

# Application of Big Data Analytics to Improve Efficiencies in Air Transportation

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January, 2016



# Agenda

- **Air Transportation**
- Air Transportation, Economic Trends & Big Data
- Substitution of Capital for Labor in Air Transportation
  - Application of Big Data Analytics
- Lessons Learned

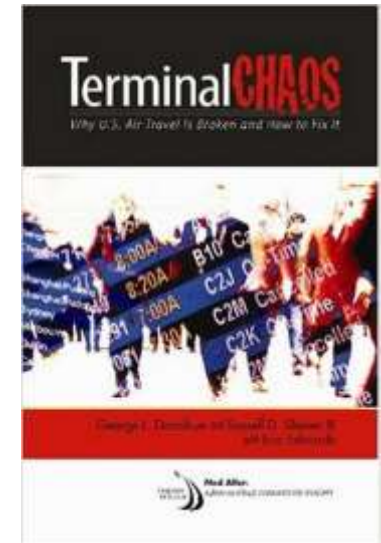
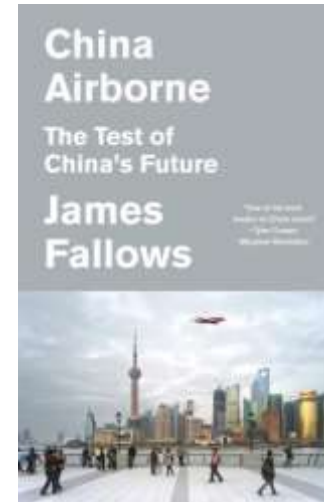
# Air Transportation – Engine of Economy

- Transportation of goods and services
  - Affordable
  - Fast
  - Remote geographic locations
  - Safe
  - Secure
- 5.1% of GDP
- 8.4% of U.S. jobs directly dependent



# Air Transportation – Network-of-Networks

- Behavior determined by Autonomous agents
  - Distributed
  - Using incomplete information
  - Operating in presence of uncertainty (e.g. weather, economics, safety, ...)
  - Adaptive
  - Competing for resources
- Complex Adaptive System-of-Systems
- 24/7/365



# Air Transportation - Scale

<b>Characteristic</b>	<b>United States</b>	<b>Europe</b>
Geographic Area covered	5.62 M square nm	6.21 M square nm
Airports with ATC services	513	433
Number of Enroute Airspace Control Centers	20	63
Total Air Traffic Controllers	13,300	17,200
Total Staff	35,500	58,000
Radar/Radio Navigation Facilities	41,000	
Technical Operations Specialists	6,000	
ATC Controlled Flights (i.e. IFR)	15.2 M	9.5 M
Average length of flight	511 nm	559 nm
Flight hours controlled	22.4 M	14.2 M

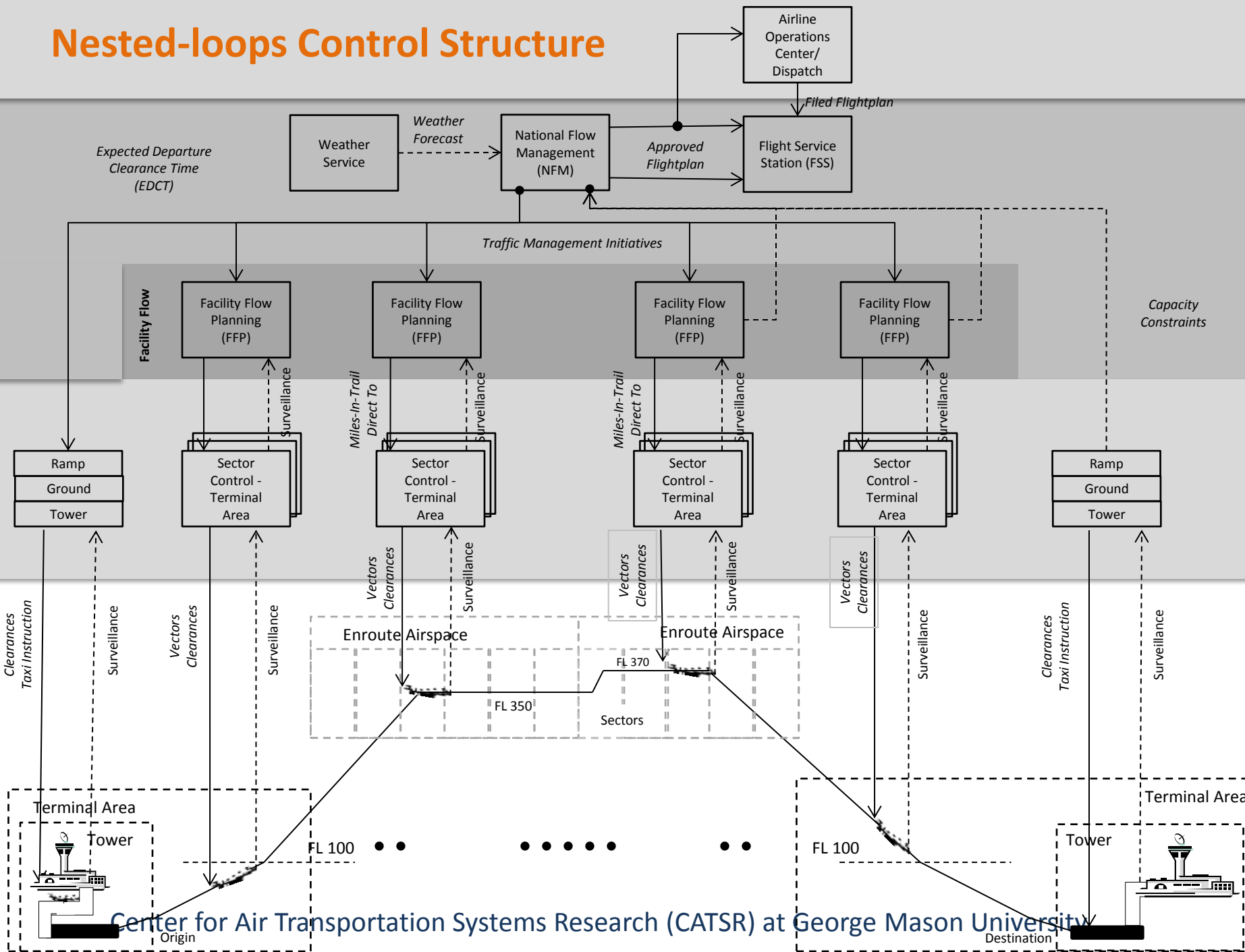
Airlines

# Nested-loops Control Structure

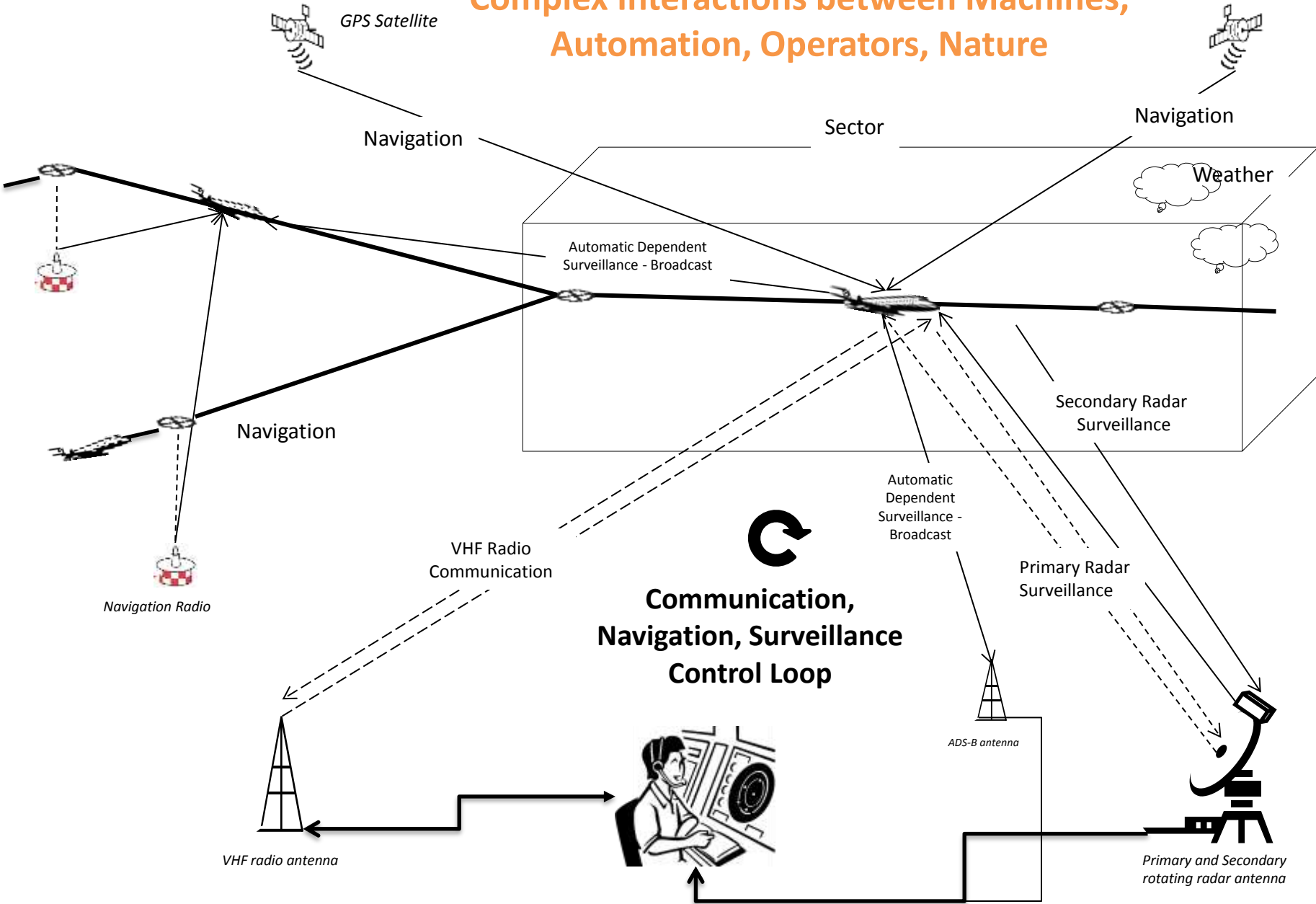
Air Traffic Management

Air Traffic Control

Flight Operations



# Complex Interactions between Machines, Automation, Operators, Nature



# Modern Day Challenges in Air Transportation

**Complexity of Interactions in Network of Distributed Agents**



**Optimized Stochastic, Capacity-limited Networked Operations**

**Optimized Networked Operations**

**Air Transportation**

- Flexible Airline Business Models
- Low Cost Carriers/Regional Jet Airlines
- Network configurations (Hub, point-to-point)

**Air Traffic Control**

- Collaborative Decision Making
- Revenue/Cost Synchronization
- Aircraft Self-separation
- Facility Resizing
- Safety/Capacity Tradeoff

**Networked Scheduled Operation**

**Air Transportation**

- Deregulation
- Hub monopolies
- Schedule/Network optimization
- Overscheduling
- Yield Management
- Fuel Management airlines

**Air Traffic Control**

- Radar
- Precision Approach

**Point-to-Point Scheduled Operations**

**Air Transportation**

- National/International Network airlines
- Civil Aviation Board

**Air Traffic Control**

- Radar
- Precision Approach
- 

**Barnstorming Operations**

**Air Transportation**

- Air Transportation - Mail

**Air Traffic Control**

- Basic Airport Traffic Control

**Aircraft**

- Basic Aero
- Propulsion

1920

1940

1960

1980

2000

**Years**

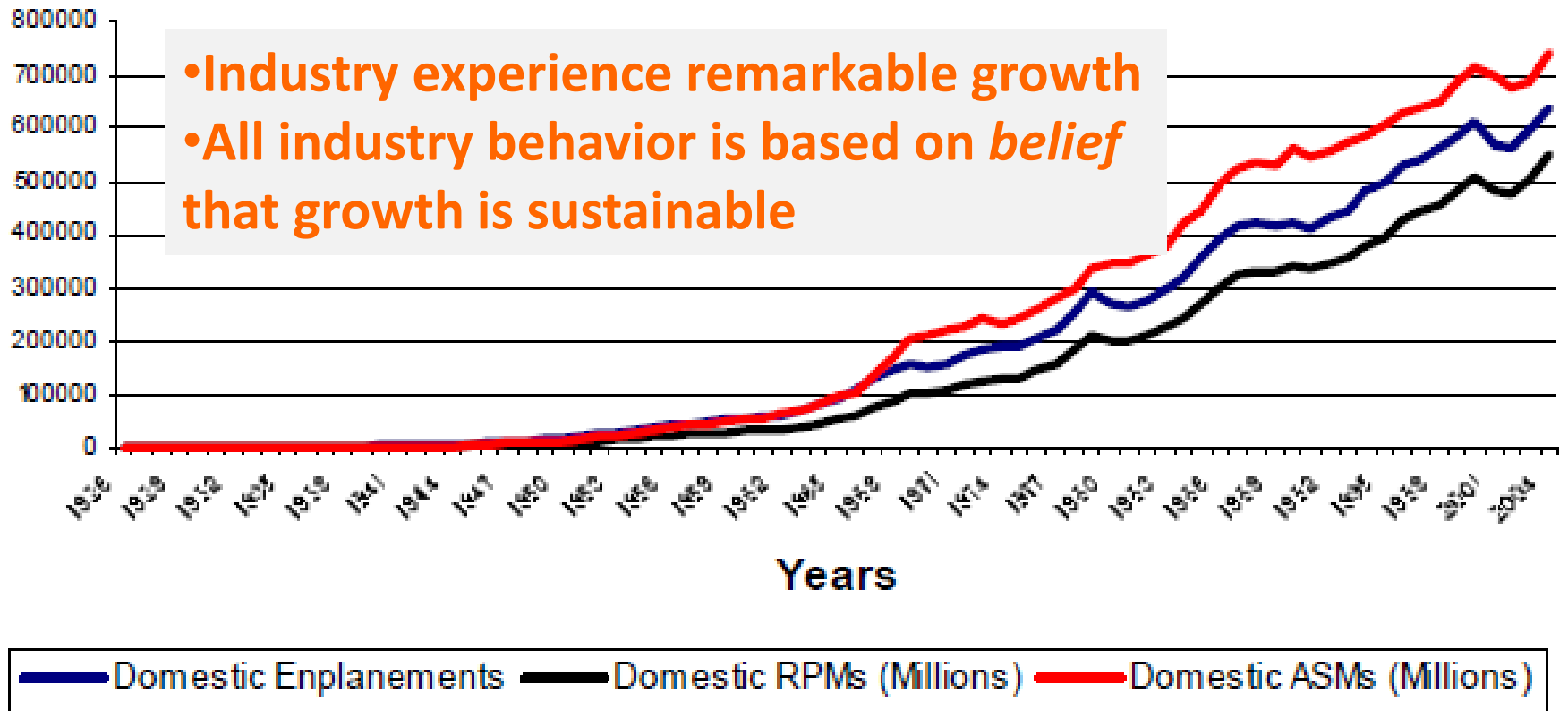


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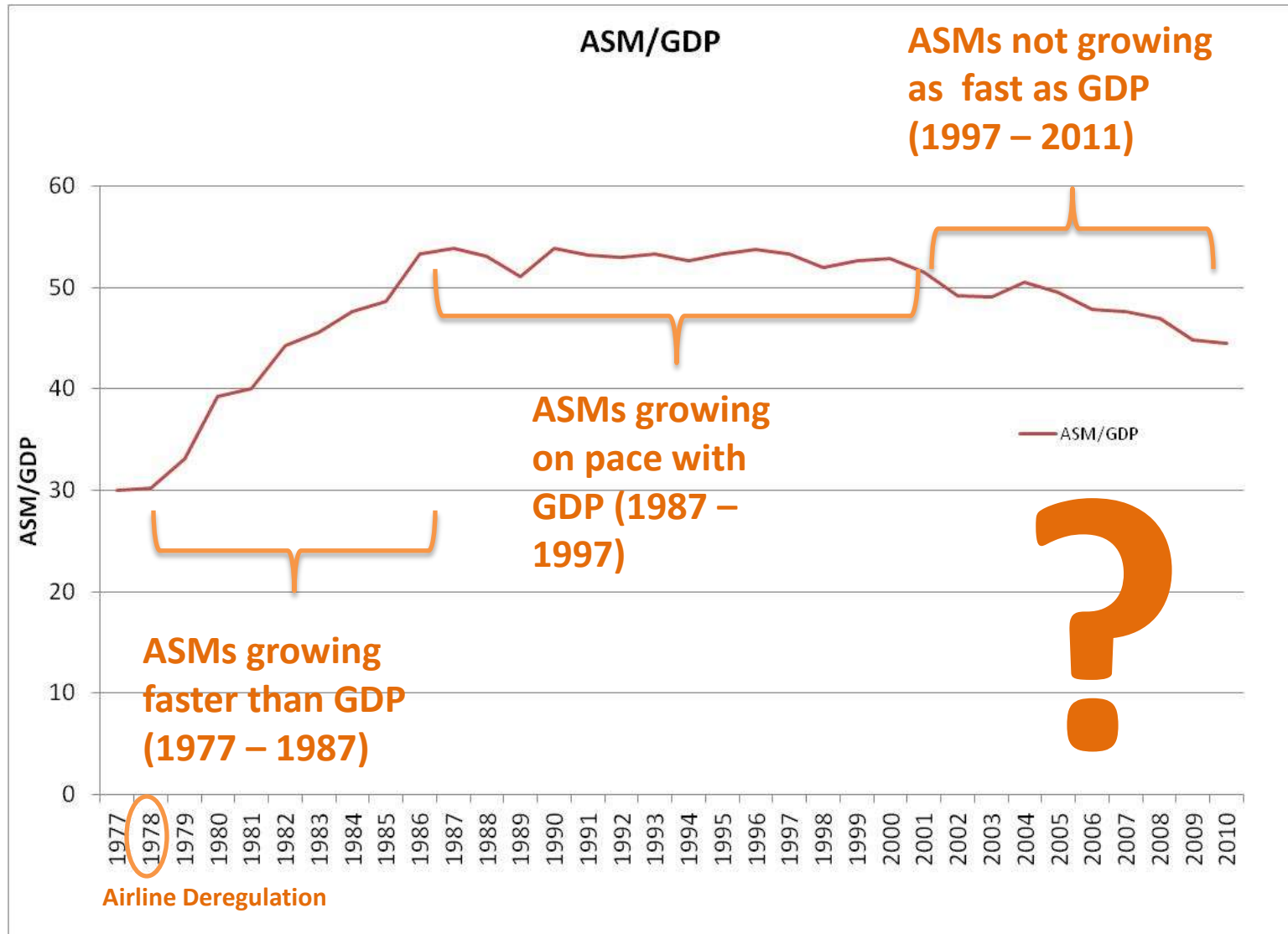
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# Air Transportation, Economic Trends

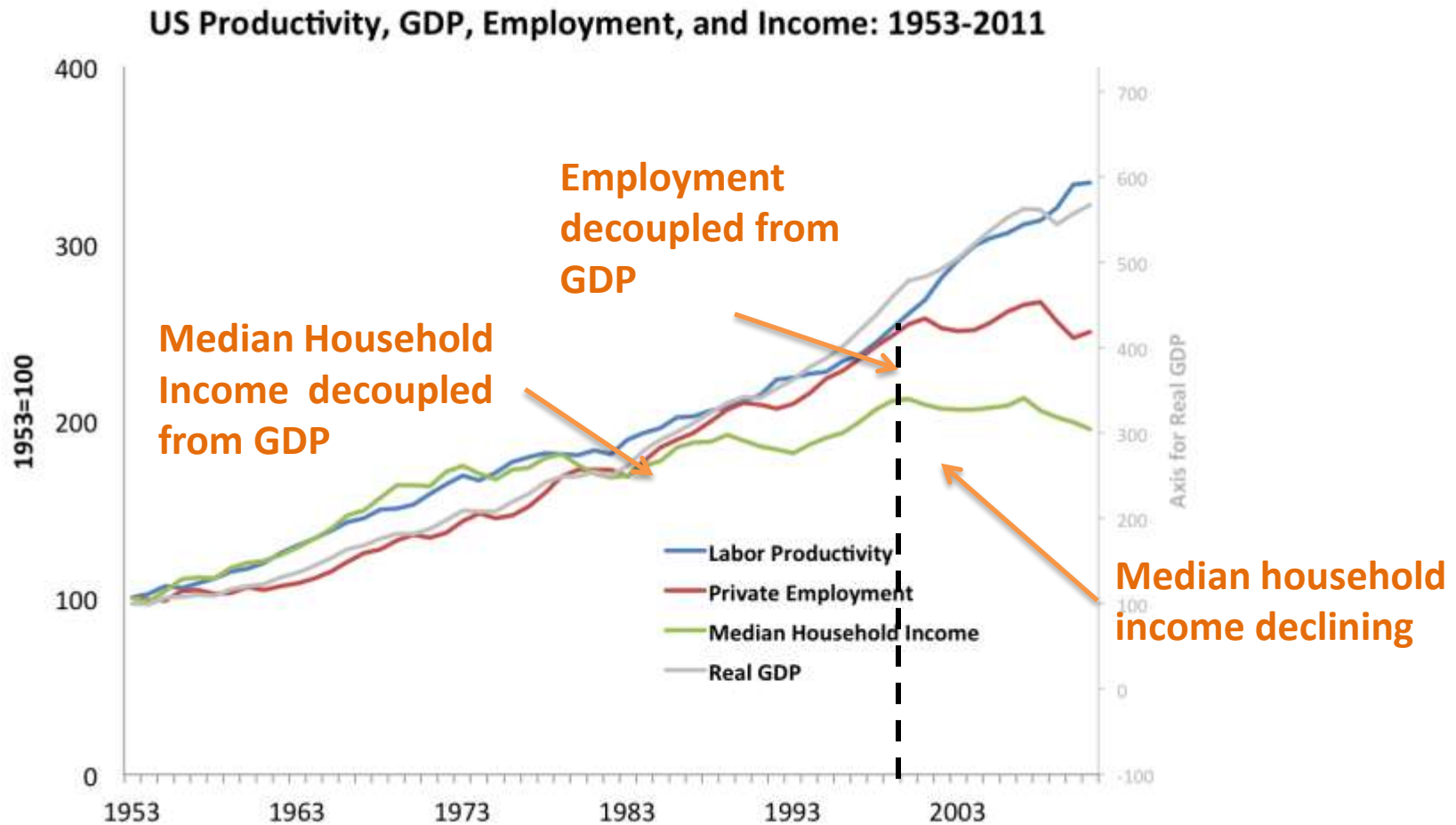
## Air Transportation Capacity and Demand



# Air Transportation Capacity and GDP



# Decoupling Income & Employment from GDP



<http://andrewmcafee.org/2012/12/the-great-decoupling-of-the-us-economy/>

Sources: Census Bureau, Bureau of Labor Statistics

# Causes of Decoupling

- Globalization
- Economic cycles
- Industry Sector Structural Changes
  
- *Digitization*
- *Recombining Innovation*
- *Changing Social Values* → *Sharing Economy*
- ...

- Substituting Capital for Labor

- Robots in manufacturing (Baxter)
- Automated Point-of-Service (iPads at Panera, Vending Machines)
- Web-based Services (Insurance, Search Engines)
- Efficiencies through Sharing and Collaboration (Uber, ...)
- Adaptive Forecasting
- Adaptive, Embedded Management and Control

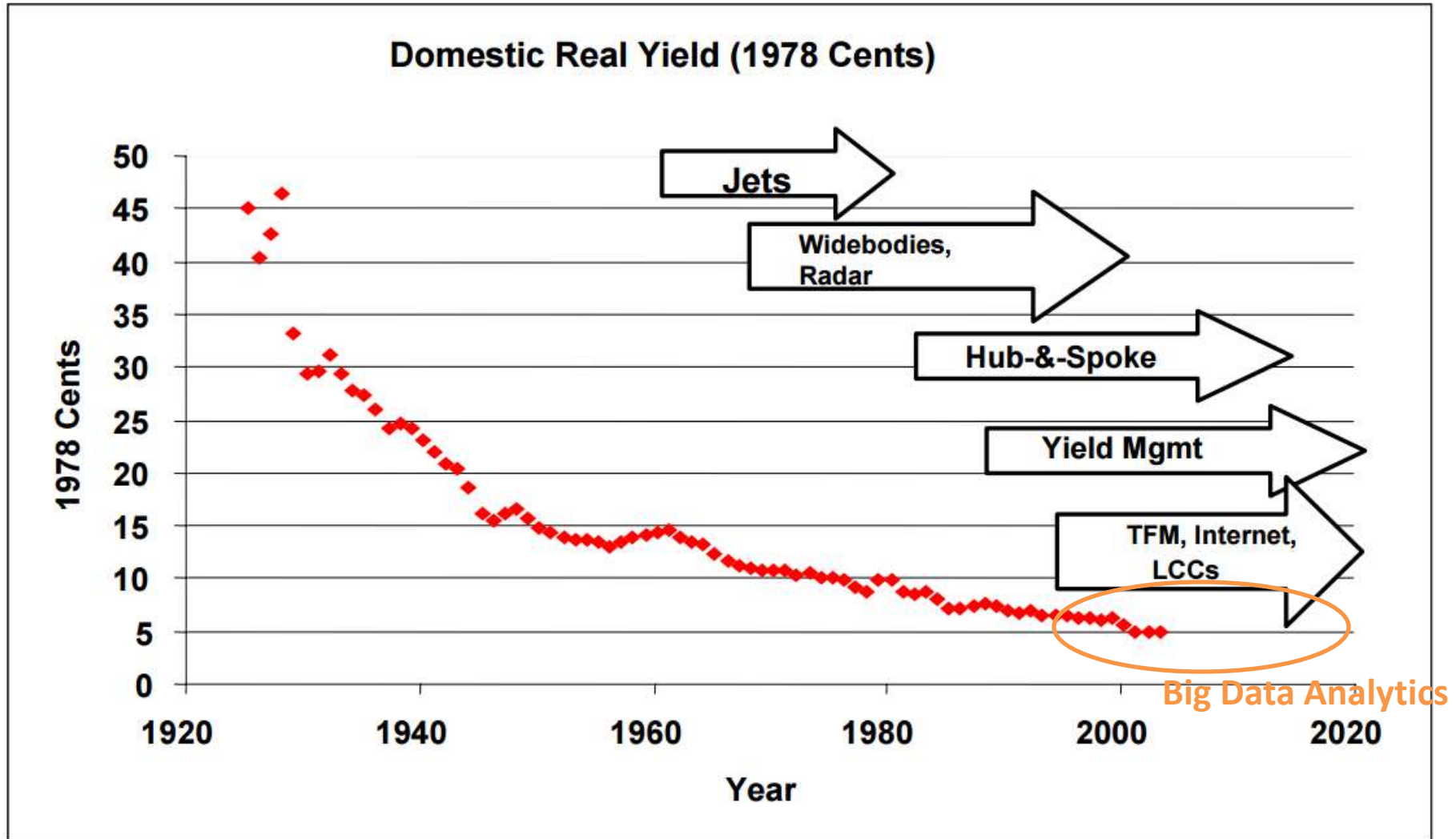
*Second Machine Age*  
(Brynjolfsson, McAfee)



# Substituting Capital for Labor

- Big Data Revolution
  - Significant improvements in size, costs of sensors
  - Sensor communications networks
  - Internet
  - Cloud storage
  - Cheap, local processing power
  - Big Data Analytics
  - Low-hanging fruit been taken

# Air Transportation Costs per Seat-Mile

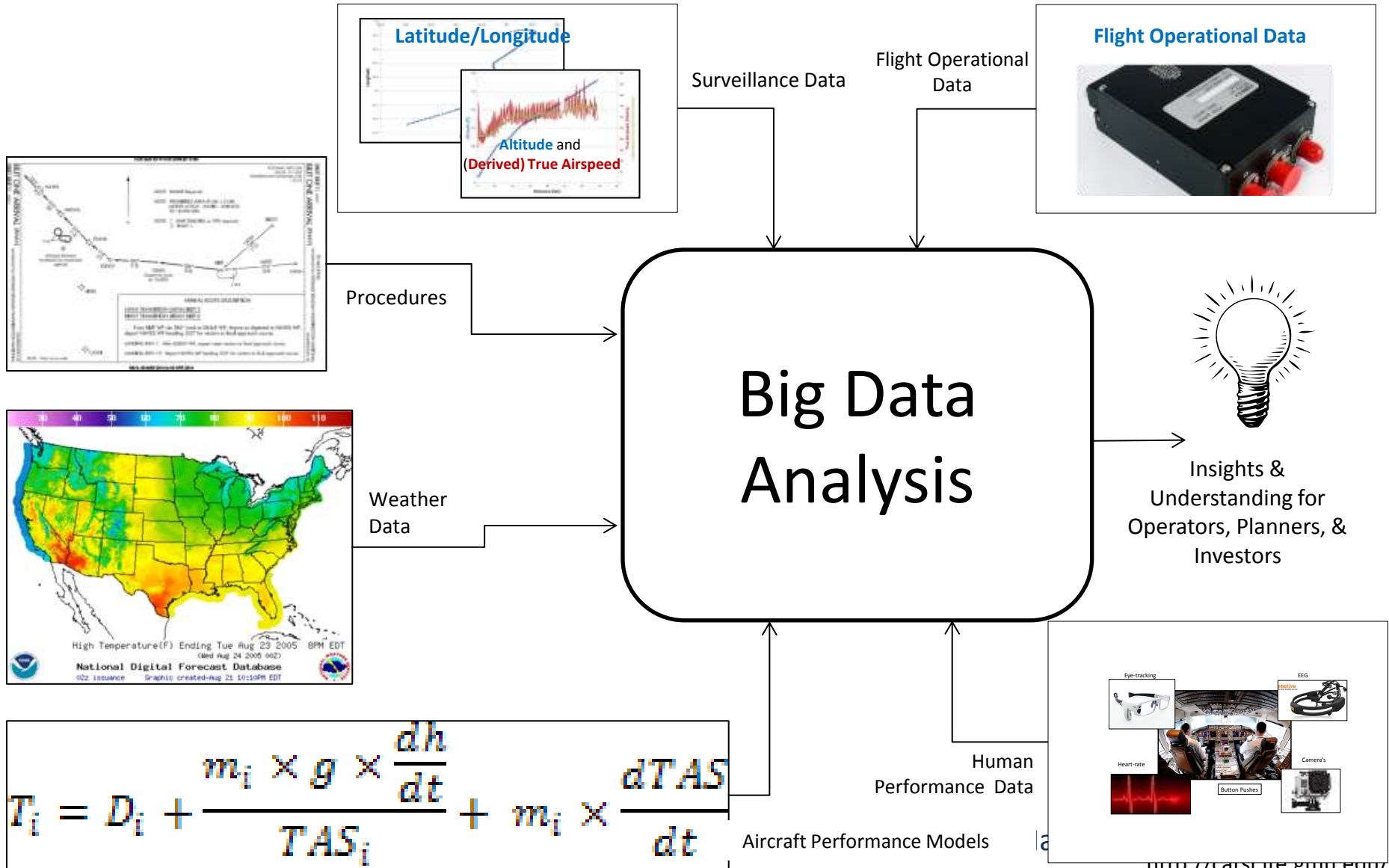


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# Big Data Analytics in Air Transportation



# Evolution of Data in Air Transportation

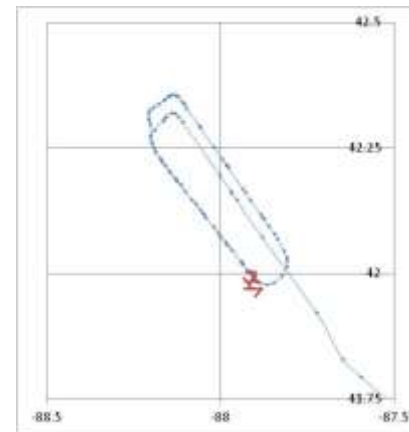
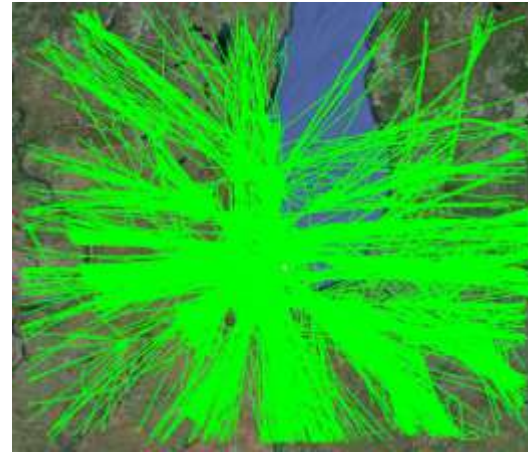
- Clip-board & Stop-watch
- Time-stamped Event Data
  - OOOI (Out, Off, On, In)
    - Automatically transmitted on ARINC Comm network
- Air Traffic Surveillance Track Data
  - ASDI
    - Radar track data
  - ASDE-X
    - Airport Vicinity & Surface
      - Multi-lateration
- Flight Data Recorder (FDR)/Flight Operational Quality Assurance (FOQA)
- Weather Data (Historic/Forecast)
  - Rapid Update Cycle (<http://ruc.noaa.gov/>)
- Human Performance
  - Eye-tracking, EEG, Heart-rate

# Agenda

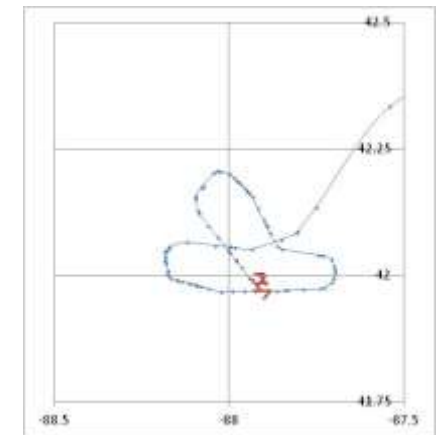
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  - **Applications of Big Data Analytics**
    1. **Event Identification (Go Arounds)**
    2. **Performance Measurement (Environmental Reporting)**
    3. **Nowcasting (Unstable Approaches)**
    4. **Anomaly Detection (Accident Analysis)**
    5. **Human Factors (From Actions to Decision-making)**
- Lessons Learned

# 1. Identify Events not Previously Possible

- **Event Identification - Go Arouds**
- Go Arouds are not measured/reported
- Track data used to count and analyze
- 80% abort – no procedures
  - Only 20% Go Around with procedure
- Merge with voluntary pilot reports to understand causes



20% - Go Around

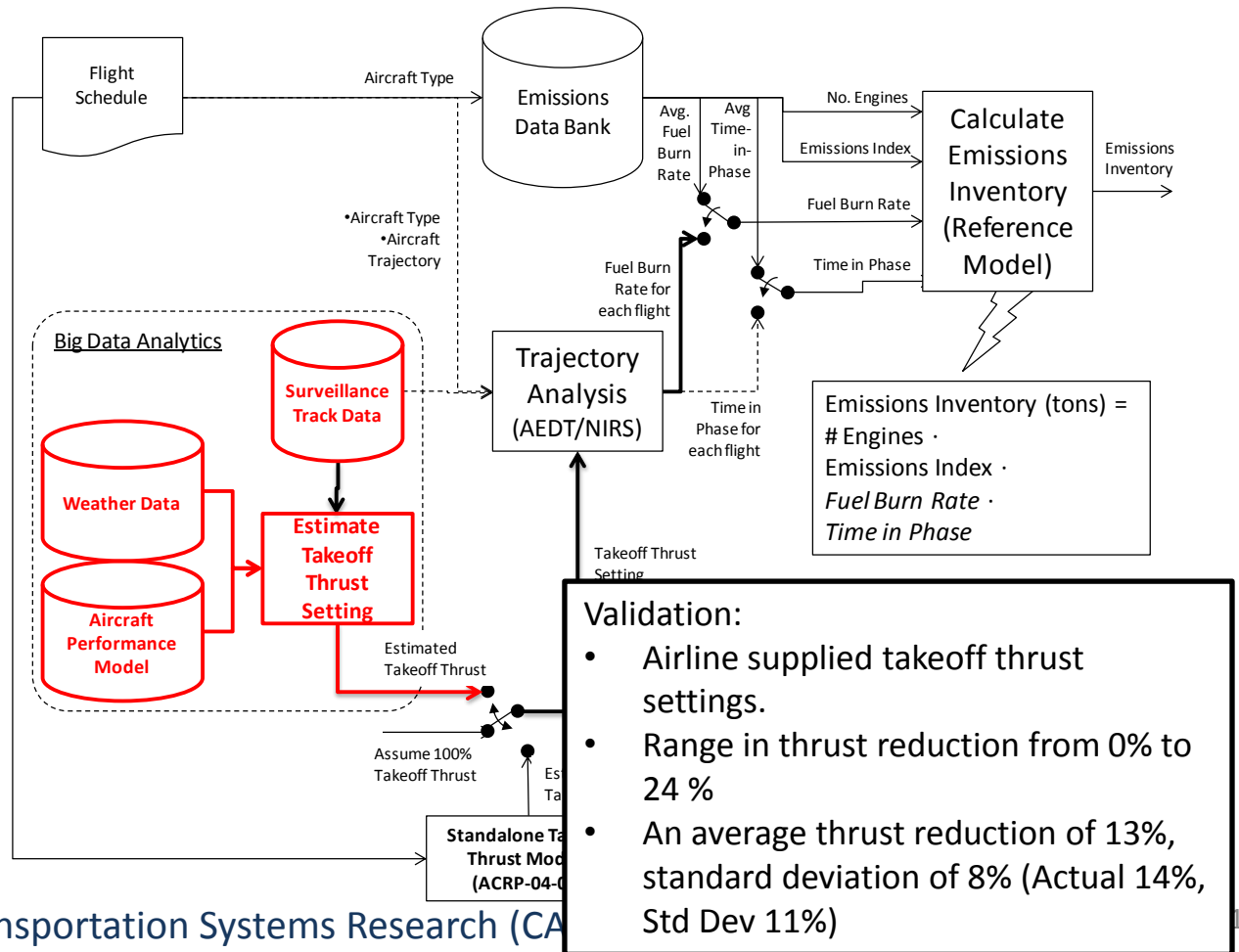


80% - Aborted Approach

# 2. Automate Manual Reporting Task with Improved Accuracy

- Automate Manual Task
- Improved Accuracy

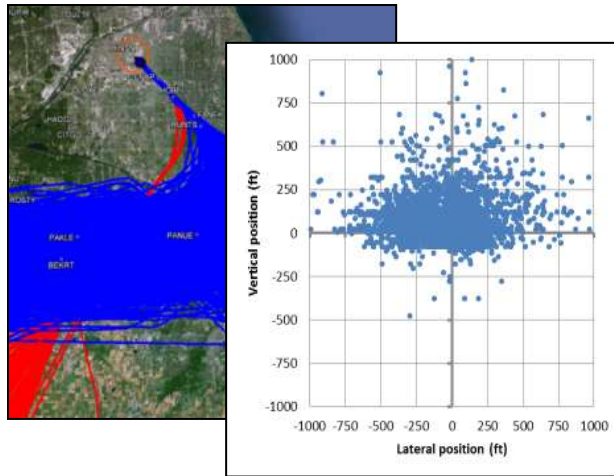
## Performance Measurement & Environmental Reporting



- Insight
- Performed Task Not Done Before
- Improved Safety

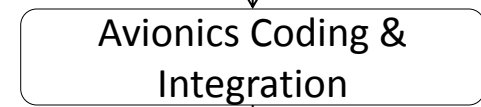
# 3. Nowcasting Operations

- Flight tracks
- Weather
- Aircraft Performance
- ATC Constraints

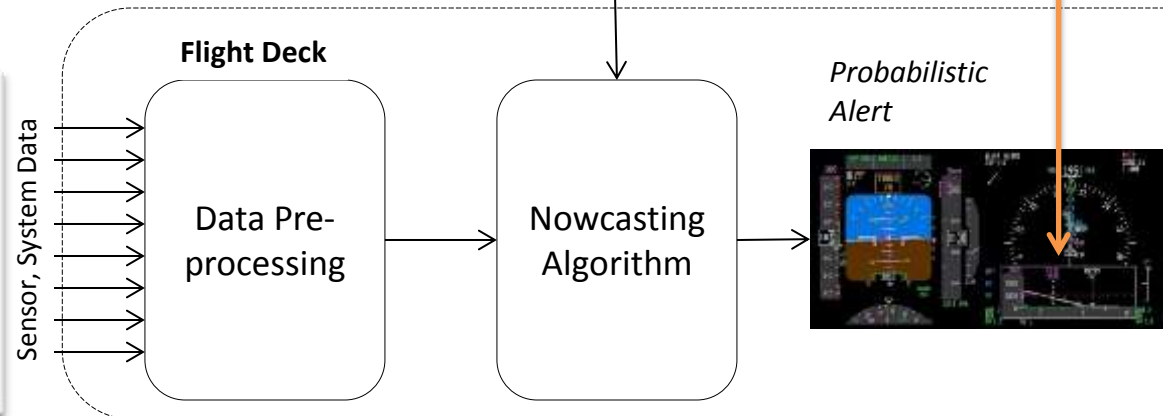
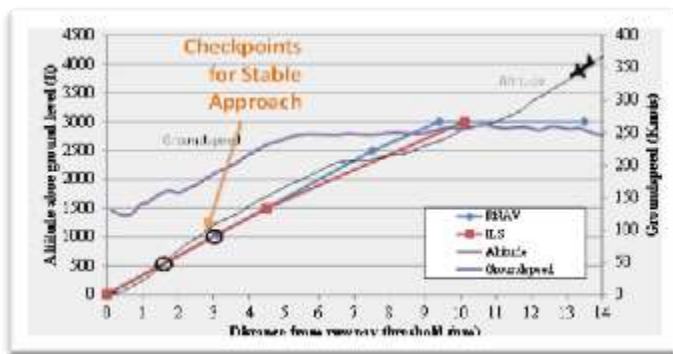


Accuracy  
Precision  
Recall

Algorithms

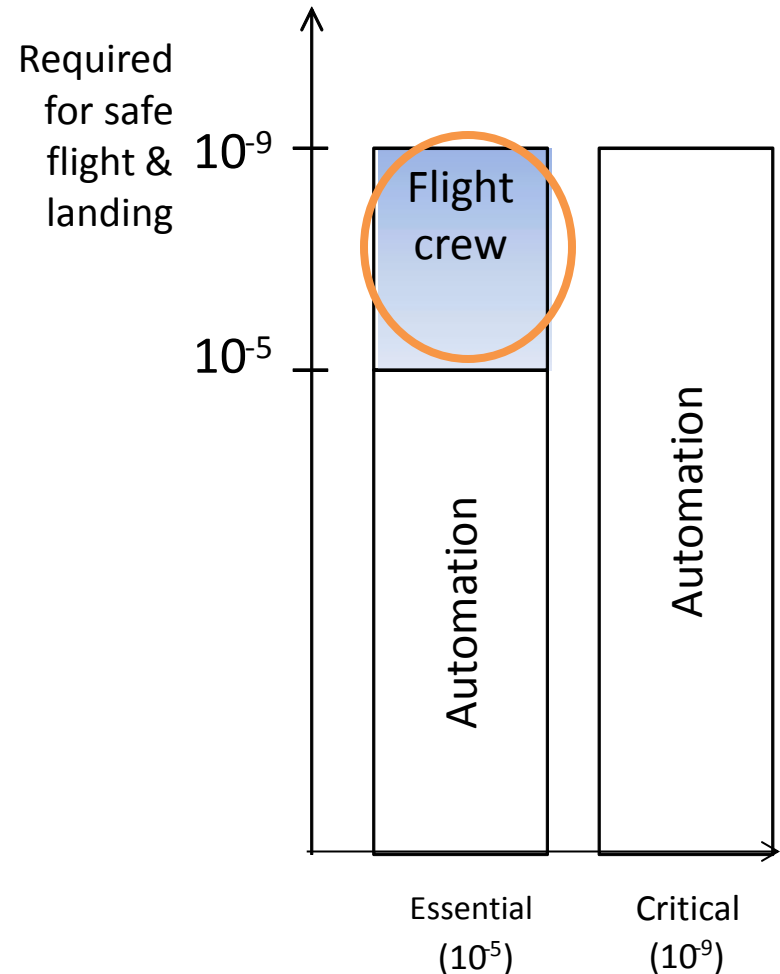


UNSTAB – SPD  
OR  
UNSTAB - ROD



# 4. Anomaly Detection

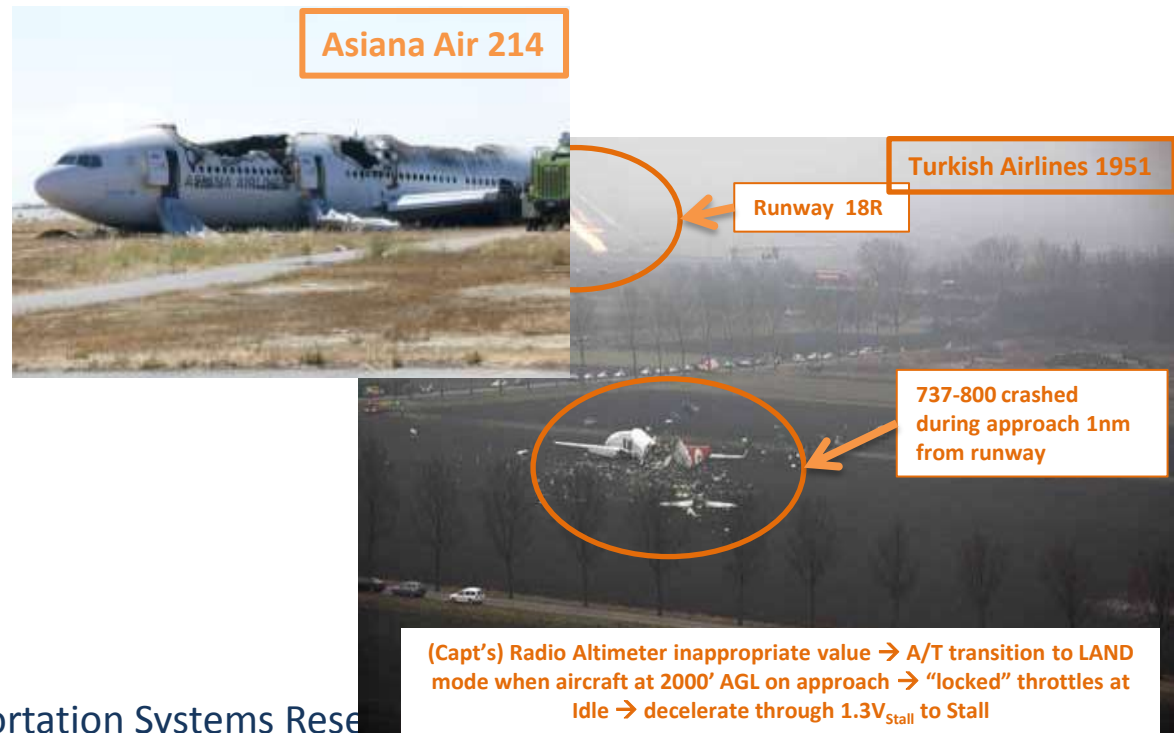
- **Flightdeck is designed for flightcrew to close the gap between  $10^{-5}$  and  $10^{-9}$  (when required)**
- In the event of failure or inappropriate command by  $10^{-5}$  automation function, flightcrew can intervene:
  - Stick-and-rudder, Throttle
  - Select Autopilot, Autothrottle



# 4. Anomaly Detection

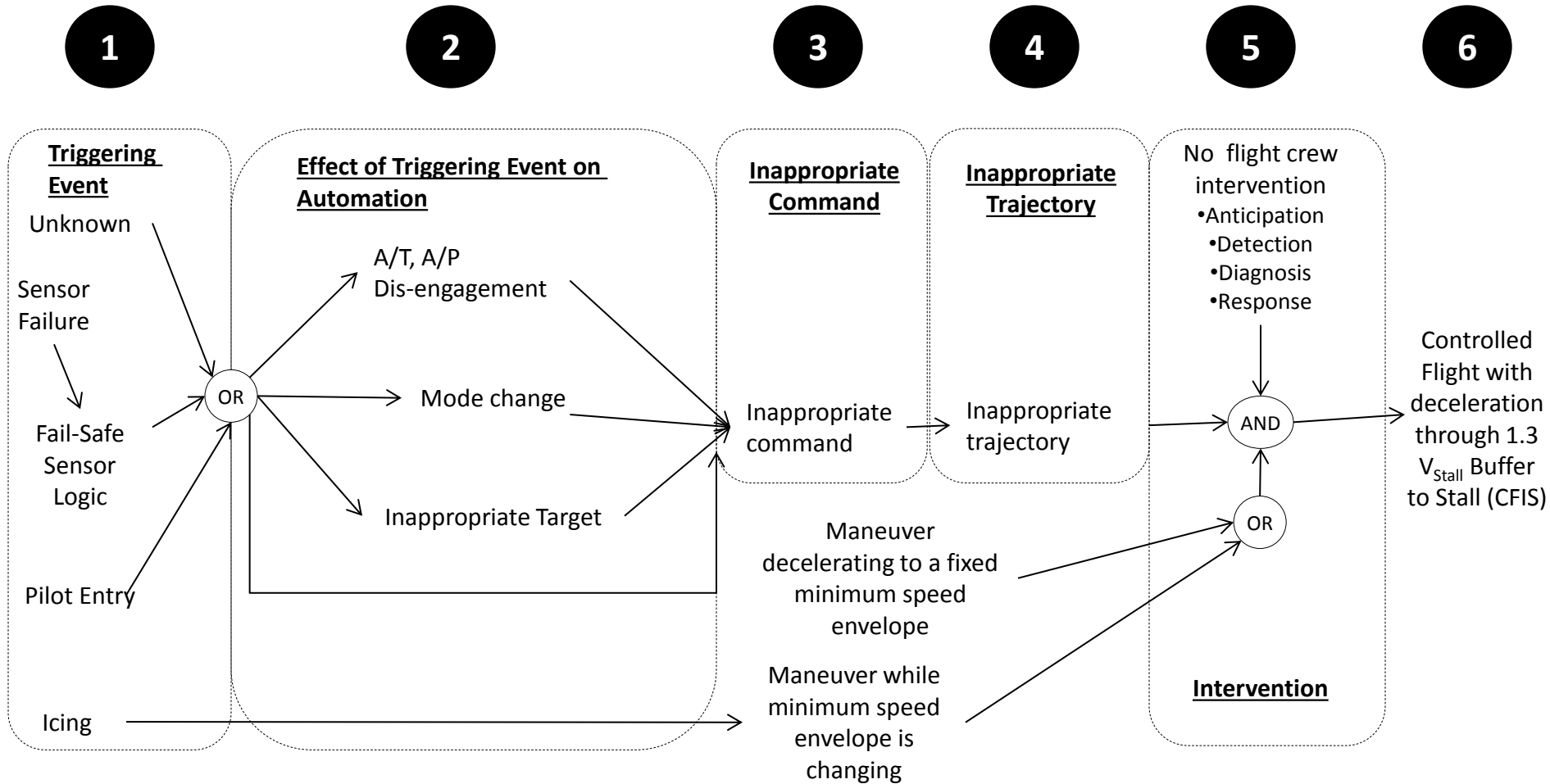
## ***Controlled Flight into Stall (CFIS)*** ***Structurally, mechanically, electronically sound aircraft flew into an aerodynamic stall***

Asiana Air (2013)
Air France (2009)
Colgan Air – Burlington (2009)
Colgan Air – Buffalo (2009)
XL Germany (2008)
ThompsonFly (2007)
Turkish Airlines (2007)
B737 - Belfast (2007)
American Eagle (2006)
Midwest (2005)
Iceland Air (2002)
King Air (2002)
American Airlines – West Palm Beach (1997)
Birgen Air (1996)
United Express - Columbus, Ohio (1994)
NWA – Stoney Point, NY ((1974)





# 4. Anomaly Detection - CFIS Scenario



No single, common cause

Complex logic/architecture

Command/Trajectory "masked"

# 5. Human Factors: From Actions to Decision-making

Eye-tracking



EEG



Heart-rate



Camera's



Button Pushes

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- **Lessons Learned**
  - 1. Organizational**
  - 2. Threats**
  - 3. Enterprise Integration**

# Lessons Learned – Organizational Issues

1. Trend of substitution of Capital for Labor will continue for foreseeable future

1. Staffing

- Growth
  - High pay data analysts
  - Low pay “operations maintenance”
- Elimination of “middle class”
  - “Occupy/Tea Party” movements

2. Investments

- Process instrumentation
- Data collection and storage
- Data analytics

3. Organizational shift to Data Science Management

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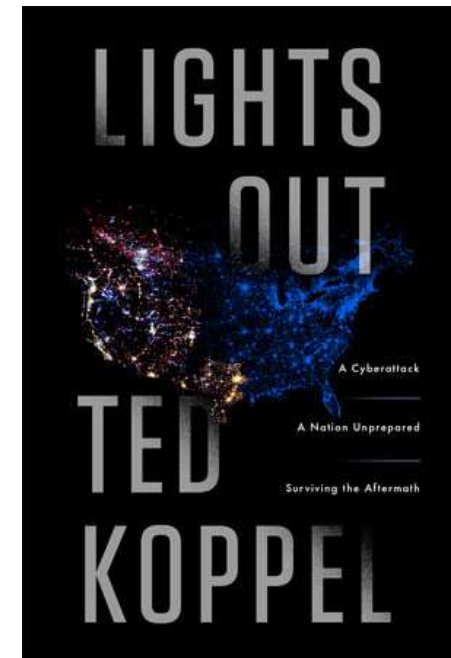
# Lessons Learned - Security

## 2. Biggest threats

- Proprietary data
- Privacy issues

## –Security

- Catch 22
  - Can't improve without research
  - Can't do research without sharing vulnerabilities
- Needs a new approach to Research
  - Incentives
  - Information sharing & control



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# Lessons Learned – Enterprise Integration

## 3. Productivity Improvements through Big Data Analytics

– Integration of Big Data Analytics and Management and Control

### **1. Know your process/product/market**

- Metrics for business goals
- Simplify process

### 2. Have the right data

### 3. Integrate/Join data across domains

### 4. Migrate from “deterministic” management and control to “probabilistic”

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# Big Data Analytics in Air Transportation

