Knowledge Discovery Process

Case Study of RNAV Adherence of Radar Track Data

Bryan Matthews March 22nd 2018

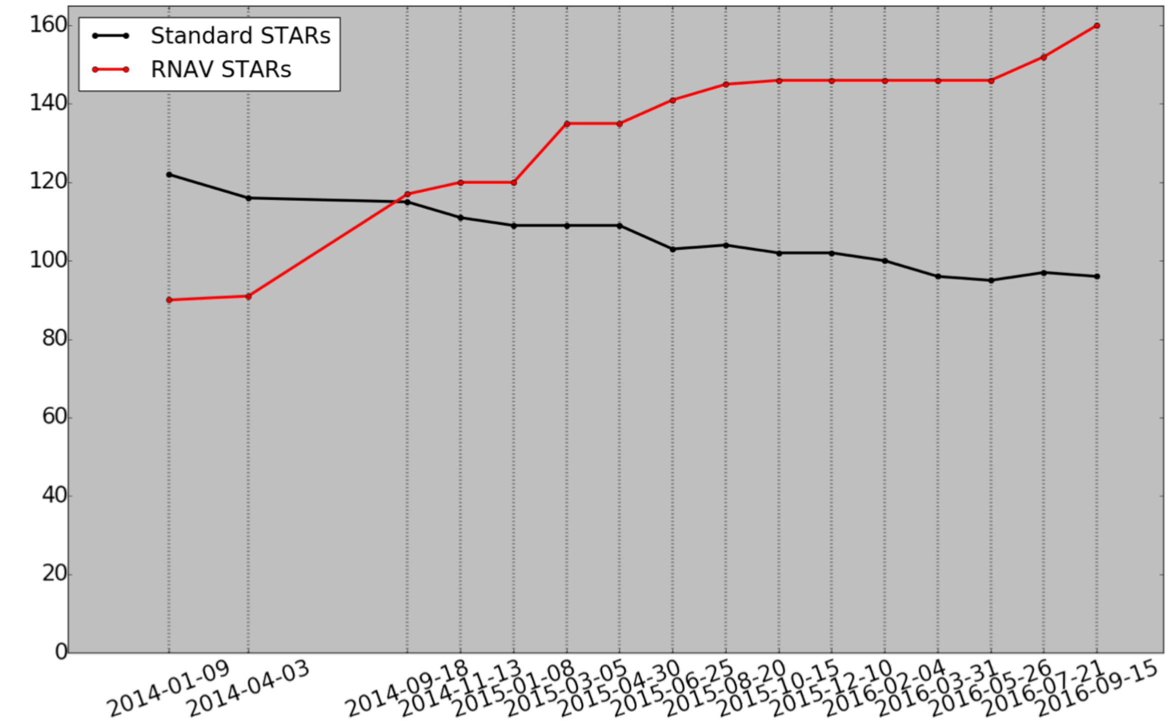
Outline

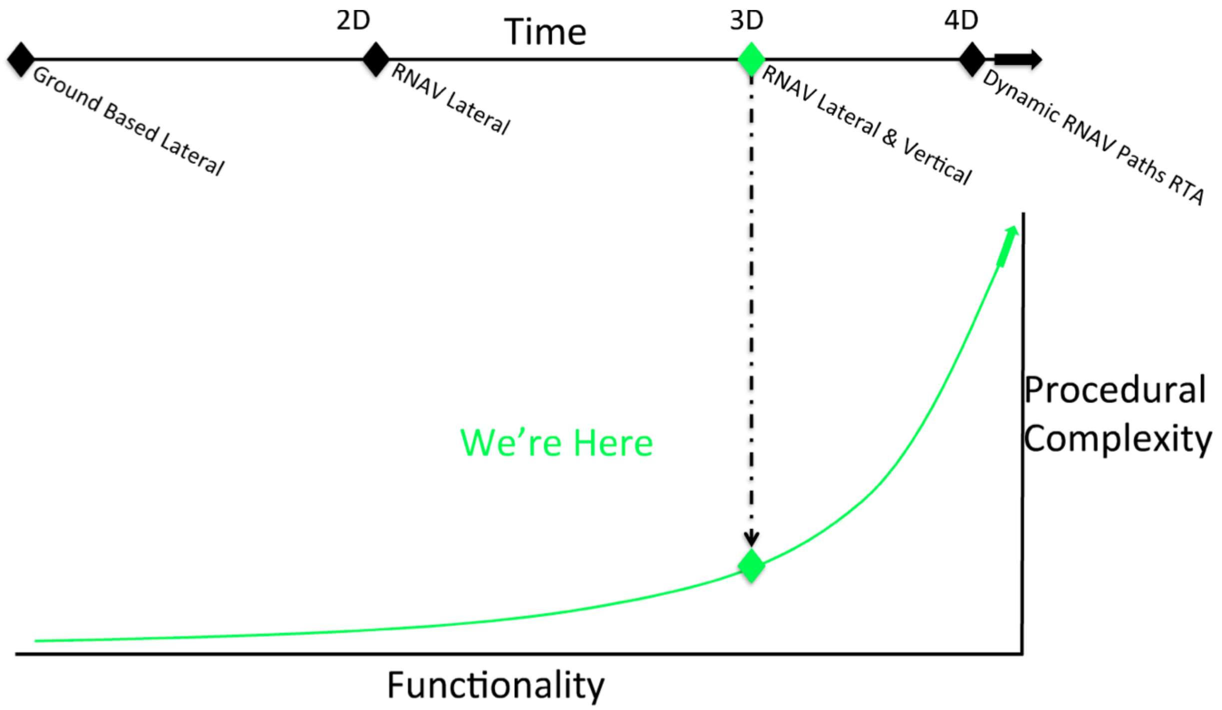
- Identify the problem (prediction, classification, statistical analysis, etc.)
- Initial fact gathering (interview domain experts, review reports, articles)
- Survey supporting data sources
- Selecting relevant features and sources
- Understand the data (numerical, categorical, text, sampling rate, data quality issues, etc.)
- Acquire the data
- Merge data sources (temporal, spatial, common key, other...)
- Derive new features (non linear relationships)
- Build data processing pipeline (may need to tap into data stream, develop parallel processing algorithm etc.)
- Build model and test (tune hyper-parameters, cross validation. Map to original problem.)
- Analyze results (do the results make sense. Does it answer the original question).
- Deploy/Publish

Identify Problem

- What are the shortcomings that need to be addressed
  - What is well understood and what is not?
  - What do we need to learn?
  - How can data mining/machine learning help achieve this?
- What sort of problem is being addressed?
  - Choosing White/Gray/Black Box Method
  - Prediction
    - Event/category or scalar value
  - Classification
    - Binary/multi-class
  - Statistical Analysis
    - Identifying trends
    - Summary statistics

Identify Problem: Case Study





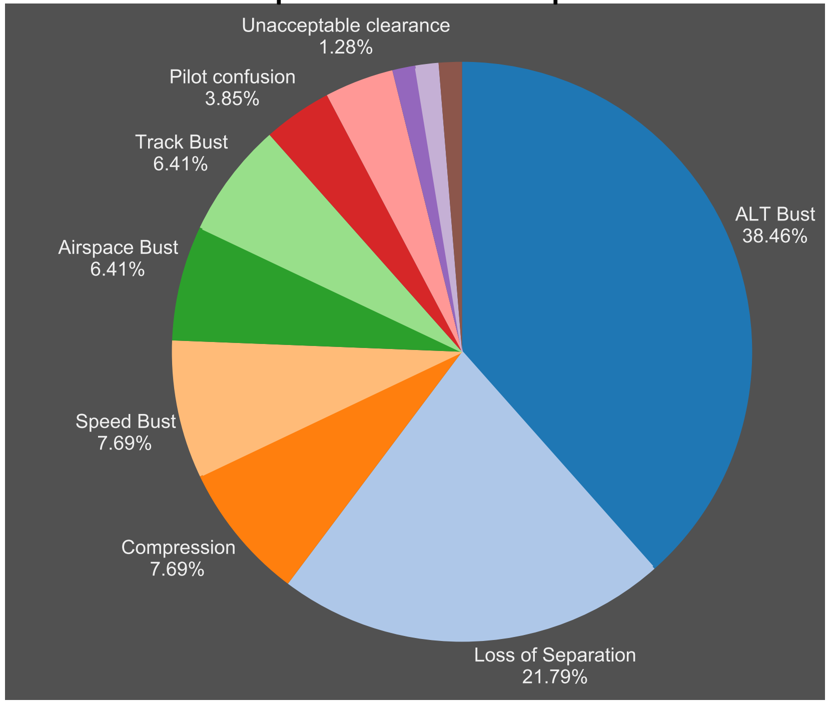
- What is the impact of the increase in more complex operations?
  - How often are these utilized? (Statistical assessment)
  - Does this help or hinder efficiency/safety? (Statistical assessment)
  - If not fully utilized what factors affect usability? (Predictability of event type)
    - White box algorithm needed for interpretability
    - Classification problem to identify adverse events (non-adherence)

Initial fact gathering

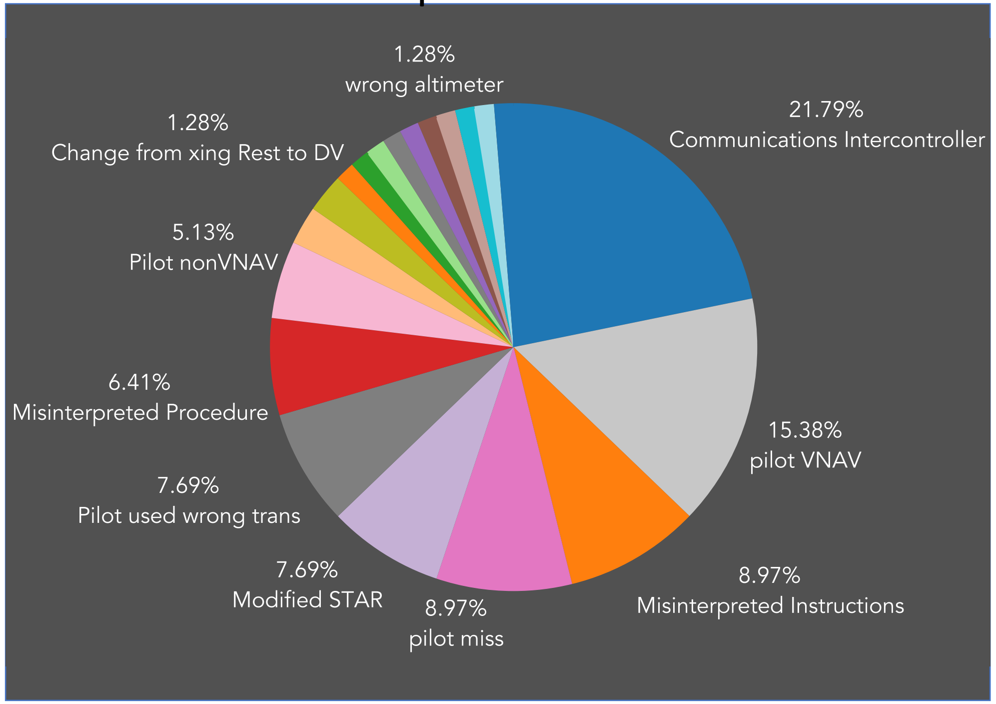
- Interview domain experts
  - Learn how the domain currently operates.
  - Is there automation, what roll do humans have?
- Review reports
  - Are their logs, complaints, free text reports that support the need to address the deficiency in the system?
- Review State-of-the-art research
  - Has anyone addressed this or part of this problem and how?
  - Have similar problems been solved in other domains?

Initial fact gathering: Case Study

Reported Consequences



Reported Causes



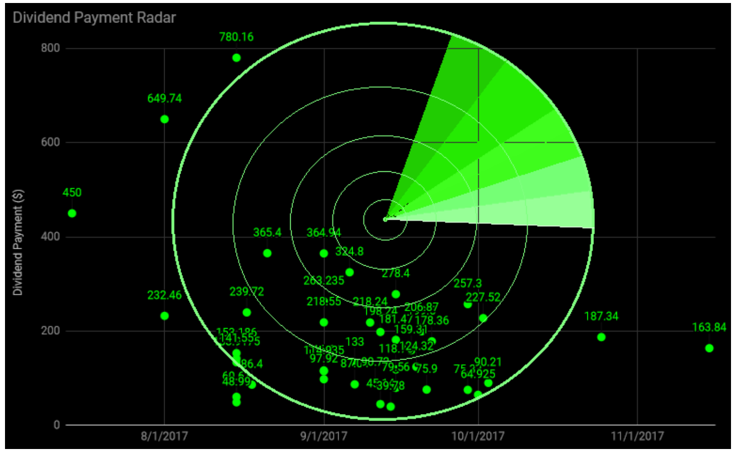
- Survey user reports :
  - Controllers report in free text safety issues in Aviation Safety Reporting System.
    - Highlight causes and consequences to safety issues.
  - Use this to identify adverse events and areas of non-adherence
- Identify deficiency in the system
  - Current state-of-the-art does not measure full adherence to procedures
  - Procedural/Environmental/Human factors have not been explored to explain factors of non-adherence.

Survey supporting data sources

- What sources of data are available?
  - Traditional data sources numerical, text
  - Non-traditional data sources (social media/crowd sourcing)
  - What is the reliability of these data sources
- What is the scale of data (MB/GB/TB/PB)
- Who owns the data?
  - Publicly available
  - Does an agreement need to be set up to acquire (programmatic/legal)?
  - Is the data sensitive PII, SBU, ITAR, Classified etc.
    - What layer of protection does it need?
      - Encryption
      - Secure server
      - Limited user access

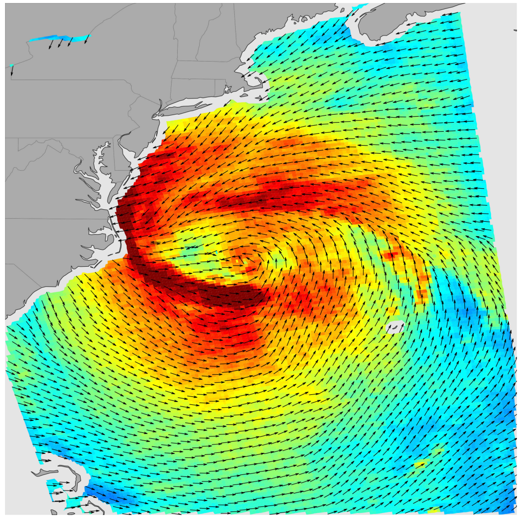
Survey supporting data sources: Case Study

- How do we measure the flight paths?



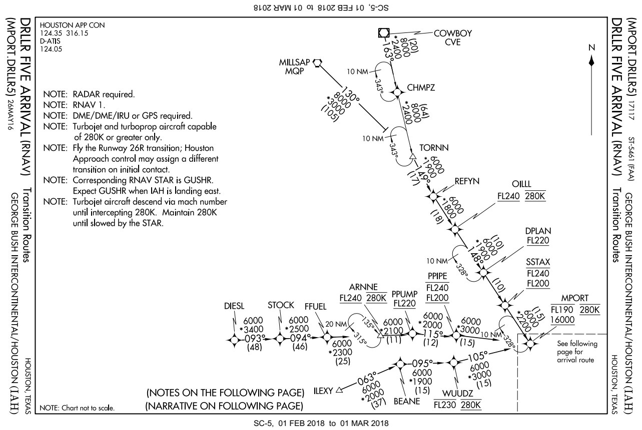
Flight Radar Track Points

- What impact do tail winds have on the operations?



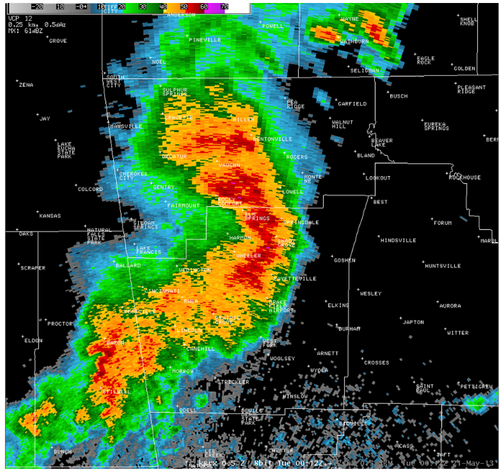
Wind Vectors

- How are the routes defined?



Procedural Data

- What type of weather impacts the operations?

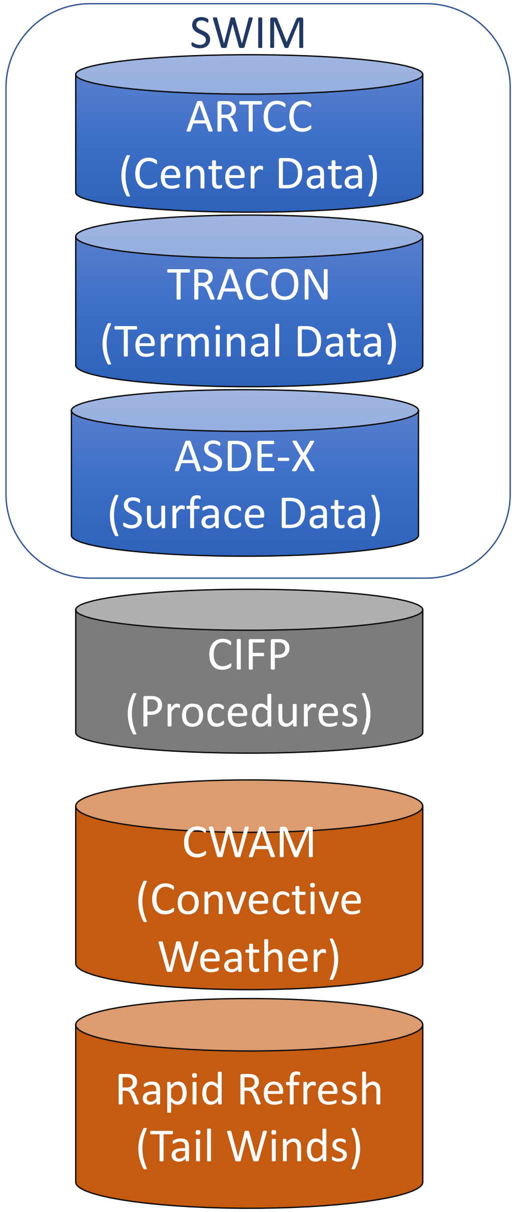


Convective Weather

Selecting relevant features and sources

- Domain experts can help identify relevant features
- Identify sources that are reliable
  - Key features may be unreliable and unusable unless handled properly
- Identify redundant features
  - Feature pruning

Selecting relevant features and sources: Case Study



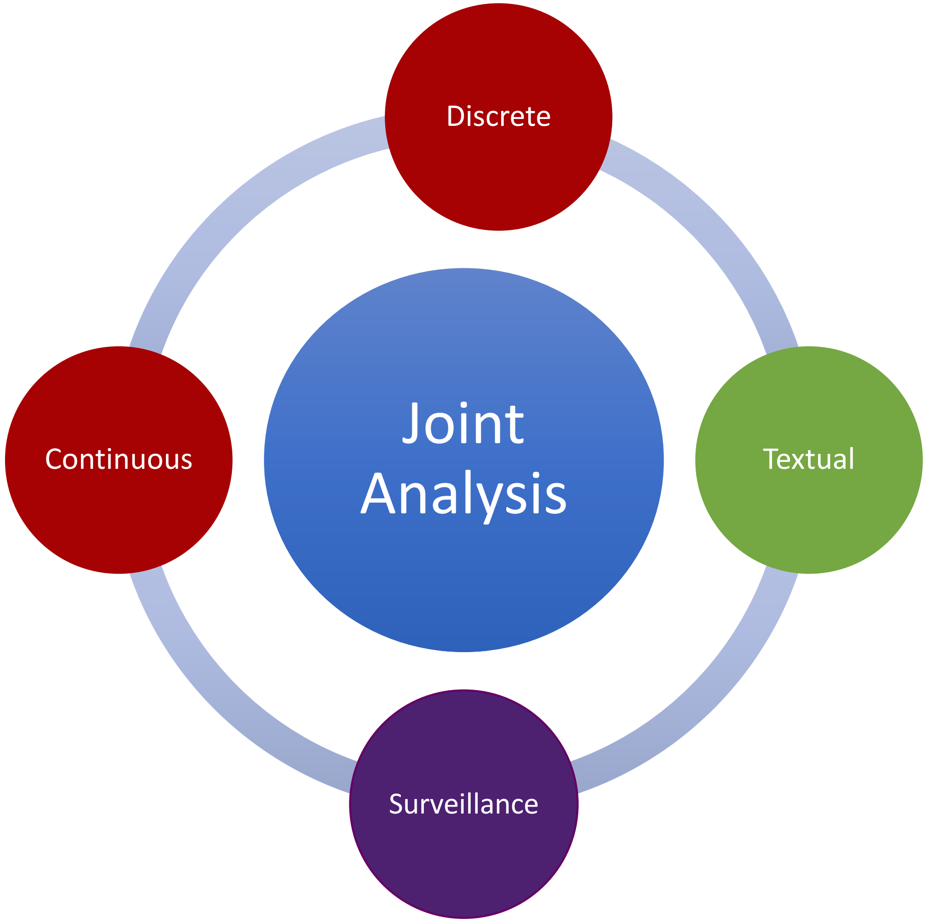
- What records the flight track positions?
  - FAA SWIM network provides access to historical radar track data feeds (lat/lon/alt/speed) from air traffic control facilities.
- How are the procedures defined?
  - Coded Instrument Flight Procedures defines routes with waypoint coordinates with altitude/speed restrictions.
- Is there data that indicates severe weather?
  - MIT Lincoln Labs produces the Convective Weather Avoidance Model (CWAM), which defines sever convective weather polygons.
- Can we characterize the tail winds?
  - Rapid Refresh (NOAA product) defines a grid estimate of winds aloft.

Understand the data

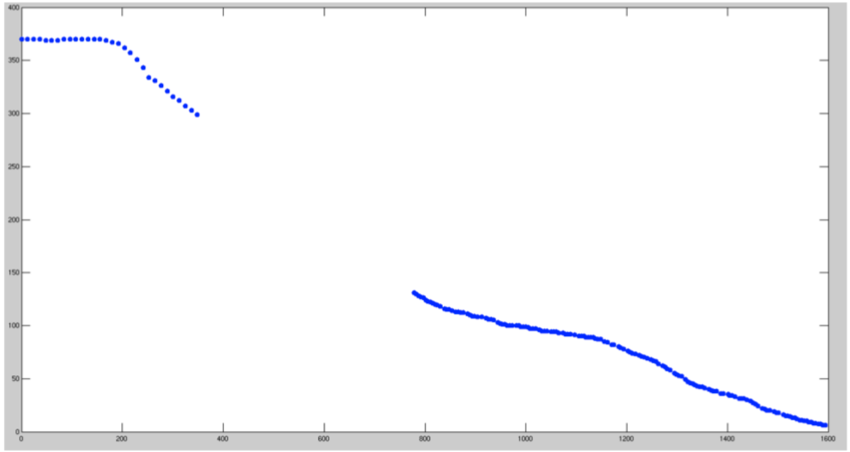
- Review initial sample data
  - Identify known data quality issues (veracity) and mitigation approaches
    - Gaps in the data
    - Sampling rate inconsistencies
    - Corrupted fields
  - If possible resolve issues at source
  - Assess features:
    - Numerical (continuous/binary)
    - Categorical
    - Text

Understand the data: Case Study

Heterogeneous Data



Missing/Gaps in Data

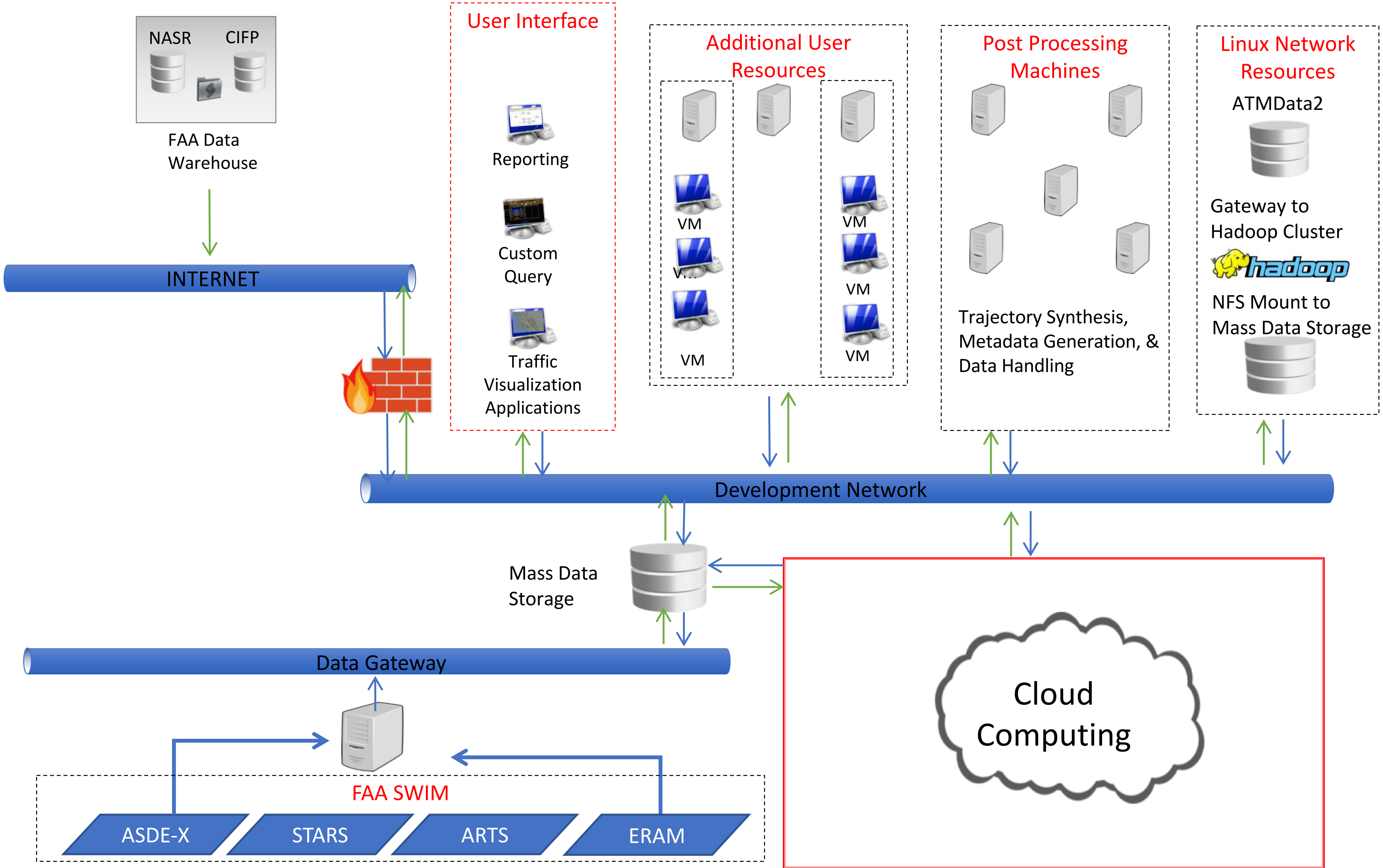


Corrupted Data

Acquire the data

- Initial data dump
  - Shipping/hand delivery external hard drive
  - File transfer over network
  - Data security encryption keys etc.
- Ongoing acquisition
  - API needed to tap into streaming data
  - Automatic SFTP transfer
  - Scripts to verify and ensure data are transferred automatically

Acquire the data: Case Study



Merge data sources

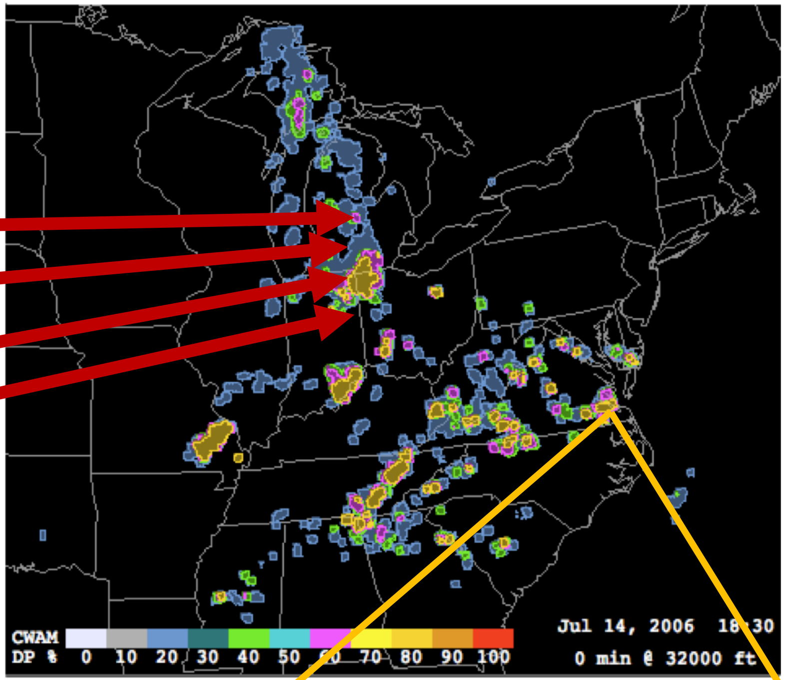
- Identify ways to merge the data (Data Ontology):
  - Temporal
  - Spatial
  - Individual’s ID
  - Common key, other.
- How to synchronize the data
  - High/low sample rates
    - Sample hold
    - Interpolate
- Across physical network boundaries
  - Sensitive data vs public
  - VPN/Firewall network technical issues

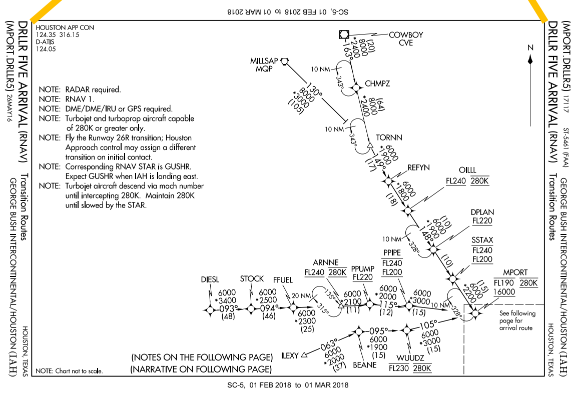
Merge data sources: Case Study

Flight Track Data

Unix time	Latitude	Longitude	
1461976876	40.63463	-73.78158	UALXXX
1461978073	40.63472	-73.78175	UALXXX
1461979526	40.63482	-73.78196	UALXXX
1461979533	40.63491	-73.78216	UALXXX
…	…	…	..

Convective Weather





Procedural Information

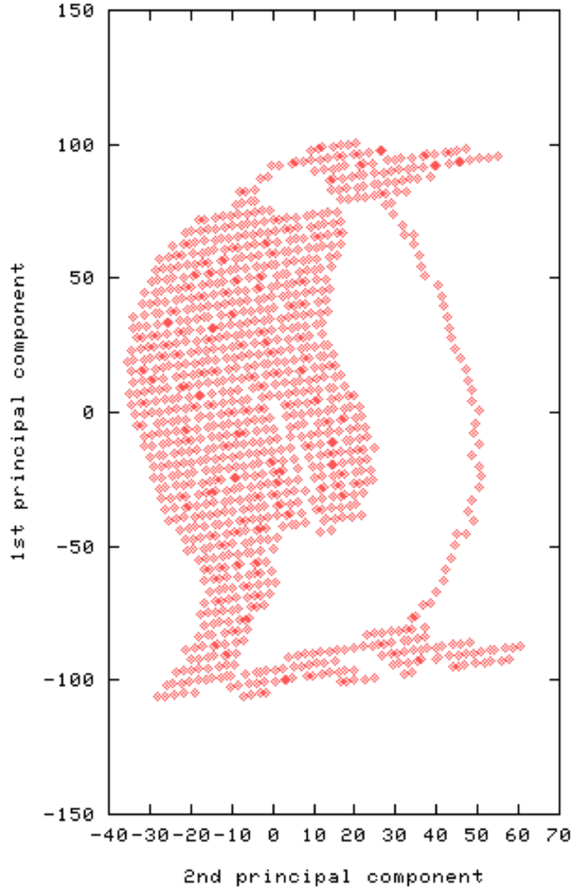
Time (PDT)	Temp.	Dew Point	Humidity	Pressure	Visibility	Wind Dir	Wind Speed	Gust Speed	Precip	Events	Conditions
1:03 AM	51.1 °F	51.1 °F	100%	29.96 in	6.0 mi	SSW	12.7 mph	19.6 mph	0.01 in	Rain	Light Rain
1:13 AM	51.1 °F	51.1 °F	100%	29.96 in	3.0 mi	SW	12.7 mph	20.7 mph	0.02 in	Rain	Light Rain
1:25 AM	50.0 °F	50.0 °F	100%	29.96 in	5.0 mi	SW	10.4 mph	-	0.03 in	Rain	Light Rain
1:42 AM	50.0 °F	50.0 °F	100%	29.96 in	10.0 mi	SSW	8.1 mph	-	0.03 in		Overcast
…	…	…	…	…	…	…	…	…	…	…	…

Ground Weather Observations

Derive new features

- Non-linear relationships
  - Physics based models to derive relevant parameters
  - Frequency based features
  - Compute deviations from distributions (statistical features)
- Dimensionality reduction
  - Principle component analysis
  - Non-negative matrix factorization
  - Independent component analysis
- Signal processing techniques
  - Isolate signal
    - Low-pass/high-pass/band-pass filters
- Filter with meta data

PCA

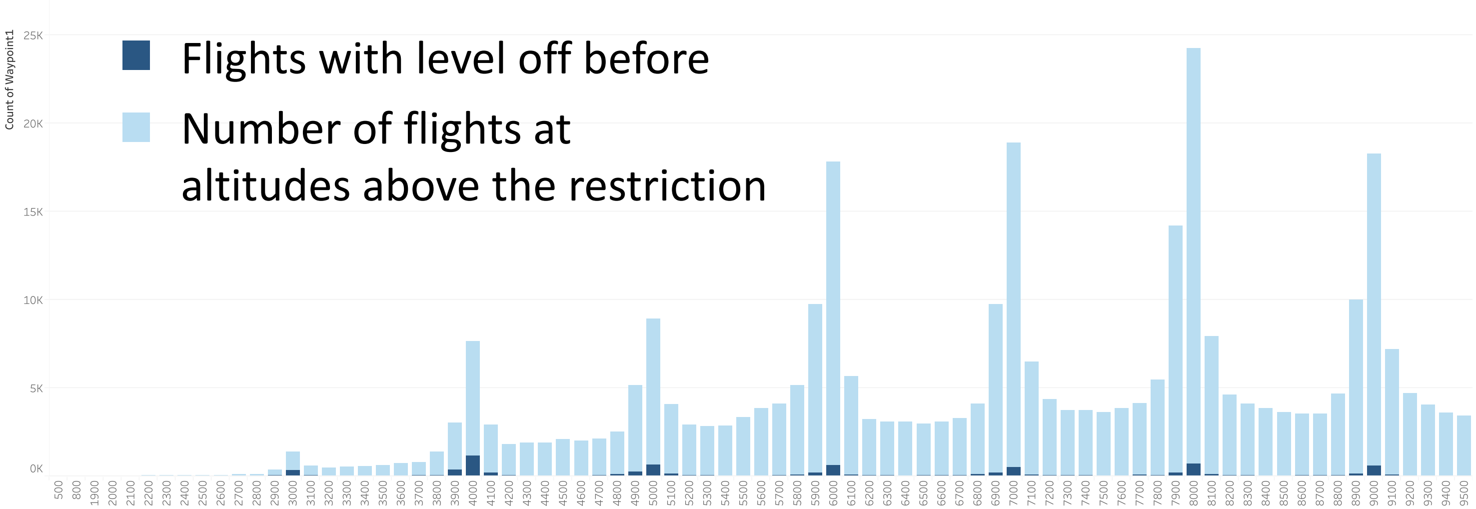


Derive new features: Case Study

- New Features
  - Time Conflicts at Merging Waypoints
  - Level off before waypoint (indicate intentional deviations)
  - Miles in Trail

- Filtering:
  - Used Runway Landing to our advantage.

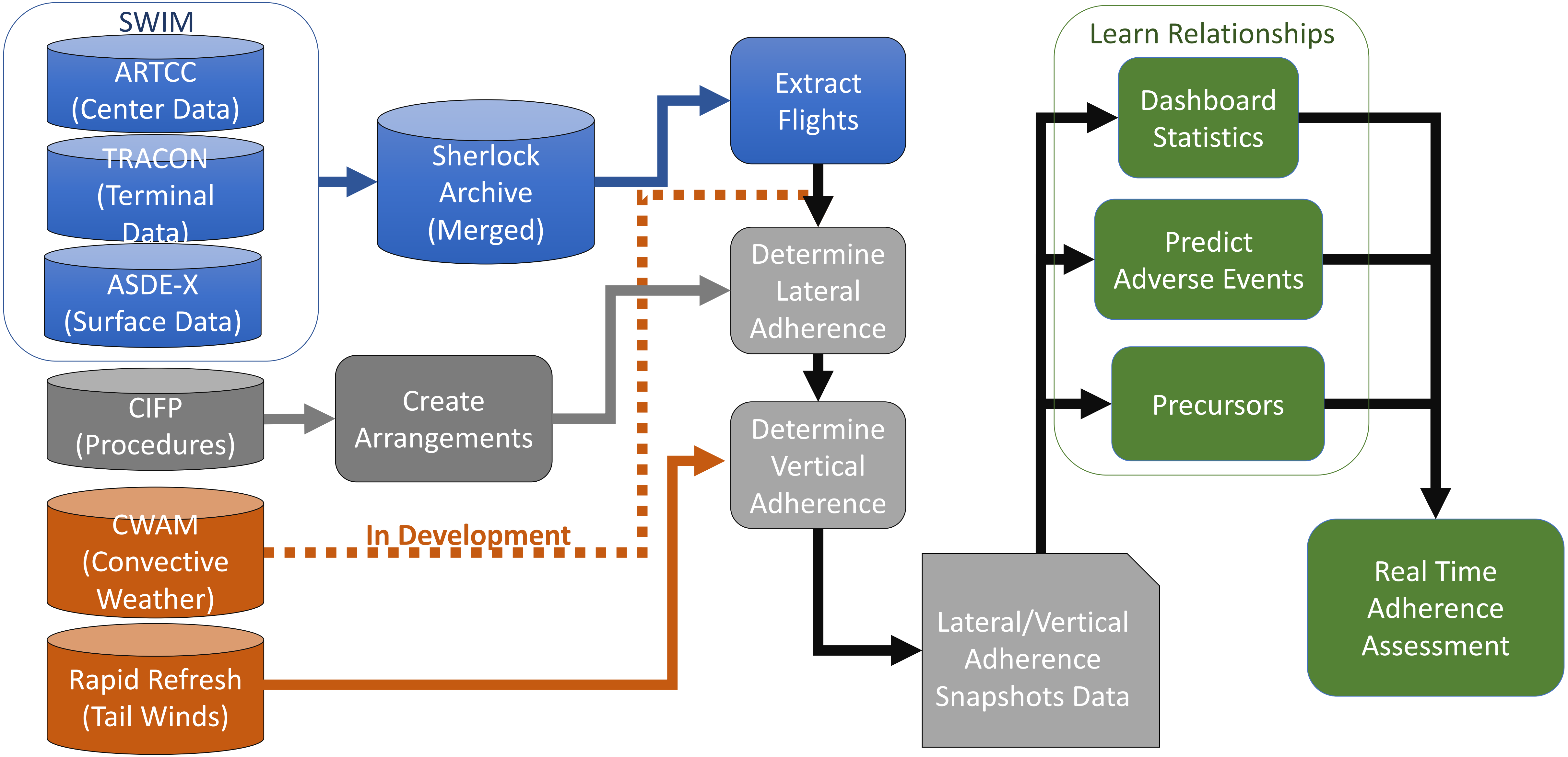
- Statistical Features:
  - Computed deviations from mean for altitudes and wind speeds.



Build data processing pipeline

- Determine input file formats
- Address error handling
- Identify System Requirements
  - Disk space
  - Computing resources
  - Memory
  - Network bandwidth
  - Determine if parallel computing is necessary
    - Is Map/Reduce framework necessary or is batch processing or single thread sufficient?
- Choose appropriate programing language
  - Scala
  - Python
  - Java
- Develop and Test Code
  - V/V Output (Make sure the processed data maps to the original problem)

Build data processing pipeline: Case Study

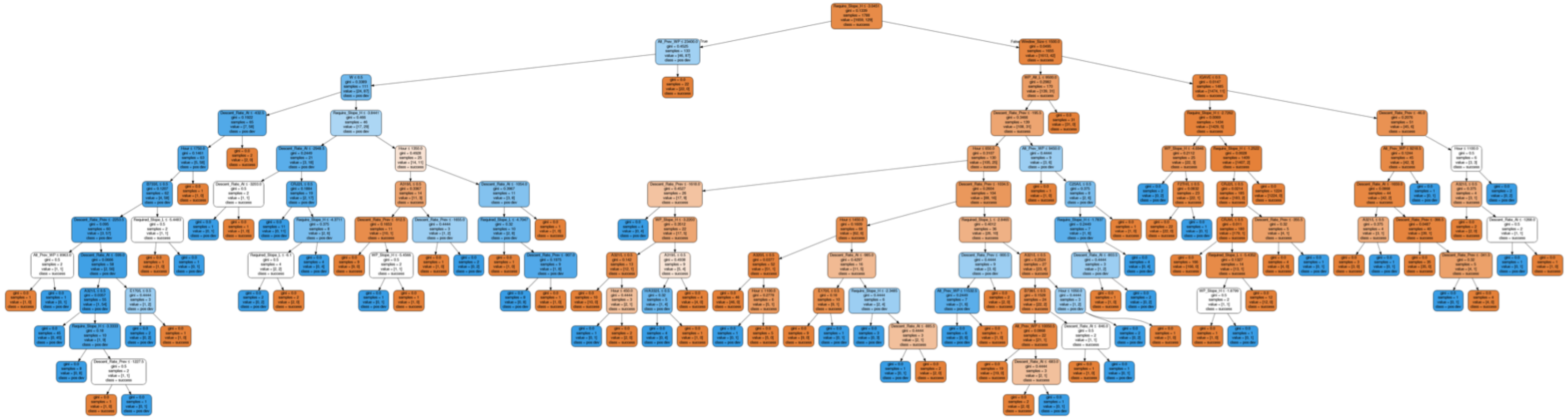


Build model and test

- Based on problem definition select algorithm
  - Black box (typically non-linear methods)
    - Good for performance
    - Poor for interpretability
  - White box
    - Good for interpretability
    - May not give best performance
- Train model
  - Determine what hyper parameters generalize well
    - Grid search
    - Cross validation
- Test model
  - If data is stationary a fixed model will work
  - If non-stationary (in temporal problems) updates to the model may be needed to account for shifts in data.
- Interpretability
  - Summary statistics
  - Parameter significance (weights)
  - Thresholds (decision trees)
  - Probabilistic models with confidence bounds

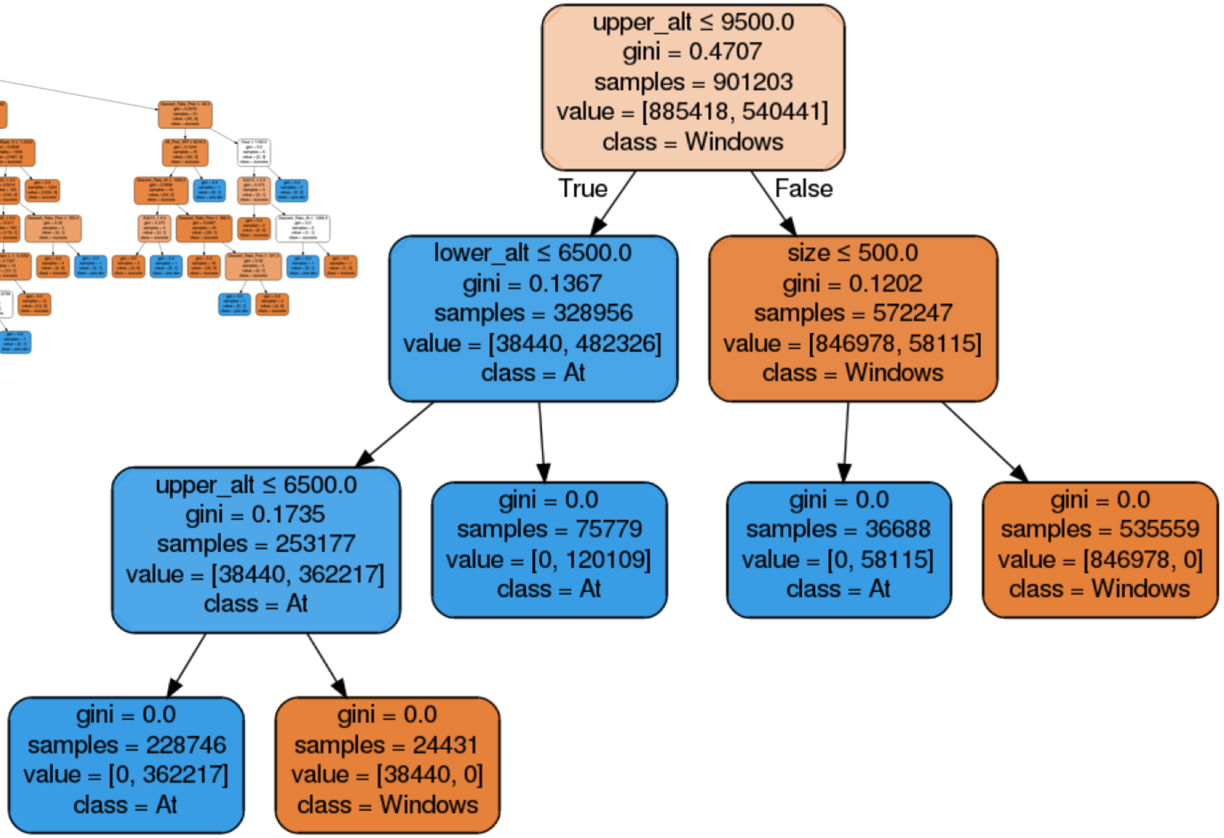
Build model and test: Case Study

Complex



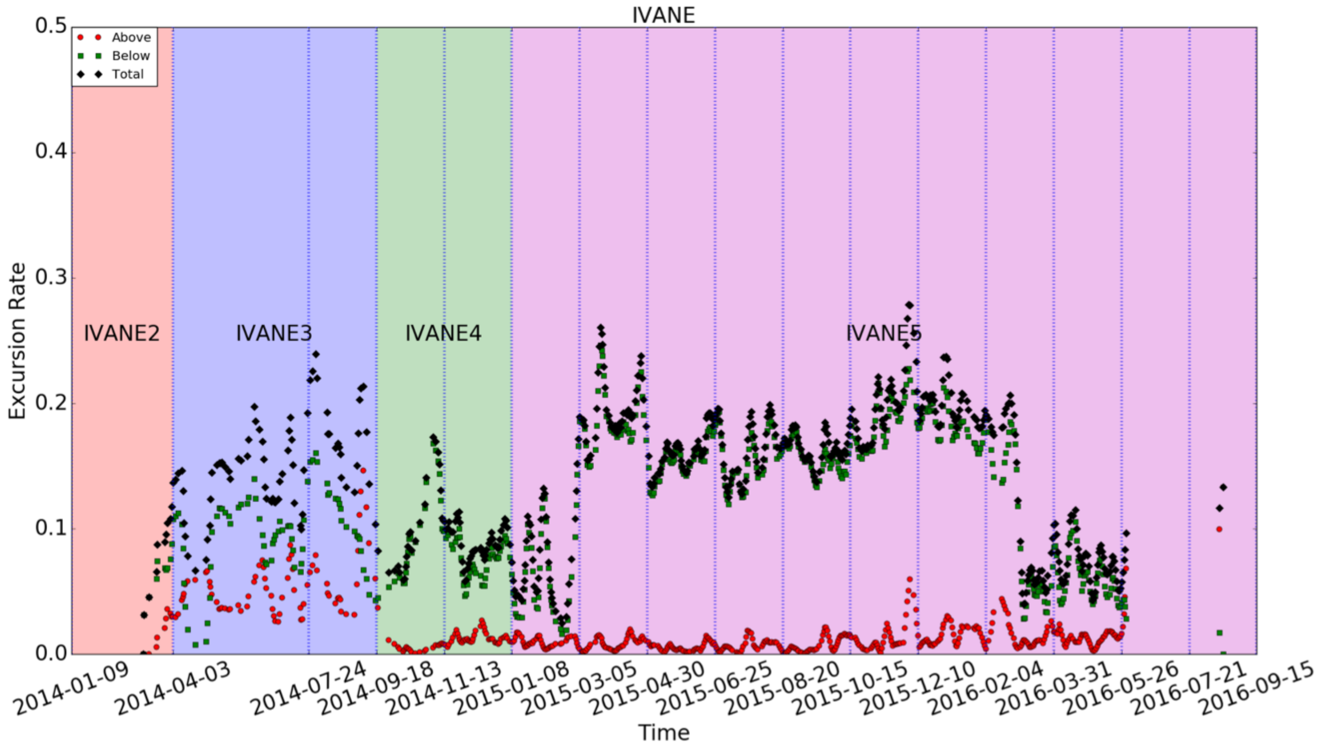
Vs

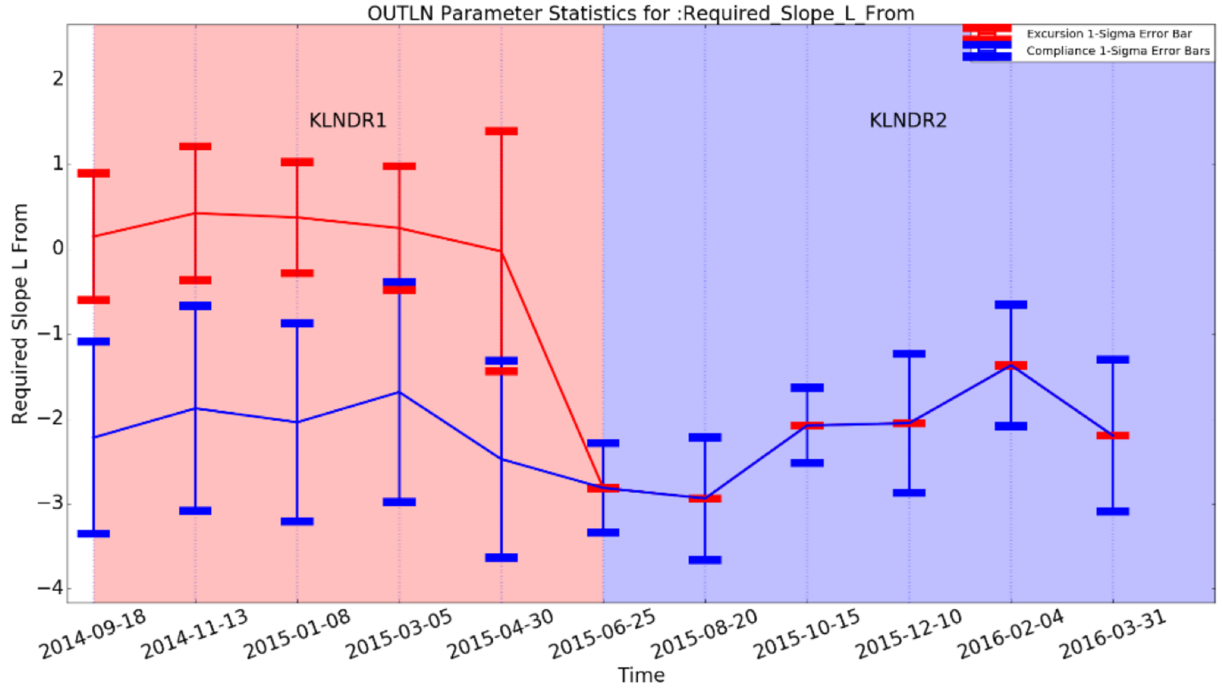
Interpretable



Build model and test: Case Study

Behavior Can Change Over Time



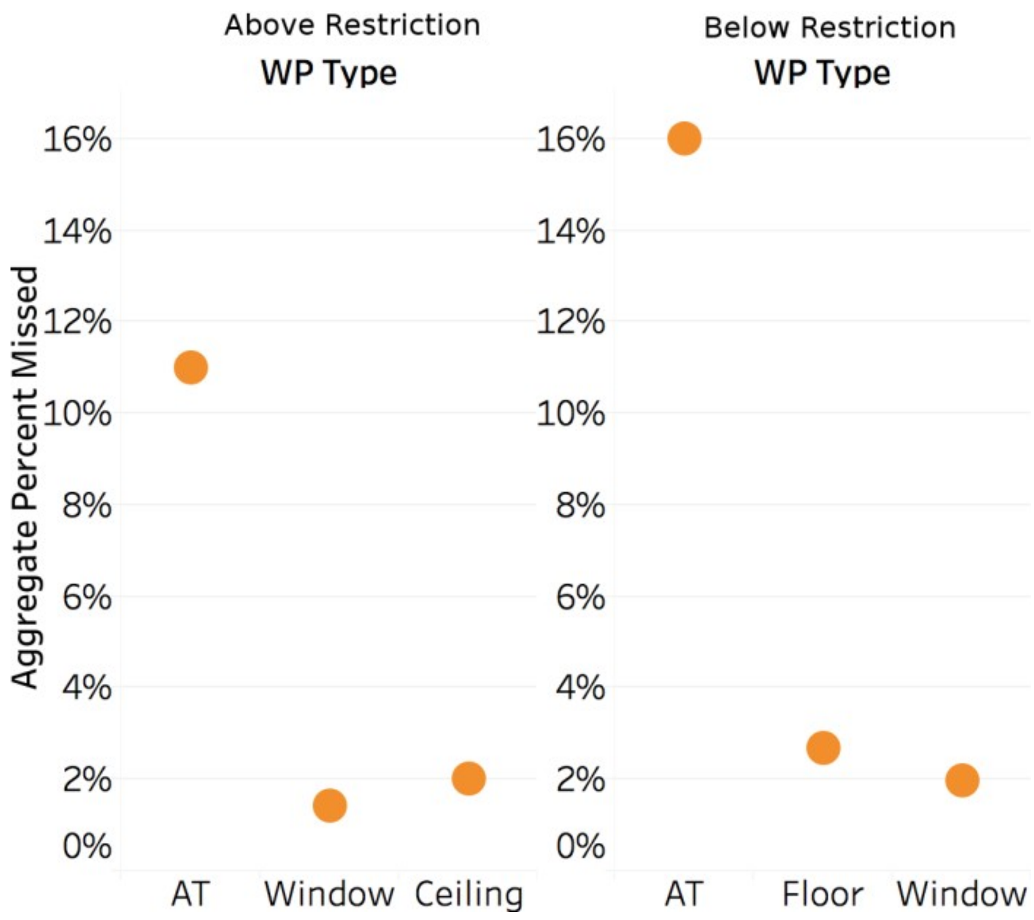


Analyze results

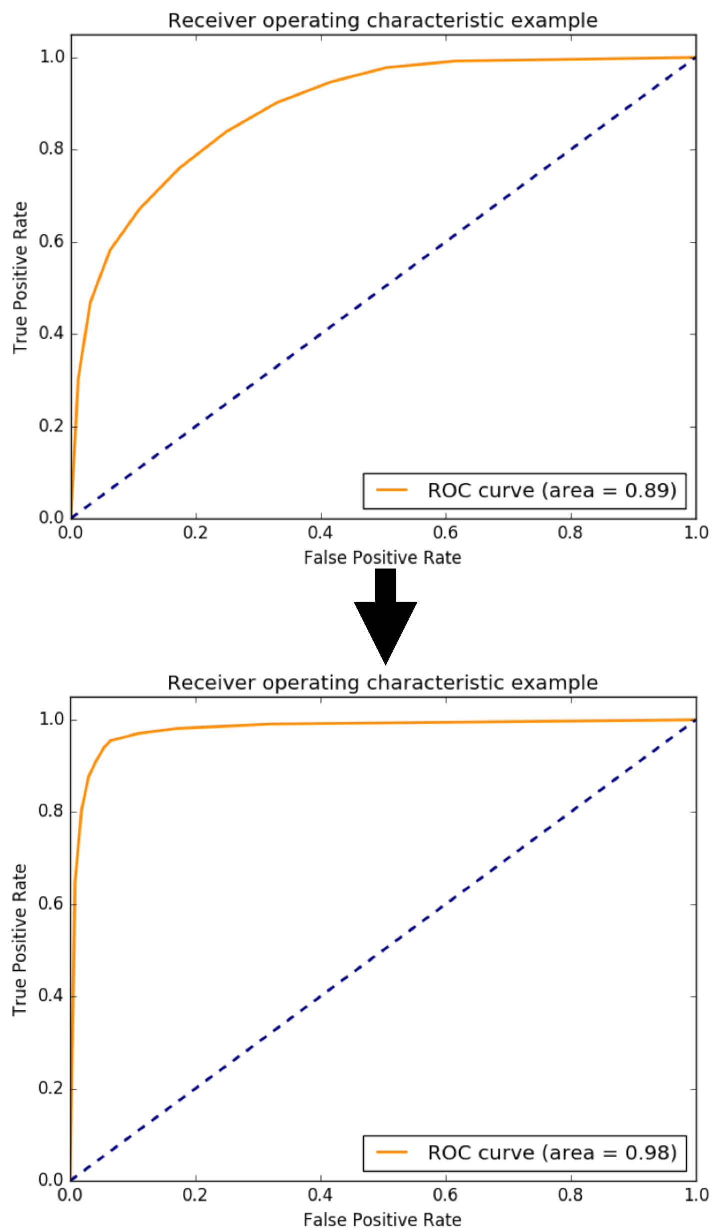
- Do the results make sense?
  - Is the performance what you expected? (100% can be fishy)
  - Review with subject matter expert
    - In white box algorithms do highly weighted features match what the domain says should be important?
- Does it answer the original question?
  - Are results significant?
    - Can the results leveraged to improve the system?
  - Is there added value over the previous state-of-the-art?
    - Saves (Time/$$)
    - Improves safety/lowers risks
    - Improves user experience

Analyze results: Case Study

- Do Results Make sense?
    - Tighter restrictions result in less adherence



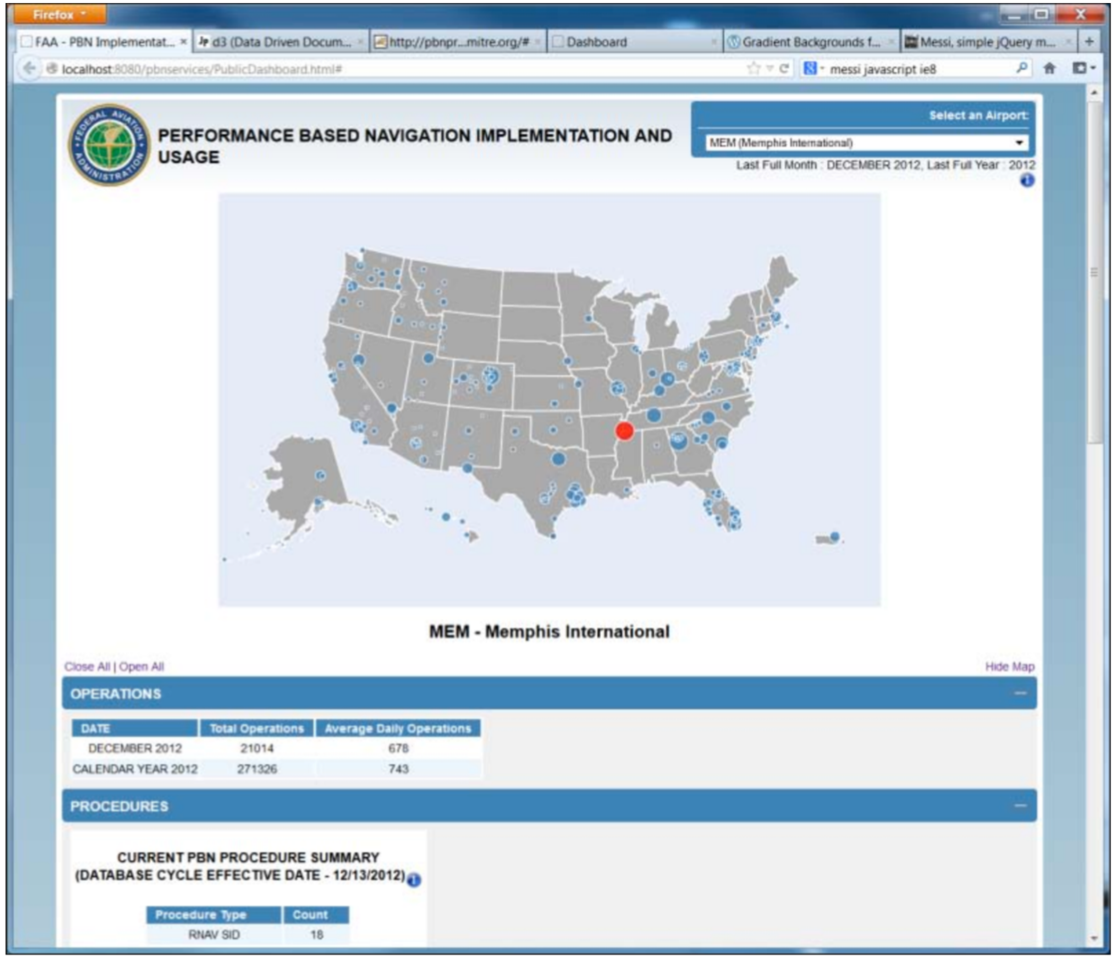
- Is there improved performance?
    - False Positive/ True Positive Rates



Deploy/Publish

- Document so results can be reproduced
- Deploy
  - Review prototype
    - Are there areas that need improvement
      - Error handling
      - Port to more efficient coding language
    - Identify dedicated machinery to run production environment
  - Write user guide
    - Write code to work out of the box on sample data for demo purposes and package handoff.
- Publish
  - Identify appropriate venue
  - Cite foundational work
  - Distill findings so that there is a clear message describing the new approach’s added value
  - When appropriate release code and data for transparency and reproducibility

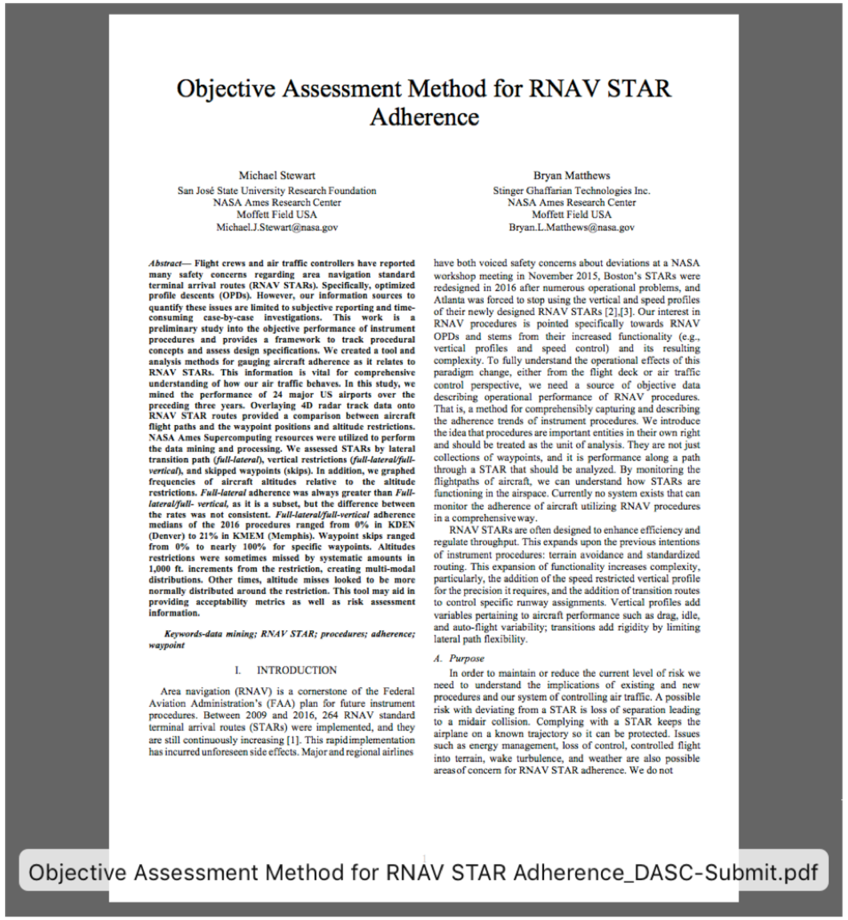
Deploy/Publish: Case Study



Performance Based Navigation Dashboard

T. Becher, "Performance-based navigation analysis and reporting," *2013 Integrated Communications, Navigation and Surveillance Conference (ICNS)*, Herndon, VA, 2013, pp. 1-17. doi: 10.1109/ICNSurv.2013.6548637
URL: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6548637&isnumber=6548506

Deploy/Publish



Objective Assessment Method for RNAV STAR Adherence

Michael Stewart
San José State University Research Foundation
NASA Ames Research Center
Moffett Field USA
Michael.J.Stewart@nasa.gov

Bryan Matthews
Stinger Ghaffarian Technologies Inc.
NASA Ames Research Center
Moffett Field USA
Bryan.L.Matthews@nasa.gov

***Abstract*— Flight crews and air traffic controllers have reported many safety concerns regarding area navigation standard terminal arrival routes (RNAV STARs). Specifically, optimized profile descents (OPDs). However, our information sources to quantify these issues are limited to subjective reporting and time-consuming case-by-case investigations. This work is a preliminary study into the objective performance of instrument procedures and provides a framework to track procedural concepts and assess design specifications. We created a tool and analysis methods for gauging aircraft adherence as it relates to RNAV STARs. This information is vital for comprehensive understanding of how our air traffic behaves. In this study, we mined the performance of 24 major US airports over the preceding three years. Overlaying 4D radar track data onto RNAV STAR routes provided a comparison between aircraft flight paths and the waypoint positions and altitude restrictions. NASA Ames Supercomputing resources were utilized to perform the data mining and processing. We assessed STARs by lateral transition path (*full-lateral*), vertical restrictions (*full-lateral/full-vertical*), and skipped waypoints (skips). In addition, we graphed frequencies of aircraft altitudes relative to the altitude restrictions. *Full-lateral* adherence was always greater than *Full-lateral/full- vertical*, as it is a subset, but the difference between the rates was not consistent. *Full-lateral/full-vertical* adherence medians of the 2016 procedures ranged from 0% in KDEN (Denver) to 21% in KMEM (Memphis). Waypoint skips ranged from 0% to nearly 100% for specific waypoints. Altitudes restrictions were sometimes missed by systematic amounts in 1,000 ft. increments from the restriction, creating multi-modal distributions. Other times, altitude misses looked to be more normally distributed around the restriction. This tool may aid in providing acceptability metrics as well as risk assessment information.**

Keywords-data mining; RNAV STAR; procedures; adherence; waypoint

I. INTRODUCTION

Area navigation (RNAV) is a cornerstone of the Federal Aviation Administration's (FAA) plan for future instrument procedures. Between 2009 and 2016, 264 RNAV standard terminal arrival routes (STARs) were implemented, and they are still continuously increasing [1]. This rapid implementation has incurred unforeseen side effects. Major and regional airlines have both voiced safety concerns about deviations at a NASA workshop meeting in November 2015, Boston's STARs were redesigned in 2016 after numerous operational problems, and Atlanta was forced to stop using the vertical and speed profiles of their newly designed RNAV STARs [2],[3]. Our interest in RNAV procedures is pointed specifically towards RNAV OPDs and stems from their increased functionality (e.g., vertical profiles and speed control) and its resulting complexity. To fully understand the operational effects of this paradigm change, either from the flight deck or air traffic control perspective, we need a source of objective data describing operational performance of RNAV procedures. That is, a method for comprehensibly capturing and describing the adherence trends of instrument procedures. We introduce the idea that procedures are important entities in their own right and should be treated as the unit of analysis. They are not just collections of waypoints, and it is performance along a path through a STAR that should be analyzed. By monitoring the flightpaths of aircraft, we can understand how STARs are functioning in the airspace. Currently no system exists that can monitor the adherence of aircraft utilizing RNAV procedures in a comprehensive way.

RNAV STARs are often designed to enhance efficiency and regulate throughput. This expands upon the previous intentions of instrument procedures: terrain avoidance and standardized routing. This expansion of functionality increases complexity, particularly, the addition of the speed restricted vertical profile for the precision it requires, and the addition of transition routes to control specific runway assignments. Vertical profiles add variables pertaining to aircraft performance such as drag, idle, and auto-flight variability; transitions add rigidity by limiting lateral path flexibility.

A. Purpose

In order to maintain or reduce the current level of risk we need to understand the implications of existing and new procedures and our system of controlling air traffic. A possible risk with deviating from a STAR is loss of separation leading to a midair collision. Complying with a STAR keeps the airplane on a known trajectory so it can be protected. Issues such as energy management, loss of control, controlled flight into terrain, wake turbulence, and weather are also possible areas of concern for RNAV STAR adherence. We do not

Objective Assessment Method for RNAV STAR Adherence_DASC-Submit.pdf

Conclusion

- Process may vary from application to application, but generally the data understanding and acquisition accounts for >80% of the effort.
- Understanding the data (strengths and weaknesses) is key to successful machine learning.
- As in all V&V processes it is important to continually be checking that each step maps back to the original problem statement.
    - If you do change the goals make sure all previous steps map to the new problem.

Questions?