Application of Big Data Analytics to Improve Efficiencies in Air Transportation

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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

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

Air Traffic Management

- Expected Departure Clearance Time (EDCT)
- Weather Service
  - National Flow Management (NFM)
    - Approved Flightplan
      - Filed Flightplan
        - Airline Operations Center/Dispatch
            - Facility Flow Planning (FFP)
              - Traffic Management Initiatives
                - Capacity Constraints

- Facility Flow Planning (FFP)
  - Sector Control - Terminal Area
    - Enroute Airspace
      - FL 100
        - Terminal Area
          - Ramp
          - Ground
          - Tower
      - FL 370
        - Terminal Area
          - Ramp
          - Ground
          - Tower

Air Traffic Control

- Ramp
- Ground
- Tower

Flight Operations

- Ramp
- Ground
- Tower

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Complex Interactions between Machines, Automation, Operators, Nature

Communication, Navigation, Surveillance Control Loop

GPS Satellite

VHF Radio Communication

Navigation Radio

VHF radio antenna

Primary and Secondary rotating radar antenna

Primary Radar Surveillance

Secondary Radar Surveillance

Automatic Dependent Surveillance - Broadcast

Automatic Dependent Surveillance - Broadcast

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Modern Day Challenges in Air Transportation

Complexity of Interactions in Network of Distributed Agents

Aircraft
• Basic Aero
• Propulsion

Air Transportation
• Air Transportation - Mail

Air Traffic Control
• Basic Airport Traffic Control

Point-to-Point Scheduled Operations

Air Transportation
• National Air Carriers
• Point-to-Point Service
• Inter-modal

Air Traffic Control
• En-route Air Traffic Control
• Terminal Area Traffic Control

Optimized Networked Operations

Air Transportation
• Flexible Airline Business Models
• Low Cost Carriers/Regional Jet Airlines

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

Networked Scheduled Operation

Air Transportation
• National/International Network airlines
• Civil Aviation Board

Air Traffic Control
• Radar
• Precision Approach

Optimized Stochastic, Capacity-limited Networked Operations

Air Transportation
• Deregulation
• Hub monopolies
• Schedule/Network optimization
• Overscheduling
• Yield Management
• Fuel Management airlines

Air Traffic Control
• Radar
• Precision Approach

2000 Barnstorming Operations
Agenda

• Air Transportation

• **Air Transportation, Economic Trends & Big Data**

• Substitution of Capital for Labor in Air Transportation

• Applications of Big Data Analytics

• Lessons Learned
Air Transportation, Economic Trends

- Industry experience remarkable growth
- All industry behavior is based on belief that growth is sustainable
Air Transportation Capacity and GDP

- **1977 – 1987**: ASMs growing faster than GDP
- **1987 – 1997**: ASMs growing on pace with GDP
- **1997 – 2011**: ASMs not growing as fast as GDP

Airline Deregulation
Decoupling Income & Employment from GDP

Median Household Income decoupled from GDP

Employment decoupled from GDP

Median household income declining

http://andrewmcafee.org/2012/12/the-great-decoupling-of-the-us-economy/
Causes of Decoupling

- Globalization
- Economic cycles
- Industry Sector Structural Changes

- *Digitization*
- *Recombining Innovation*
- *Changing Social Vales ➔ 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
Agenda

• Air Transportation
• Air Transportation, Economic Trends & Big Data
• **Substitution of Capital for Labor in Air Transportation**
  – Applications of Big Data Analytics
• Lessons Learned
Big Data Analytics in Air Transportation

Surveillance Data
Flight Operational Data
Latitude/Longitude
Altitude and (Derived) True Airspeed

Procedures
Weather Data

Flight Operational Data

Human Performance Data
Aircraft Performance Models

Insights & Understanding for Operators, Planners, & Investors

http://catsr.ite.gmu.edu/
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

• Air Transportation
• Air Transportation, Economic Trends & Big Data
• Substitution of Capital for Labor in Air Transportation
  – 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 Arounds**
- Go Arouunds 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
2. Automate Manual Reporting Task with Improved Accuracy

Performance Measurement & Environmental Reporting

Validation:
- Airline supplied takeoff thrust settings.
- Range in thrust reduction from 0% to 24%
- An average thrust reduction of 13%, standard deviation of 8% (Actual 14%, Std Dev 11%)
3. Nowcasting Operations

- Flight tracks
- Weather
- Aircraft Performance
- ATC Constraints

Algorithm Training & Testing

Avionics Coding & Integration

Flight Deck

Data Pre-processing

Nowcasting Algorithm

Accuracy
Precision
Recall

UNSTAB – SPD
OR
UNSTAB - ROD

Probabilistic Alert

• Insight
• Performed Task Not Done Before
• Improved Safety
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

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Essential ($10^5$)  
Critical ($10^9$)  
Required for safe flight & landing
4. Anomaly Detection

**Controlled Flight into Stall (CFIS)**

*Structurally, mechanically, electronically sound aircraft flew into an aerodynamic stall*

<table>
<thead>
<tr>
<th>Event</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asiana Air</td>
<td>2013</td>
</tr>
<tr>
<td>Air France</td>
<td>2009</td>
</tr>
<tr>
<td>Colgan Air – Burlington</td>
<td>2009</td>
</tr>
<tr>
<td>Colgan Air – Buffalo</td>
<td>2009</td>
</tr>
<tr>
<td>XL Germany</td>
<td>2008</td>
</tr>
<tr>
<td>ThompsonFly</td>
<td>2007</td>
</tr>
<tr>
<td>Turkish Airlines</td>
<td>2007</td>
</tr>
<tr>
<td>B737 - Belfast</td>
<td>2007</td>
</tr>
<tr>
<td>American Eagle</td>
<td>2006</td>
</tr>
<tr>
<td>Midwest</td>
<td>2005</td>
</tr>
<tr>
<td>Iceland Air</td>
<td>2002</td>
</tr>
<tr>
<td>King Air</td>
<td>2002</td>
</tr>
<tr>
<td>American Airlines – West Palm Beach</td>
<td>1997</td>
</tr>
<tr>
<td>Birgen Air</td>
<td>1996</td>
</tr>
<tr>
<td>United Express – Columbus, Ohio</td>
<td>1994</td>
</tr>
<tr>
<td>NWA – Stoney Point, NY</td>
<td>1974</td>
</tr>
</tbody>
</table>

(Capt's) Radio Altimeter inappropriate value → A/T transition to LAND mode when aircraft at 2000’ AGL on approach → “locked” throttles at Idle → decelerate through 1.3$V_{Stall}$ to Stall
4. Anomaly Detection - CFIS Scenario

**Triggering Event**
- Unknown
- Sensor Failure
- Fail-Safe Sensor Logic
- Pilot Entry
- Icing

**Effect of Triggering Event on Automation**
- A/T, A/P Dis-engagement
- Mode change
- Inappropriate Target

**Inappropriate Command**
- Inappropriate command

**Inappropriate Trajectory**
- Maneuver decelerating to a fixed minimum speed envelope
- Maneuver while minimum speed envelope is changing

**No flight crew intervention**
- Anticipation
- Detection
- Diagnosis
- Response

**Intervention**
- Controlled Flight with deceleration through 1.3 $V_{stall}$ Buffer to Stall (CFIS)

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**No single, common cause**

**Complex logic/architecture**

**Command/Trajectory “masked”**

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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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- Procedures
- Weather Data
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Big Data Analysis

- Latitude/Longitude
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