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Unmanned Aircraft System Loss of Link Procedure Evaluation Methodology

Sponsor: Andy Lacher (MITRE Corporation)

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UL2 Team

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Background

- Sponsored by the MITRE Corporation
  - Not-for-profit organization that manages Federally Funded Research and Development Centers
  - Work is specifically from the Center for Advanced Aviation System Development (CAASD)
- Unmanned Aircraft System (UAS)
  - A UAS is an aircraft remotely piloted from ground stations via a real-time command and control (C2) data link

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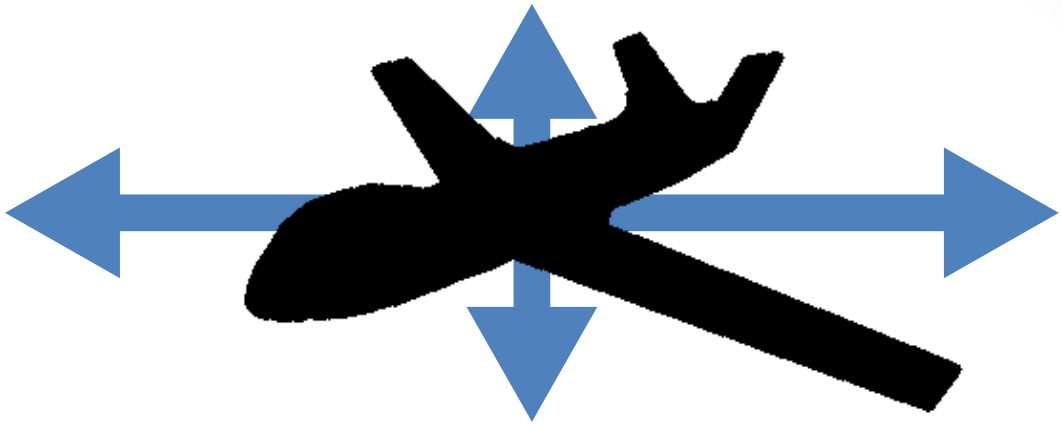

Unmanned Aircraft (UA)

Loss of Link

UA is unpredictable to ATC

- ATC cannot efficiently manage airspace
- Unnecessary rerouting of air traffic
- Excess workload for ATC
- Risk of a loss of separation or collision

Air Traffic Control (ATC)

Standardized procedures for loss of link situations are necessary to make these events more predictable and easier to manage

Ground Station

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Project Overview

- Standardized procedure - community wide issue
- Methodology for evaluating loss of link procedures
  - Purpose is to take a set of procedures and allow the sponsor to narrow down to the top few for further investigation
  - Human-in-the-Loop experiments can then be designed for top procedures
- Expected Results
  - Set of criteria/metrics that are important to UAS stakeholders
  - A methodology that can be used to evaluate procedures
    - Repeatable and adaptable to different procedures
    - Capable of being used for further research and analysis by the sponsor

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Scope

- In Scope
  - Within non-segregated civil airspace- National Airspace System (NAS)
  - UAS capable of extended flight operations in Class A airspace
  - Evaluation of our methodology with multi-agency proposed procedure
- Out of Scope
  - Identification of optimal procedure for loss of link situations

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Approach

Three Step Approach

- Qualitative
  - Identify important criteria through interviews with multiple UAS stakeholders
- Absolutes
  - Determine thresholds that must be met
- Analytical
  - Develop simulations that analyze individual procedures based on specific criteria

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Subject Matter Expert Interviews

- Met with the Subject Matter Experts (SMEs) recommended to us by our sponsor:
  - Global Hawk UAS pilot
  - ATC human-in-the-loop experiment analyst
  - UAS loss of link data analyst
  - Lead developer of automated ATC simulation tool *airspace*Analyzer
  - MITRE traffic flow management lead architect
  - MITRE lead UAS research architect

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Modeling

- Analytical modeling approaches based on:
  - Feedback from sponsor
  - Interviews with SMEs
- Focus is on two main criteria:
  - UA Predictability
    - Monte Carlo simulation
    - Process modeling- using Excel as the primary tool, Arena as secondary
  - Air Traffic Control workload
    - MITRE-developed automated ATC simulation tool called *airspace*Analyzer
- Models are **independent**, but predictability and workload **can be** related

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Predictability Model

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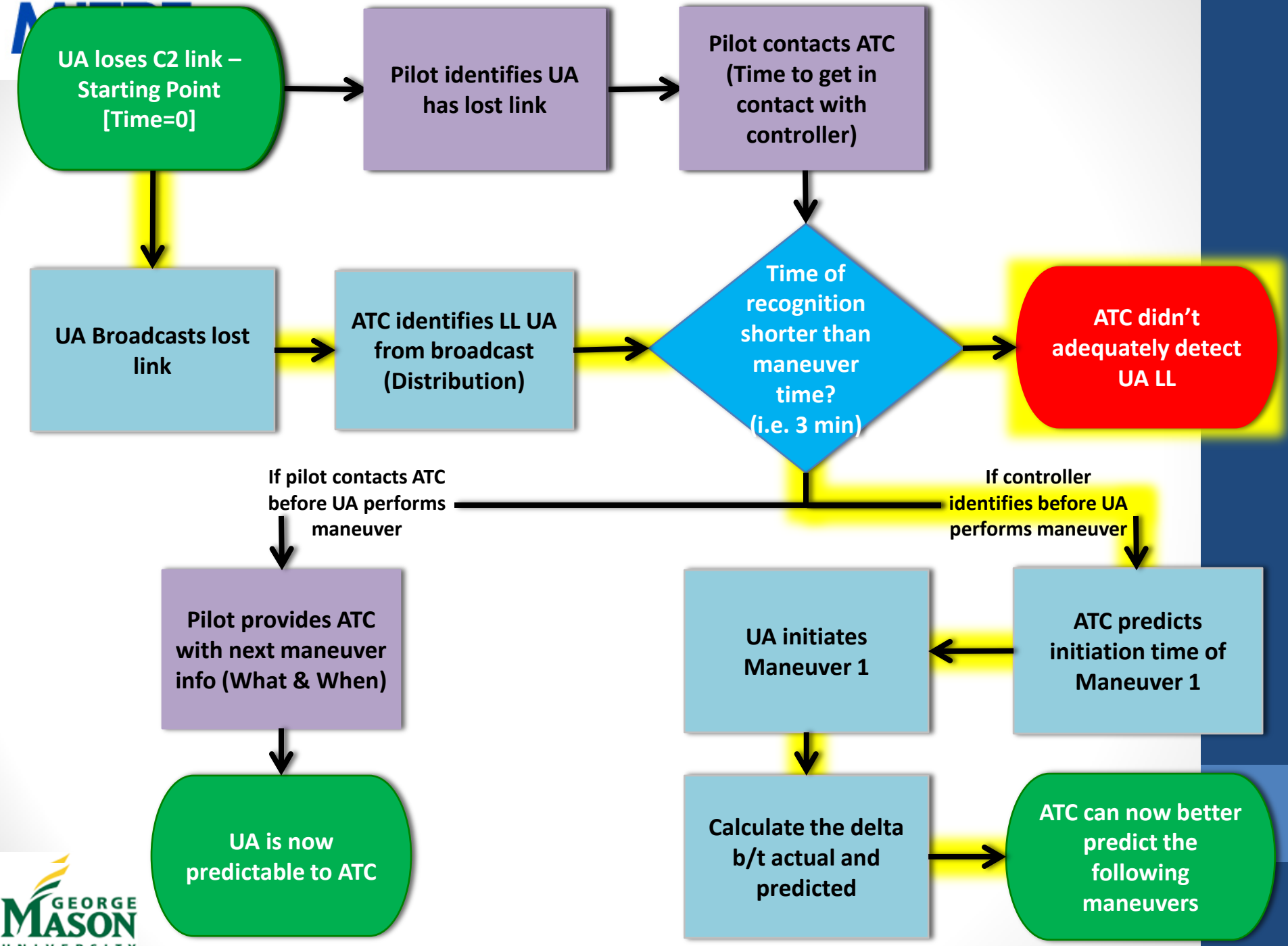
UA loses C2 link – Starting Point [Time=0]
Pilot identifies UA has lost link
Pilot contacts ATC (Time to get in contact with controller)
UA Broadcasts lost link
ATC identifies LL UA from broadcast (Distribution)
Time of recognition shorter than maneuver time? (i.e. 3 min)
ATC didn't adequately detect UA LL
If pilot contacts ATC before UA performs maneuver
If controller identifies before UA performs maneuver
Pilot provides ATC with next maneuver info (What & When)
UA is now predictable to ATC
UA initiates Maneuver 1
ATC predicts initiation time of Maneuver 1
Calculate the delta b/t actual and predicted
ATC can now better predict the following maneuvers

Predictability Model Assumptions

- Times of UA maneuvers based on sample procedure provided by sponsor
- UAS pilot/ATC knows the sample contingency procedure
- All functions (other than C2 link) on the UA are operating properly
- Loss of link is indicated to ATC by change of transponder code – Radio frequency loss (RDOF)
- If the pilot contacts ATC before the controller realizes LL from UA broadcast, the pilot will tell ATC what/when maneuvers will occur
- No loss of separation within two minutes because ATC probes for loss of separation two minutes in advance

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Predictability Model - Details

- Pseudo-measure for predictability is time
- Aim to have a flexible model that can incorporate new data easily
- Input
  - Controller reaction times to UA signaling loss of link
  - Time of when the first maneuver is initiated
- Outputs
  - Times of interest:
    - Delta between UA broadcasting loss of link and the controller identifying the UA as loss of link
- Enhanced Output
  - The model will also include the possibility of loss of separation between aircraft
    - Analyze the probability the UA will lose separation before the controller realizes there is a loss of link situation

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Predictability Model Results

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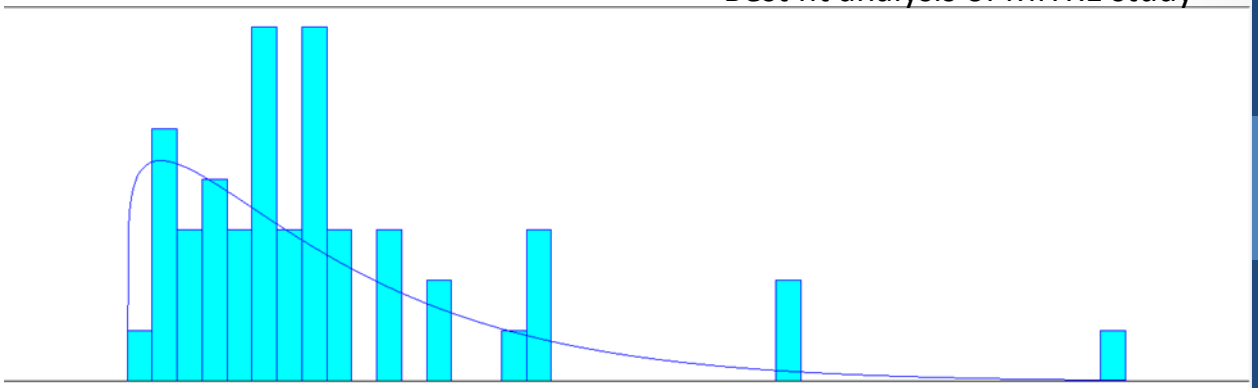
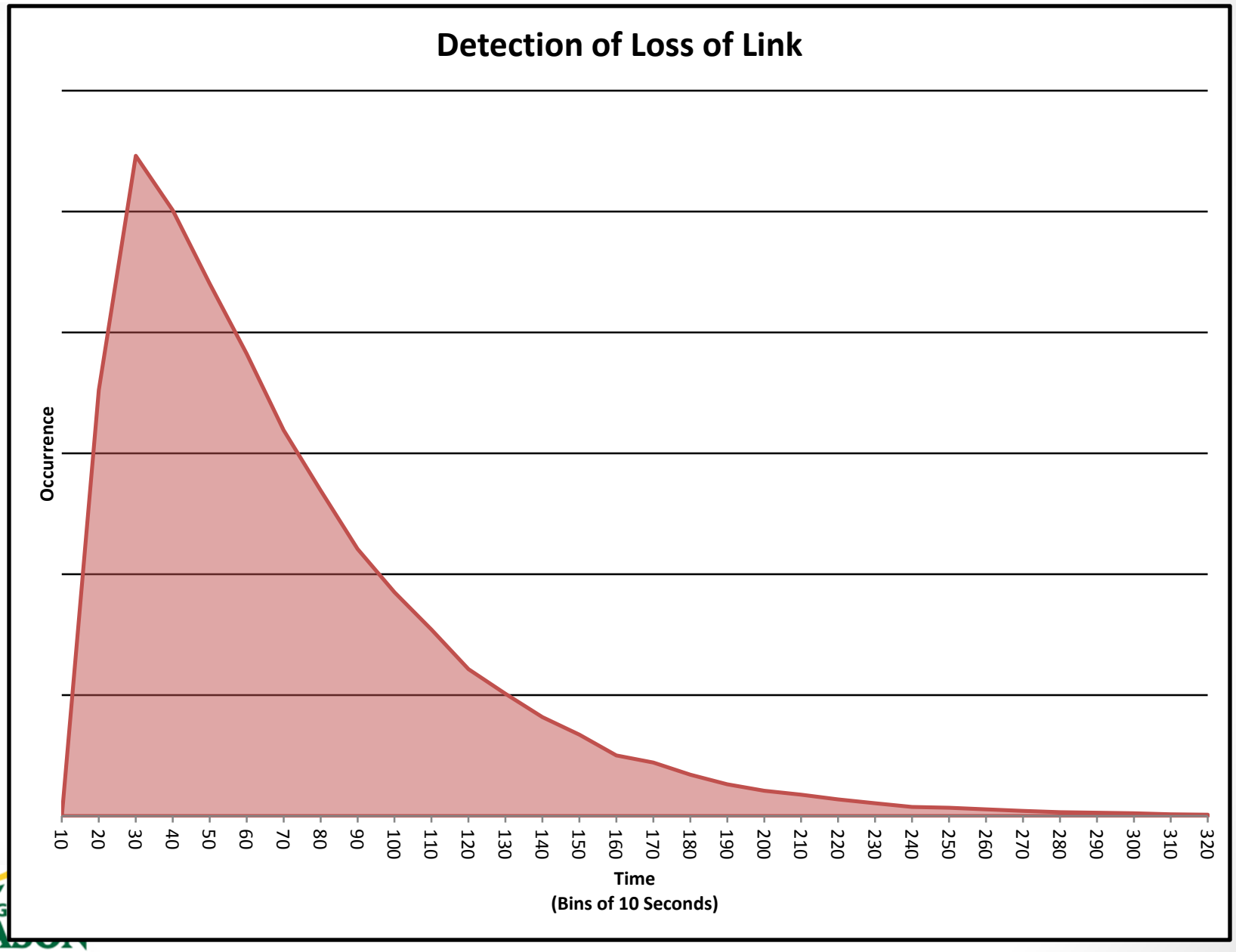
Predictability Results

- 200,000 Trials
- Data from Human-in-the-Loop study focused on RDOF recognition times
- Controller response data best matches a Weibull Distribution
  - 3+weibull (1.14, 56.7)
  - Selected the best fit using a data analyzer - Largest r^2 value
  - Cumulative Density Function is
  -
  -

Best fit analysis of MITRE study




Detection of Loss of Link
Occurrence
10
20
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80
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100
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120
130
140
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160
170
180
190
200
210
220
230
240
250
260
270
280
290
300
310
320
Time
(Bins of 10 Seconds)

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Loss of Separation

- To enhance the model, the model will also include the possibility of loss of separation between aircraft
  - Analyze the probability the UA will lose separation before the controller realizes there is a loss of link situation
- No loss of separation in the first 2 minutes
- Time of Loss of Separation
  - Uniform distribution
  -
    - (120, 330)

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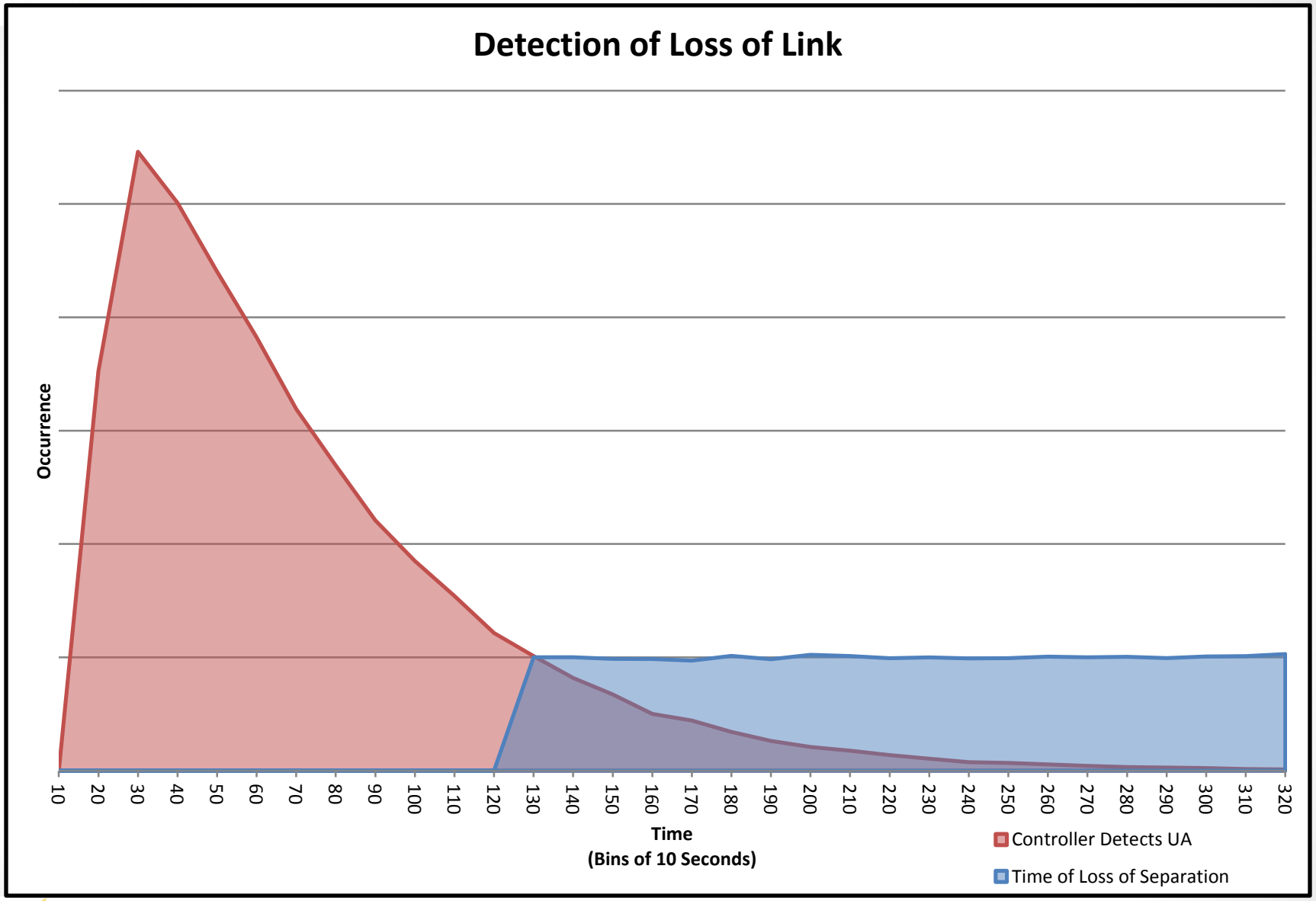
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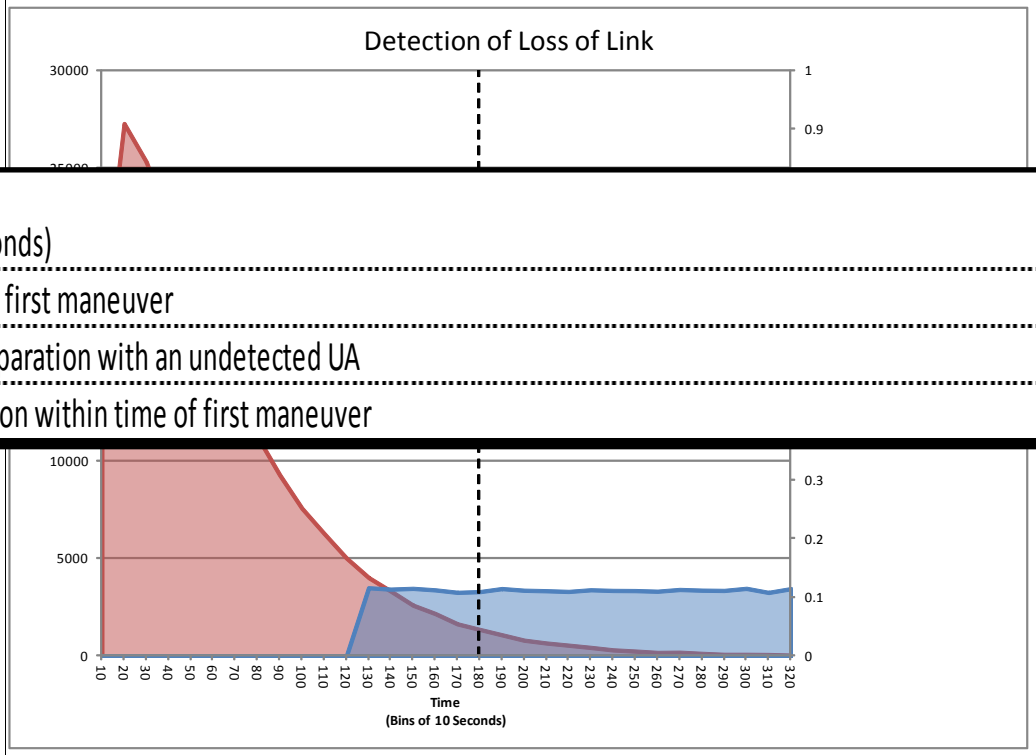
Time
(Bins of 10 Seconds)
Controller Detects UA
Time of Loss of Separation

Predictability Output Sheet

Output Sheet

Procedure: Test Procedure



Mean time of detection (seconds)	57.00
Propability of detection after first maneuver	2.54%
Total probability of loss of separation with an undetected UA	9.74%
Probability of loss of separation within time of first maneuver	7.48%

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Predictability Outputs

- Based on the sample procedure, after a loss of link
  - Mean time of detection: **57 seconds**
  - Probability the controller will detect the UA after it initiates its first maneuver: **2.5%**
  - Probability the UA will lose separation: **9.7%**
  - Probability the UA will lose separation before the initiation of the first maneuver: **7.5%**
- For further enhancements to the model:
  - Develop thresholds that are considered “acceptable”
  - Adjust the time to first maneuver to match the contingency procedure
  - Update the time of detection as more data becomes available

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Controller Workload Modeling

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Workload Modeling - Objective

- Traditional Modeling: Human-In-The-Loop simulation
  - Real controllers asked to measure complexity of a particular scenario
  - Can be expensive and time consuming

- Our Objective
  - Evaluate MITRE developed automated ATC tool as a candidate for measuring workload impact

Snapshot of HITL Simulation conducted at MITRE

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*airspace*Analyzer

- Simulation tool developed by MITRE to automatically separate, sequence, and space aircraft
- Reports a set of metrics that aid in quantifying different aspects of the scenario, including workload (e.g. Traffic count, Number of Maneuvers)
- Used to analyze impact of a change that directly affects ATC under varying traffic conditions:
  - New Traffic Flows
  - New Sector Boundaries
  - Airspace Restrictions
  - Moving weather systems
- What about UAS?

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*airspace*Analyzer – Evaluation Methodology

- Three scenarios
  1. Responsive UA
     - UA will respond to ATC commands like normal aircraft
  2. Unresponsive, predictable UA (normal separation)
     - UA will not respond to ATC commands
     - Normal separation around aircraft is 5 nautical miles (NM) laterally or 2,000 feet vertically
  3. Unresponsive, unpredictable UA (greater separation)
     - UA will not respond to ATC commands
     - ATC expands separation around lost link UA to 15 NM laterally or 4,000 feet vertically to compensate for unknown maneuvers
     - Note: Increase in separation is estimated - can be adjusted depending on how conservative the controller is

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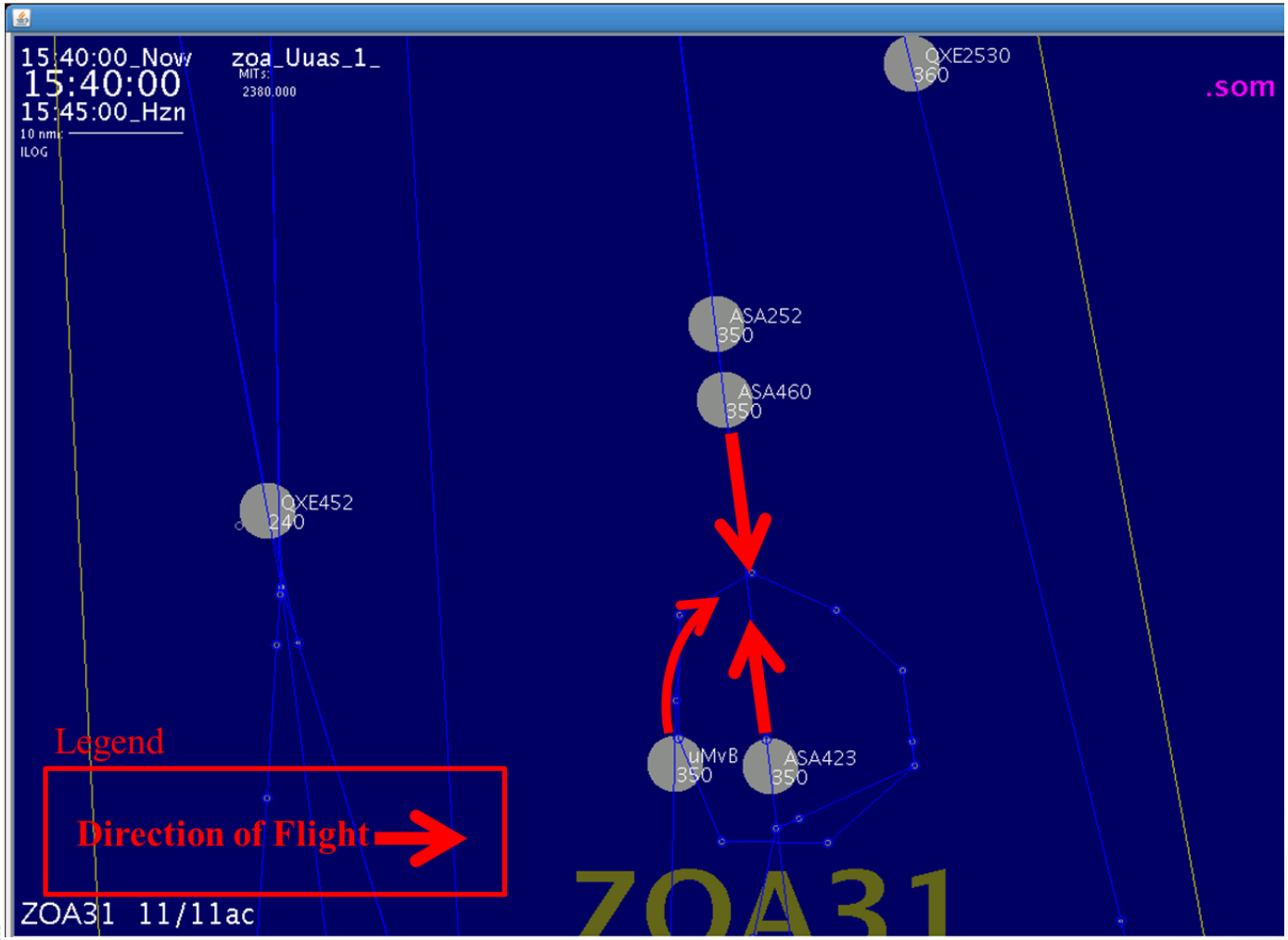
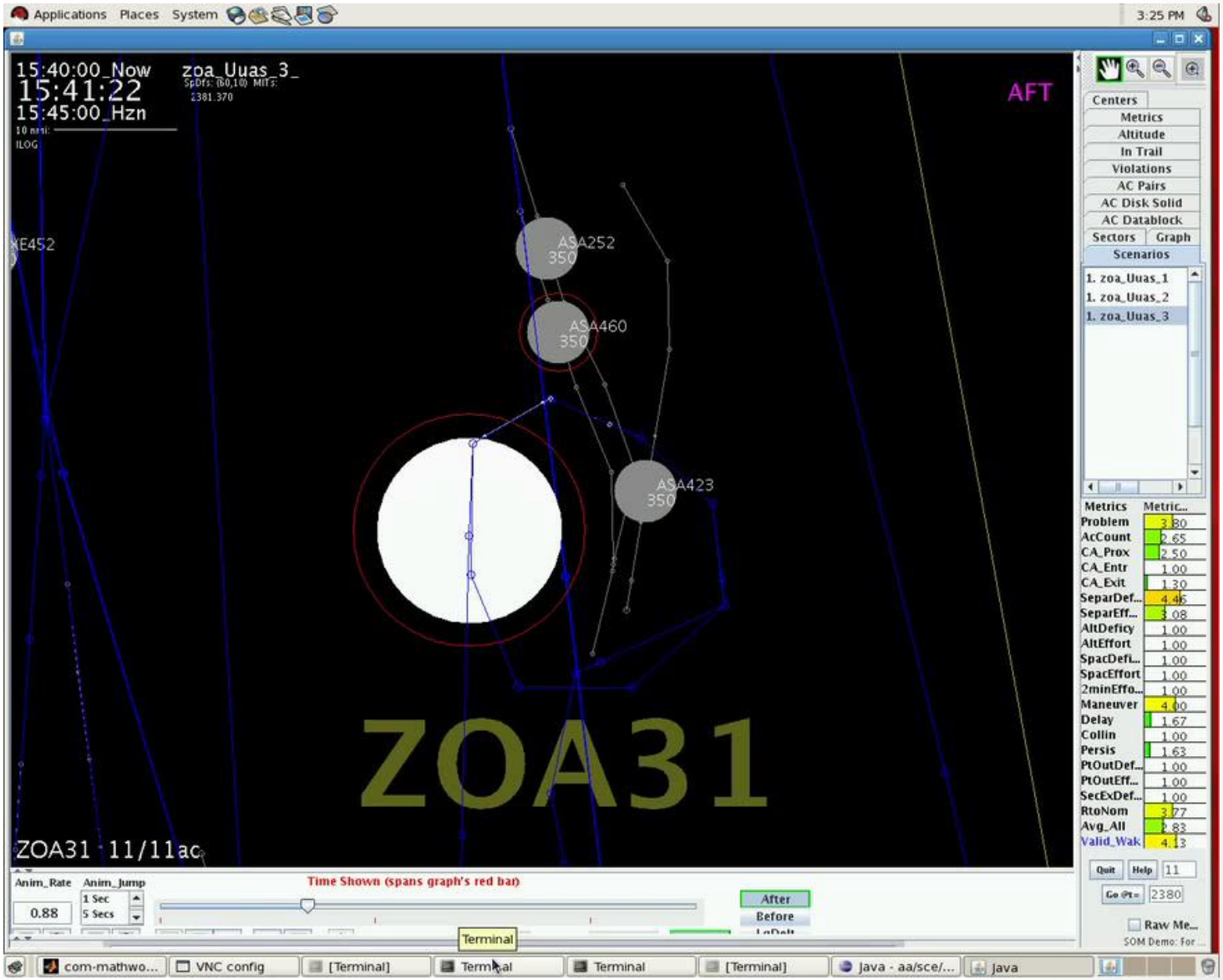
*airspace*Analyzer – Scenario as Input

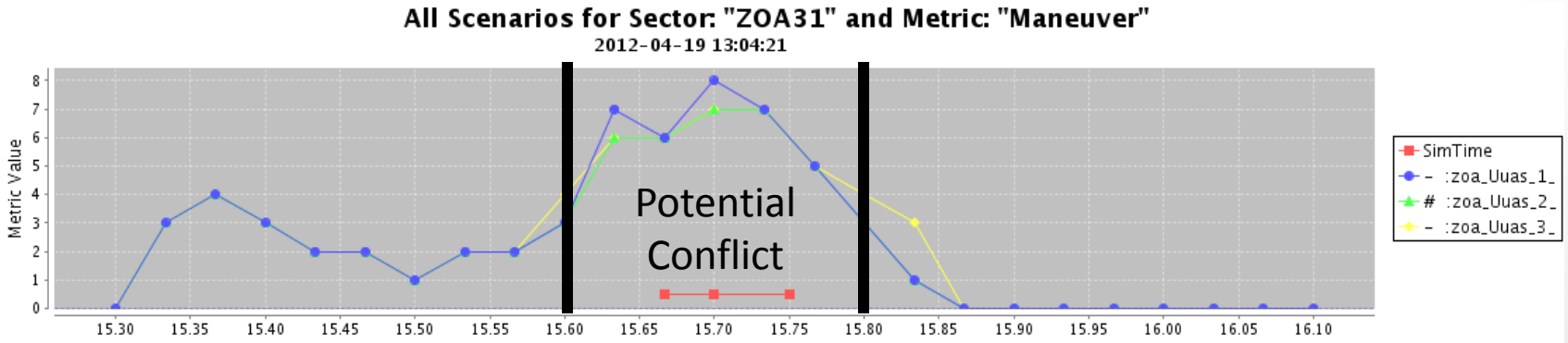


*airspace*Analyzer – Scenario 3 Demo



*airspace*Analyzer – Results

- Focused on “Maneuver” metric as a surrogate to quantify controller workload
  - Maneuver metric is a count of the total number of maneuvers required (lateral and vertical) to maintain safe separation
  - Maneuver is considered a “cognitive effort” made by the controller
  - Team hypothesized that maneuvers would increase from scenario 1 to 2 to 3



*airspace*Analyzer – Observations and Enhancements

- *airspace*Analyzer does not necessarily solve a problem in the same way ATC would
  - Expectation is that human would solve problem with as few maneuvers as possible
  - Tool attempts to maximize forward progress of all aircraft, therefore it is not uncommon for many aircraft to be maneuvered
  - This can make it difficult to interpret analysis results

- For Further Enhancements
  - Conduct similar analysis under varying traffic conditions (i.e. use many simulations to analyze thousands of scenarios)
  - Work with MITRE team to see if tool can be further manipulated to better reflect how ATC may solve a potential conflict

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Summary and Recommendations

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Summary

- A foundation for evaluating the adequacy of loss of link procedures has been developed
  - A high level of predictability and “acceptable” impact on ATC workload are both critical components of a standardized loss of link procedure
  - Both criteria should be evaluated when choosing a standardized procedure
- Models are independent of one another, but closely related
  - Low predictability can have an adverse impact on controller workload

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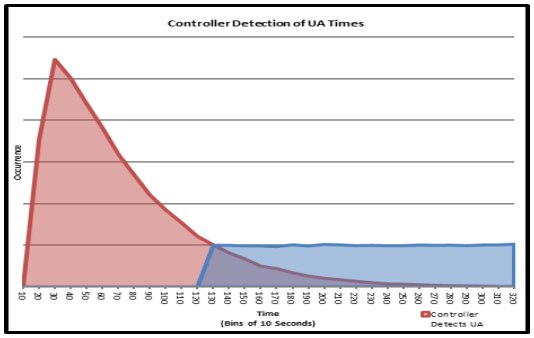
Recommendations (1 of 2)

- **Predictability Model**
  - Incorporate a method that will allow the model to evaluate procedures with multiple contingencies
  - Analyze whether different methods of notifying the controller of a loss of link situation (as opposed to RDOF flashing on the scope) will greatly change the identification time
  - Build in predictions for estimating the times of future maneuvers (look at the 2nd, 3rd, nth maneuvers)
  - Investigate the probability function of a loss of separation



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Recommendations (2 of 2)

- ***airspace*Analyzer**
  - Less confident – but not ready to give up on the tool
    - Many simulations under varying traffic conditions
    - Further modify the parameters of *airspace*Analyzer
      - More emphasis on minimizing the number of aircraft maneuvers
      - Less emphasis on maximizing forward progress of aircraft
  - Work with sponsor to determine if another tool may be more appropriate

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Impact

- Sponsor's team was very enthusiastic about our project
  - Many ideas to extend this work
- Sponsor requested that we submit this work for a company funded MITRE Innovation Project (MIP)
- Report requested from international aviation group called the Global Airspace Integration Team (GAIT)

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Questions?

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