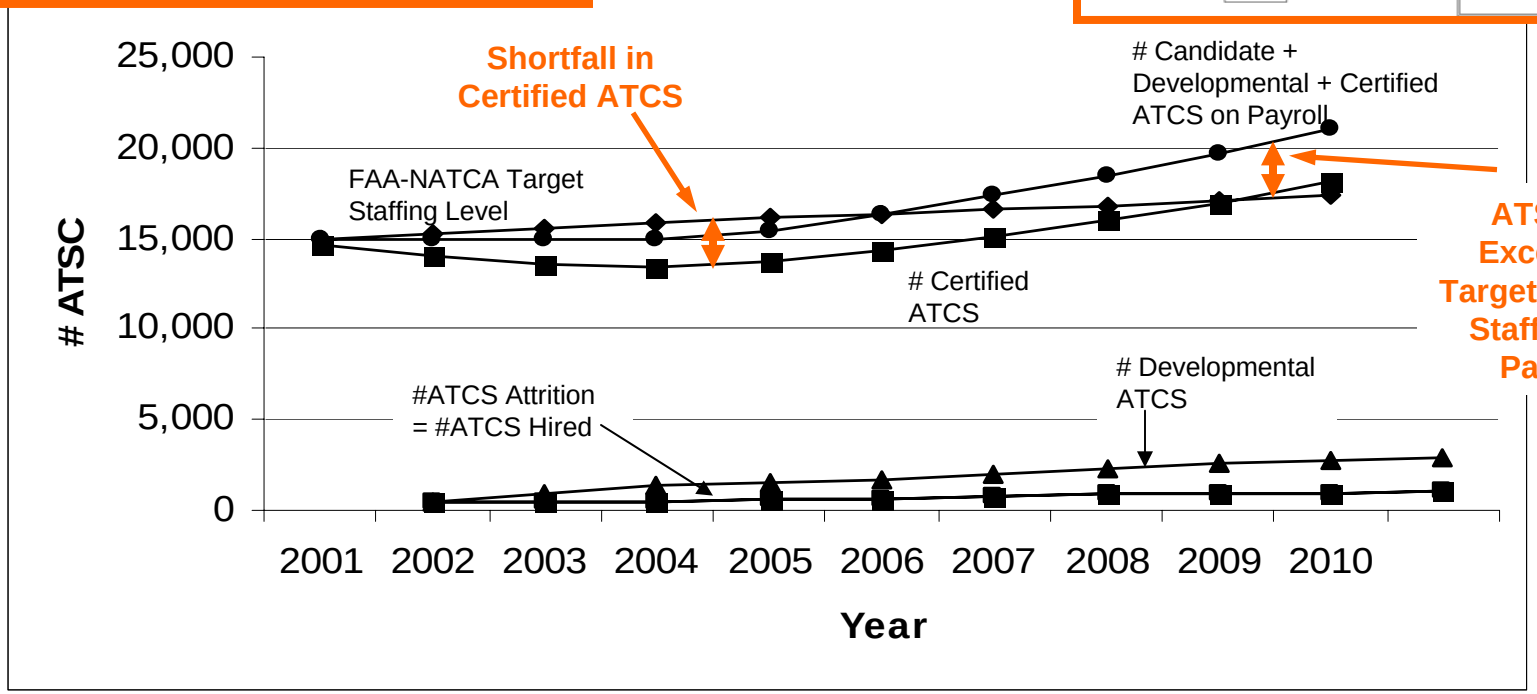
Shift to RJs, results in more ATC operations, A&TFless revenue

Sustainability ? – ATC Labor



ATSC Hiring





Sustainability ?

- Throwing $ and Technologies at the problem does not appear to be solving the problem

- What is the systemic structure of the industry?
  - Can this knowledge explain behavior?
  - Can this knowledge focus R&D?

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Analysis

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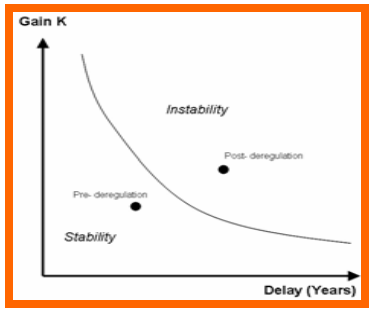
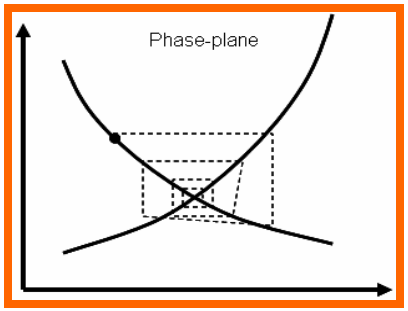
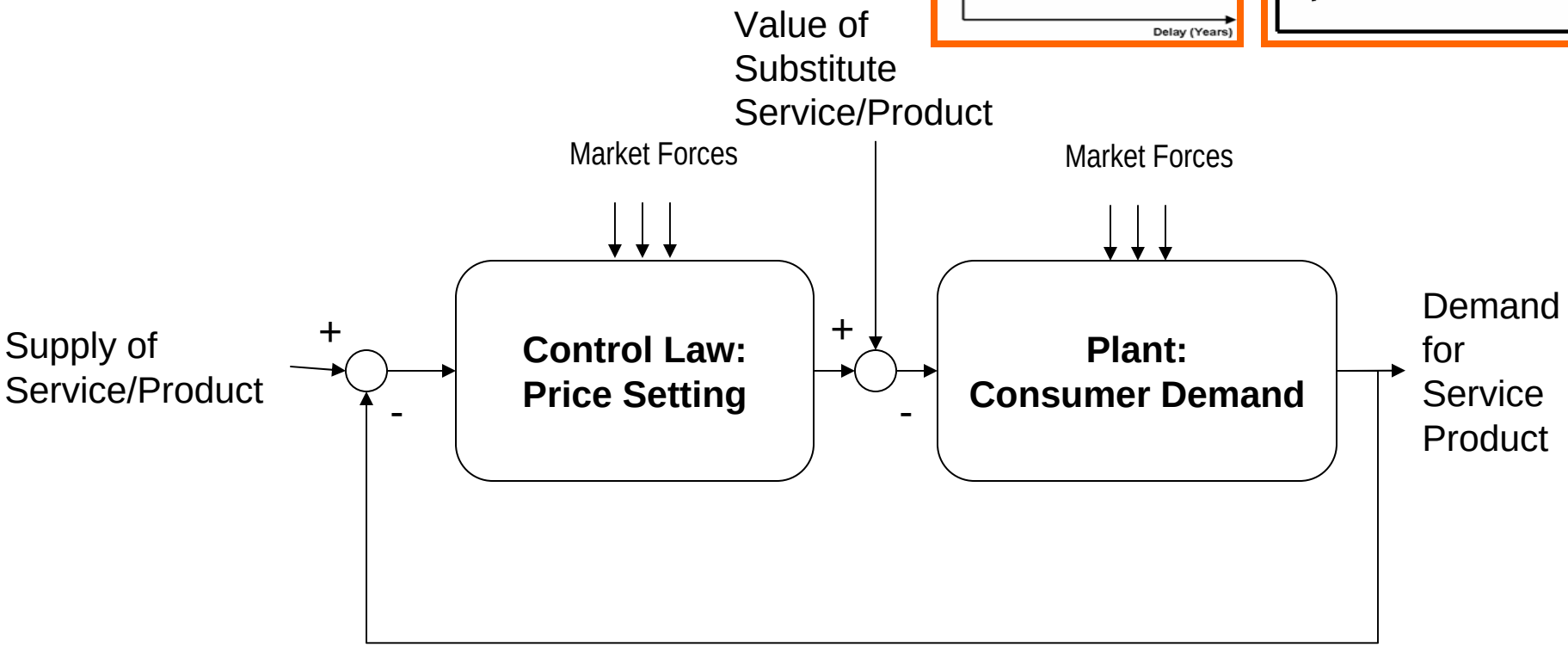
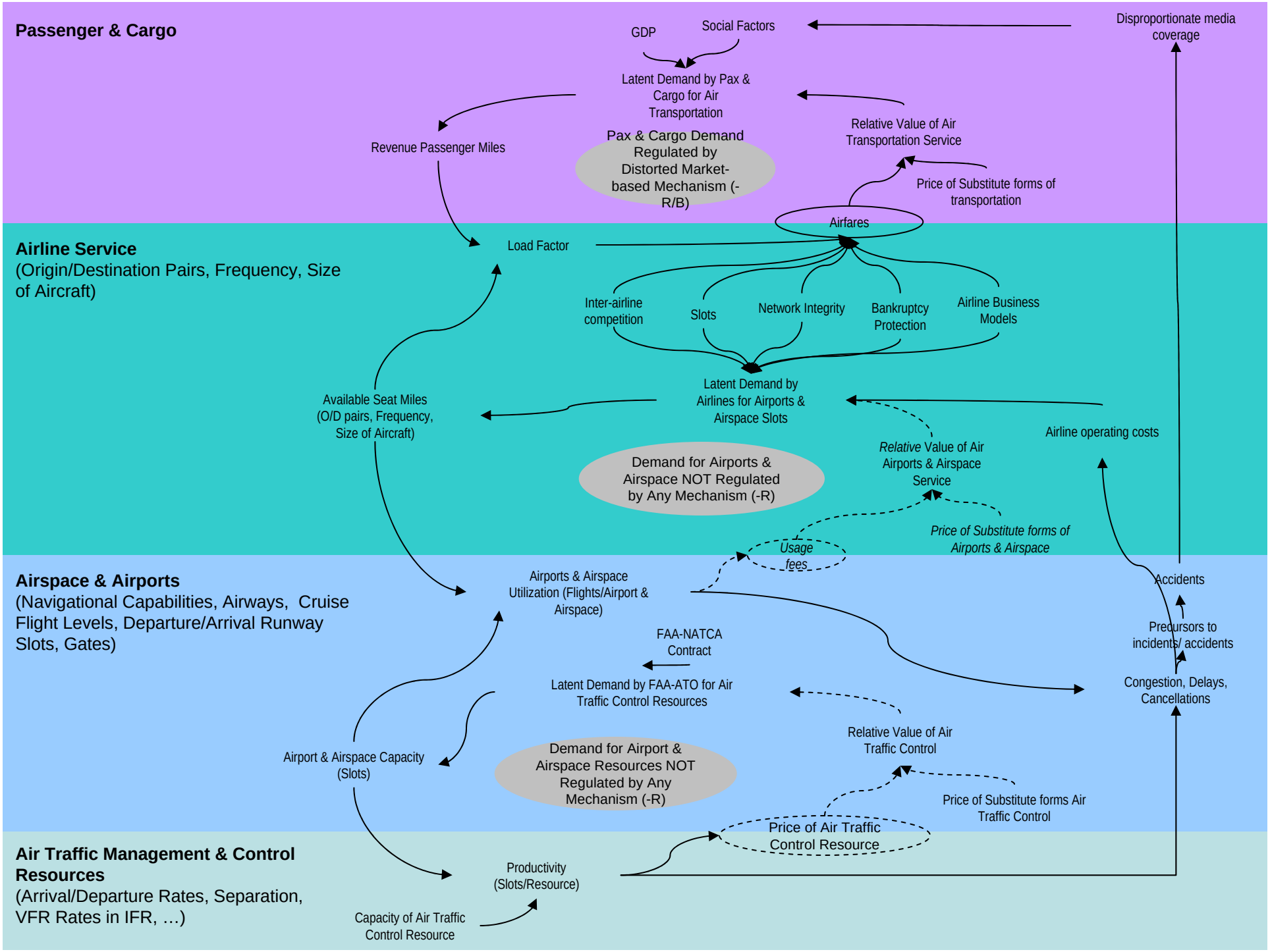
Dynamical System Models







Plant exhibits non-linear dynamics (price elasticity)


Passenger & Cargo
GDP
Social Factors
Disproportionate media coverage
Latent Demand by Pax & Cargo for Air Transportation
Revenue Passenger Miles
Pax & Cargo Demand Regulated by Distorted Market-based Mechanism (-R/B)
Relative Value of Air Transportation Service
Price of Substitute forms of transportation
Airfares
Airline Service
(Origin/Destination Pairs, Frequency, Size of Aircraft)
Load Factor
Inter-airline competition
Slots
Network Integrity
Bankruptcy Protection
Airline Business Models
Latent Demand by Airlines for Airports & Airspace Slots
Available Seat Miles (O/D pairs, Frequency, Size of Aircraft)
Airline operating costs
Demand for Airports & Airspace NOT Regulated by Any Mechanism (-R)
Relative Value of Air Airports & Airspace Service
Price of Substitute forms of Airports & Airspace
Usage fees
Airspace & Airports
(Navigational Capabilities, Airways, Cruise Flight Levels, Departure/Arrival Runway Slots, Gates)
Airports & Airspace Utilization (Flights/Airport & Airspace)
Accidents
Precursors to incidents/ accidents
FAA-NATCA Contract
Latent Demand by FAA-ATO for Air Traffic Control Resources
Congestion, Delays, Cancellations
Relative Value of Air Traffic Control
Airport & Airspace Capacity (Slots)
Demand for Airport & Airspace Resources NOT Regulated by Any Mechanism (-R)
Price of Substitute forms Air Traffic Control
Price of Air Traffic Control Resource
Air Traffic Management & Control Resources
(Arrival/Departure Rates, Separation, VFR Rates in IFR, …)
Productivity (Slots/Resource)
Capacity of Air Traffic Control Resource

Air Transportation System

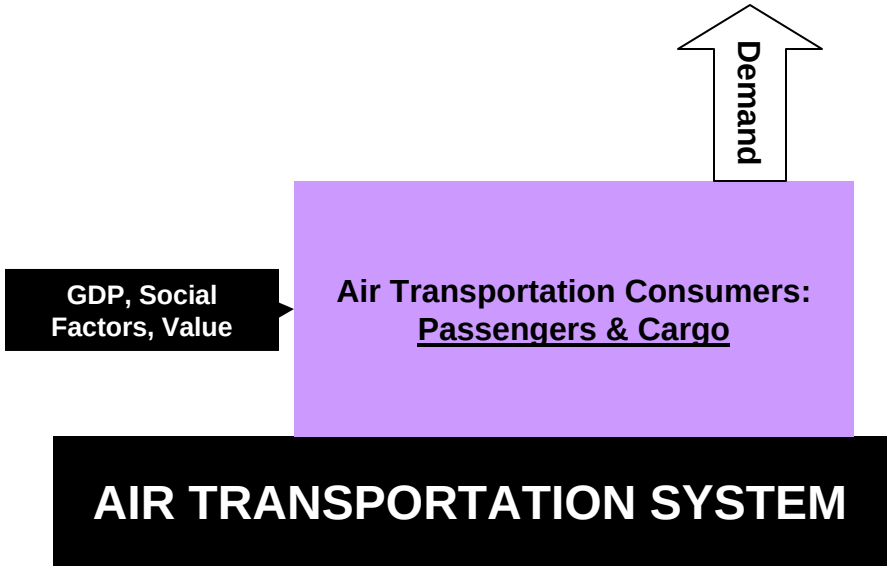
- Air Transportation System is provided by layers of networks:
  1. Passengers & Cargo
     - Purchase tickets for air transportation based on relative merit over other forms of transportation
     - Passenger & cargo transportation drives modern economy
  2. Airlines
     - Provide capacity for air transportation of passengers by providing Scheduled Flights (routes, frequency and aircraft)
  3. Airspace & Airports
     - Provide capacity for Airline Scheduled Flights through airways, navigational aids, flightlevels, runways, gates, …etc.
  4. Air Traffic Management & Control
     - Provide capacity for Airports and Airspace by managing and controlling traffic in the presence of weather using procedures, sensors

Air Transportation System

- Passengers and Cargo rely on Airlines to provide air transportation
- Airlines rely on Airspace & Airports to provide routes, runways, gates
- Airspace & Airports rely on Air Traffic Management & Control to maximize their use in the presence of weather and other variables

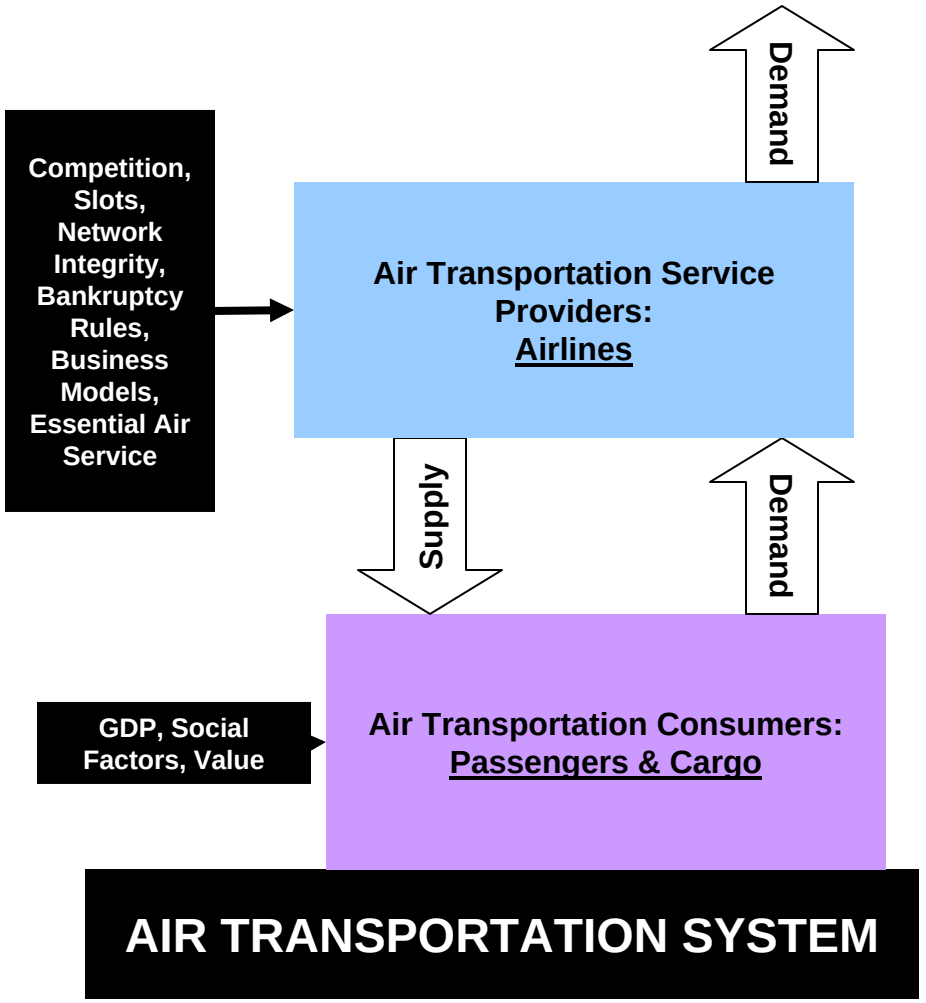
(1) Consumers: Pax & Cargo

- Air Transportation advantageous over other modes:
  - speed, cost (grows with trip length)
- Demand exhibits Variability
  - Seasonality, Day of week, Hour of day
  - Income Elasticity (Engels Law)
    - As income rises, people spend proportionately more on luxuries (and not on necessities)
  - Price Elasticity
    - Sensitivity of demand to price
    - Tourist elasticity > Business elasticity



(2) Airlines

- Air Transportation Service:
  - Seats
    - Network of routes
    - Schedules on each route (i.e. frequency of service)
    - Gauge of service (i.e. aircraft size, fleet)
- Subject to variability from:
  - Pax & Cargo demand Prices of competing modes
  - Prices determined by competition
  - Supply Chain price (e.g. Fuel)
  - Technology (speed, costs of operation)
  - Supply of resources (e.g. gates, aircraft)



(2) Airlines

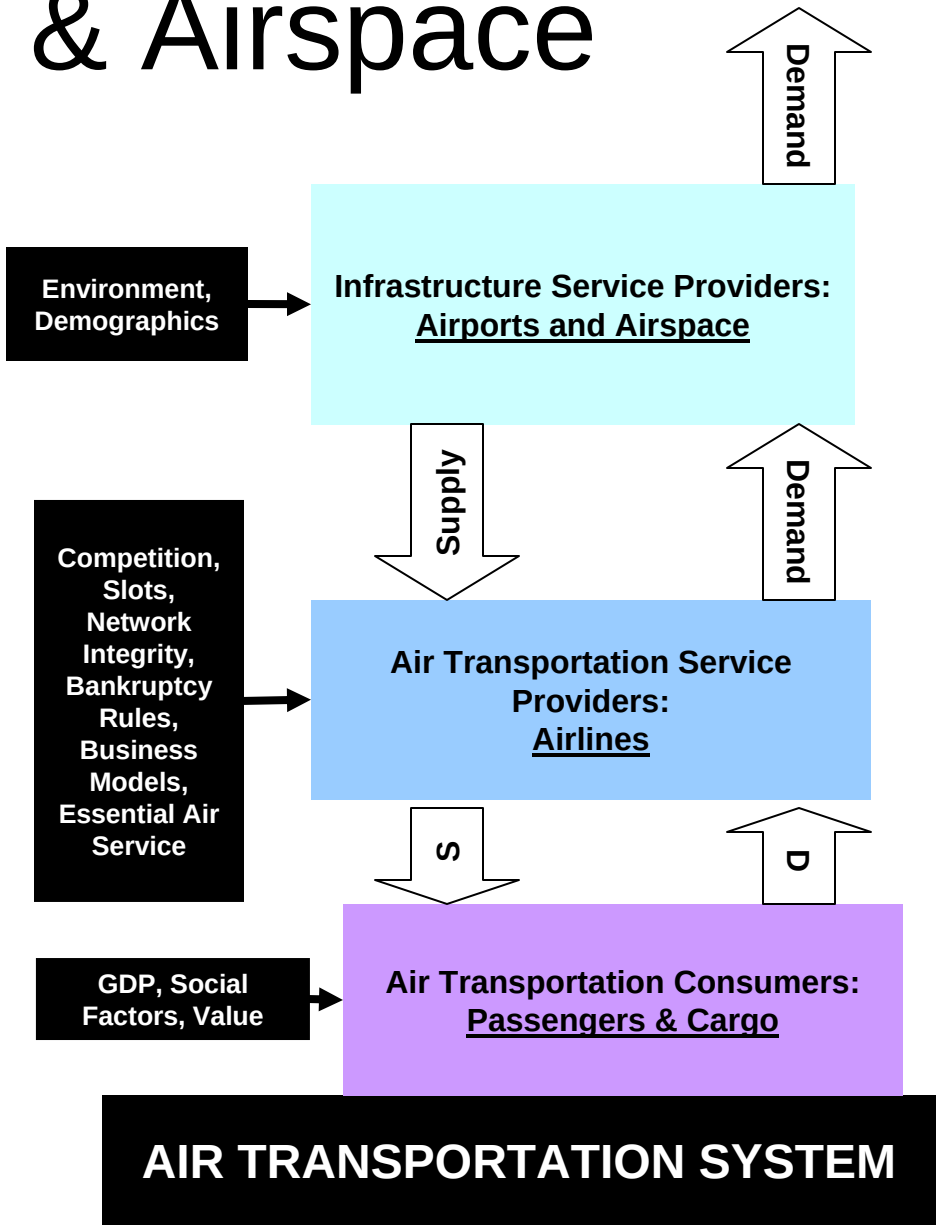
- Airline's product
  - Undifferentiated
  - Perishable
  - Subject to shifts in demand (can be sudden)
- Airline's marketplace
  - Subject to Ease-of-entry
    - Existing airline into new O/D market
  - Tendency to Monopoly or Oligolpoly
    - Tendency to gradual elimination of competitors
- Airline economics
  - Capital-intensive vs labor intensive
    - Larger, faster aircraft more capital intensive
    - High-debt/equity ratios
      - Bad position during recessions
    - Sensitive to business cycles

(2) Airlines

- Airlines largely decoupled from infrastructure
  - Exception: Hubbed operations highly dependent on hub airport (geography, capacity)
- Post-deregulation
  - High degree of flexibility in network, frequency of service, airfares
- Hyper-competitive due to low barriers to entry
  - “Price-wars” good for consumers
  - Tends towards oligopoly on specific routes (hubs)

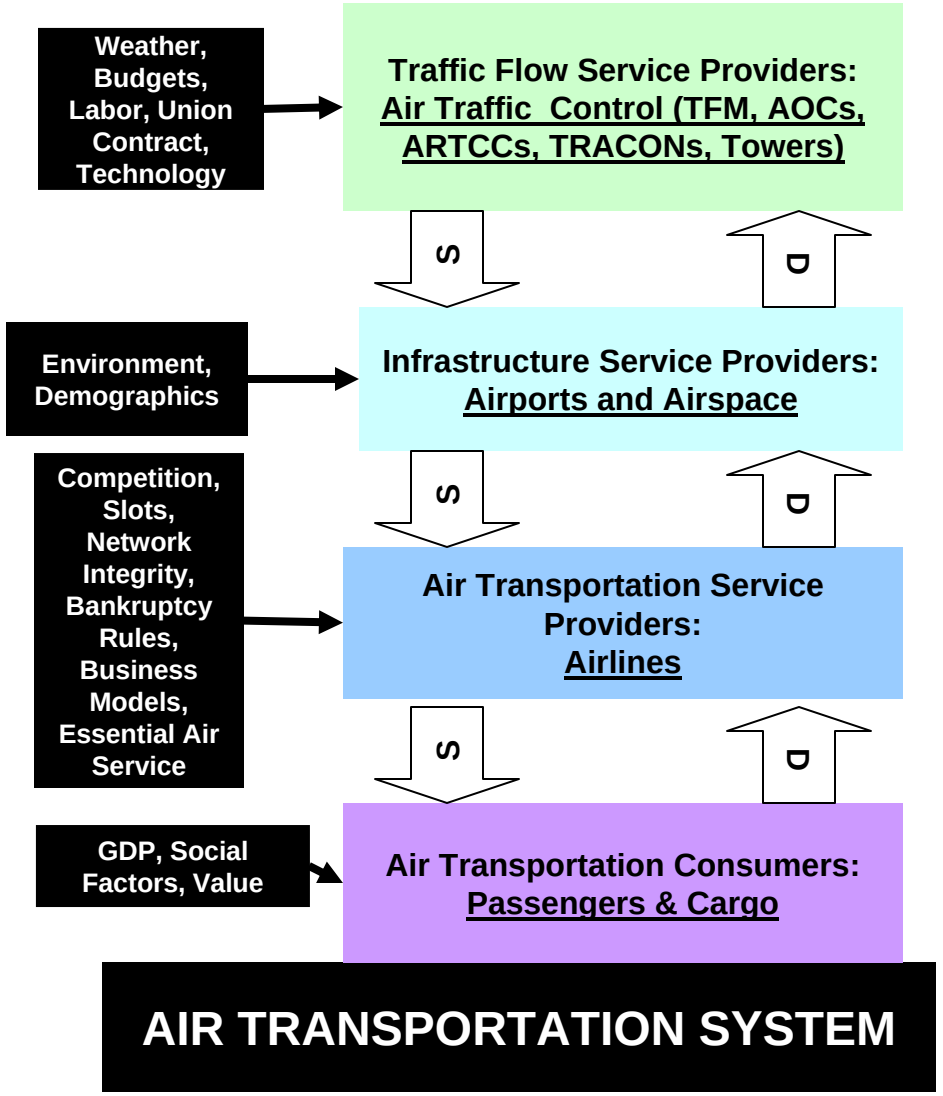
(3) Airports & Airspace

- Infrastructure Service Provider:
  - Intersection with other modes of transportation at Origin/Destination
    - Gates, runways, navigational services
  - Routes and Crz FLs
    - SIDs, STARs, airways, …
- Safety critical
  - Operates in highly regulated environment
- Subject to variability from:
  - Environment
  - Demographics
  - Weather



(4) Air Traffic Management & Control

- Flow Service Provider:
  - Sequencing and separation in Airspace & Airports
    - Coordinated by procedures
    - Performed manually today
- Involves:
  - Airline Operations Centers (AOCs)
  - Traffic Flow Management (TFM)
  - Centers, TRACONs, Towers
- Operational management of negative externalities
  - Congestion
  - accident prevention
  - Subject to variation due to weather

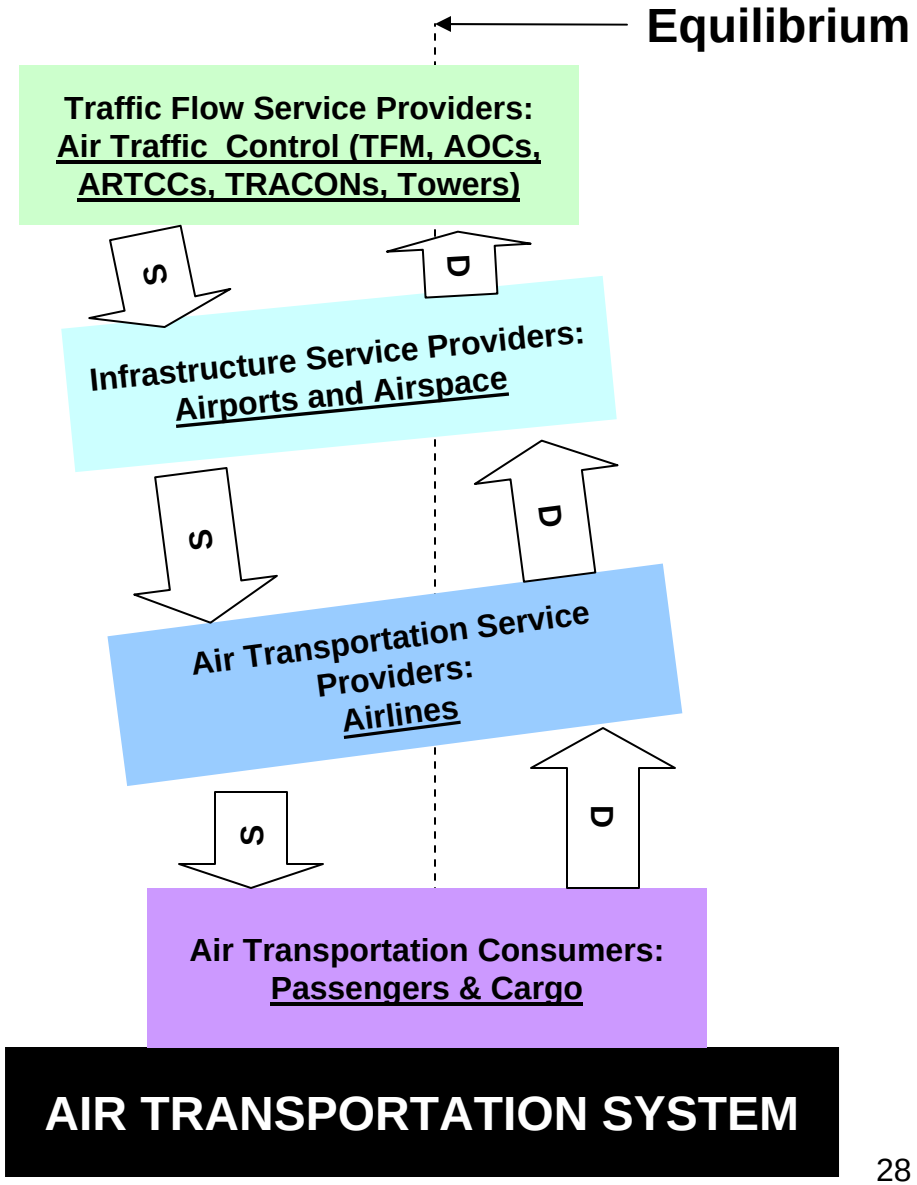


(4) Air Traffic Management & Control

- ATC operated at sector level
  - Sector is airspace controlled by ATC Specialist (ATCS)
  - Sector size determined by traffic demand and common routes
    - Human operator ability to manage traffic (12 – 20 aircraft per 15 minutes)
- Traffic Flow Management (TFM):
  - Manages traffic flow at Center Level (10 – 20 sectors)
  - Maintain aircraft count within legal threshold of ATC human workload and safe separation
  - Systematic forecast of traffic patterns that lead to overload prohibitive (Menon, Sweriduk, Bilimoria, 2004; Robelin, Sun, Wu, Bayen, 2005)
  - Decision-making based on uncertain information
- Airline Operations Centers
  - Airlines choose TFM options to maximize own-company objective function

Plant Dynamics – Inverted Pendulum

- Changes in Pax demand
  - τ = Weeks to Months
- Changes in Airlines supply
  - Routes, Frequency, Guage
    - τ = Weeks to 3 -6 Months
  - Increased Fleet
    - τ = 3 years
- Changes in A&A supply
  - Sector changes
    - τ = 3 – 6 months
  - Runways, gates, routes, Crz FLs
    - τ = 10 – 30 years
- Changes in ATM&C
  - Staffing, Sectors
  - τ = 7 – 10 years



Closing-the-Loop

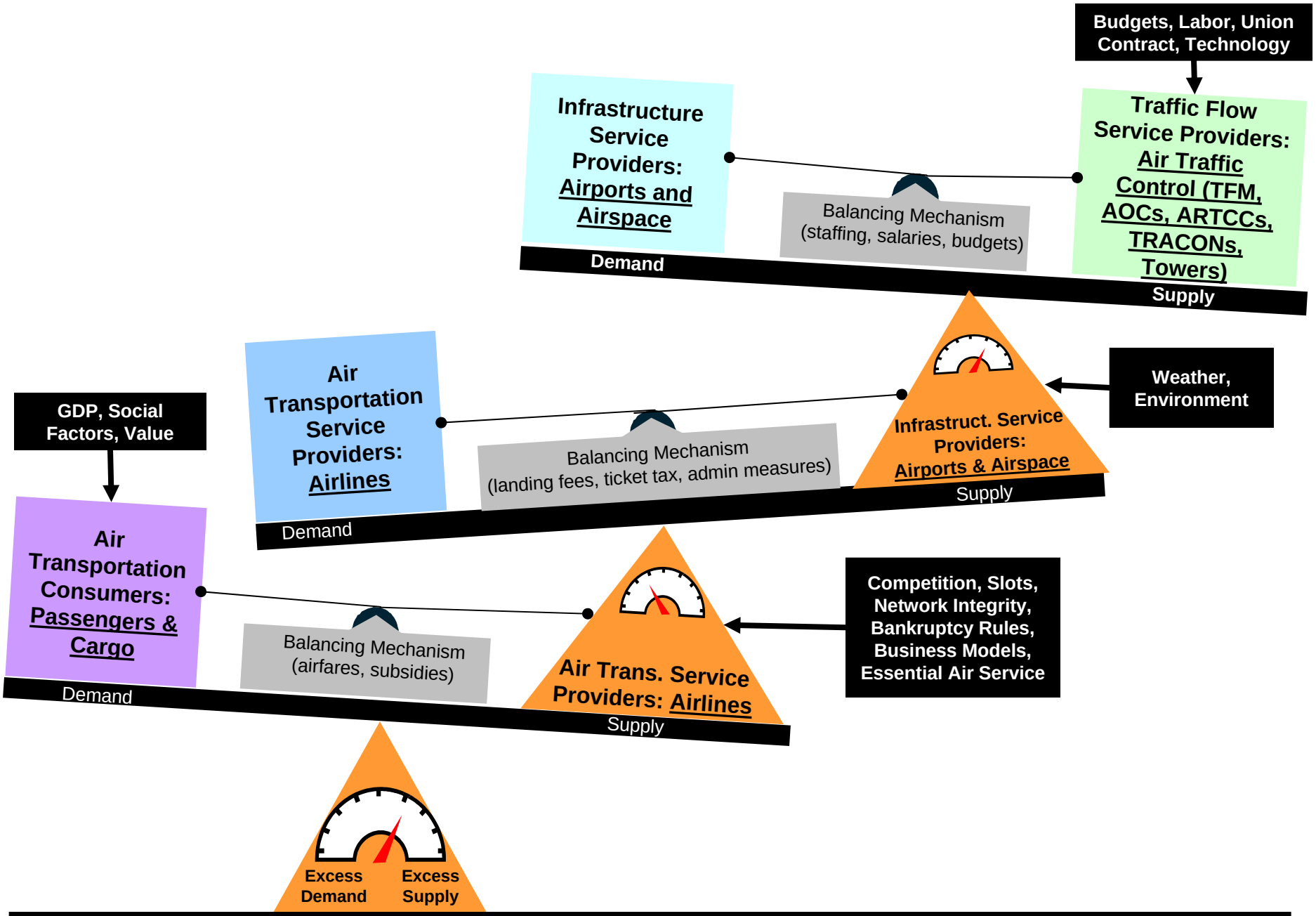
- Methods for balancing Demand and Supply for "Networked Industries "(Coase, 1988)
  1. Competitive mechanisms
  2. Market-based institutions
     - Market equilibrium through pricing (rapid and efficient)
     - Automatically manages for scarce resources
     - Subject to market-failure through monopolies, oligolopolies
  3. Private agreements
  4. Public regulation
     - Market equilibrium through regulation (slow and inefficient)
     - Slow or no response to scarce resources
     - Subject to political consideration
  5. Collaborative Decision Making
     - Voluntary (limited by collusion concerns)

Methods for Balancing Demand/Supply

- Market-based mechanisms
  - Price of service set based on cost and demand
    - When demand << capacity, price is based on cost
    - When demand ≥ capacity, price is based on demand for scarce resource
  - efficient (fast and equitable)
  - Must be protected against anti-competitive forces that lead to monopolies/oligopolies

Methods for Balancing Demand/Supply

- Public Regulation
  - Price of service set based on cost of service
    - Excise Taxes
    - Airport & Airway Trust Fund
      - Ticket Taxes
      - Fuel Taxes
    - Airport
      - Landing fees, security fees
  - Slow and inefficient (political)
  - Results in cross-subsidies
  - Emphasis on equity
    - Does not account for scarce resources



AIR TRANSPORTATION SYSTEM

Closing-the-Loop in ATS

(A) Pax/Cargo v. Airline Schedule
- Market-based: Airfare
- Administrative: Essential Air Service Subsidies

(B) Airline Schedule v. Airports & Airspace
- Market-based: Landing fees, Ticket Taxes, Fuel Taxes
  - Does not adjust for scarce resources
- Administrative: Admin Measures (slots, uni-laterals), FAA F&E budget

(C) Airport & Airspace v. Air Traffic Management & Control
- Administrative: Salaries, FAA Ops Budget
  - Does not adjust for scarce resources

(A) Pax & Cargo v. Airline Schedule

- Balancing mechanism - airfares
- Airfares distorted by:
  - Inter-airline competition for marketshare
  - Slot-ownership (use-it or lose-it)
  - Bankruptcy protection
  - Network integrity
    - Cumulative profits over network (feeders)

(B) Airline Schedules v. Airports & Airspace

- Airports & Airspace capacity limited only at congested network nodes/arcs (e.g. LGA, ORD)
- Airline demand for scheduled flights is NOT balanced with congested Airspace & Airport Capacity by any mechanism
- User-fees in the form of ticket-taxes, security taxes, and landing fees
  - intended to cover estimated costs only
  - do not take into account scarcity of resources
  - Set by political means
  - serve no purpose to regulate demand within the limits of capacity
- Administrative Measures
  - Airport capacity limits and slots
    - Favor incumbent airlines

(B) Airline Schedule v. Airports & Airspace

- Absence of “value” of “scarce” airspace & airport resources prevents application of commodity cycle
  - Airlines account for internal costs (not external)
- Problem: Property rights non-existent
    - Except Slot controlled airports (e.g. LGA, DCA)
      - Rule dependent
      - Some secondary market trading
      - Inefficient (use-it or lose-it rules)
- Value can only be assessed by consumer of resource airlines
  - Requires market-place

(C) Airspace & Airports v. ATM&C

- Airspace & Airports demand for Air Traffic Management and Control is NOT regulated by any mechanism
- Problems:
  - ATM&C Labor intensive process (ATCSs)
    - Staffing level determined by FAA-ATCS Union contract (7 years)
    - Shifting ATCS personnel is problematic
  - No signaling from Airlines or A&A
  - Political: Cross-subsidy of GA & Biz jets by Commercial
  - Absence of “value” of “slots” prevents application of commodity cycle
  - Absence of cost of ATC operations for flight prevents application of commodity cycle

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Opportunities & Challenges

Challenges for Sustainability

- Systemic changes required
  - Provide mechanisms (market-based or other) to balance demand and supply between each layer of network

1. Passenger Demand v. Airline (Seats)
   - Remove distortions in market-based mechanisms
   - Adaptive Control Laws = Revenue Management, Fleet Management
2. Airline Flight Schedules v. Airports & Airspace
   - Provide mechanism to close-the-loop to manage scarce resources
   - Schedule (and control) to departure/route/arrival slots
   - Collaborative Scheduling
3. Airports & Airspace v. ATC/AOC/TFM
   - Provide mechanism to close-the-loop to manage scarce resources
   - Control to scheduled slots
   - Collaborative Decision Making

G&C Opportunities (1)

- **Probabilistic Management of Airspace in the Presence of Weather**
- Result: Increase Capacity of Airports & Airspace
- Concept of Operations:
  - Plan traffic flows based on the probability of availability of airspace
  - Keep options open until near last minute
  - Collaborative Decision Making (CDM) provides means to equitable manage flow of traffic
  - Input to CDM “black/white” measures of availability of airspace
- Technology Transition Path
  - Extension of existing CDM process

G&C Opportunities (2)

- **Airborne Self-separation**
  - **Enroute, arrivals, and approach/landing**
- Result: Increase productivity of Air Traffic Management & Control
- Concept of Operations:
  - ATM sequences, Aircraft self-separate
  - All maneuvers
    - Multi-vehicle “energy” management problem
- Technology Transition Path
    - Typically through Experimental Class GA
    - Not in this case
    - Must come through UAVs
      - » Simple case for swarming – lead-follow

G&C Opportunities (3)

- **Contract-based ATC/Required Time of Arrival**
- Result: Increase productivity of Air Traffic Management & Control
- Concept of Operations:
  - ATM sequences and sets RTA
  - Aircraft manage trajectory
- Technology Transition Path
    - Typically through Experimental Class GA
    - Not in this case
    - Must come through UAVs
        - » Simple case for swarming – lead-follow

G&C Opportunities (4)

- **Wake Vortex Avoidance (and Encounter Guidance)**
- Result: Increase productivity of Air Traffic Management & Control
- Concept of Operations:
  - ATM sequences and sets RTA
  - Aircraft manage trajectory and self-separate
- Technology Transition Path
  - Typically through Experimental Class GA
  - UAVs not an option (too small, not jets)
  - DOD and/or Needs government program

Wake Vortex reduction through aerodynamics

G&C Opportunities (5)

- **Low Noise/Emission Guidance**
- Result: Increase Airport & Airspace Capacity
- Concept of Operations:
  - Close-loop around noise and emissions
- Technology Transition Path
    - Typically through Experimental Class GA
    - UAVs not an option (too small, not jets)
    - DOD and/or Needs government program

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Questions?

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