32nd Annual International
Test and Evaluation Symposium

Testing for Capabilities:
*The Importance of Mission Accomplishment in T&E*

# Continuous System Monitoring as a Test Tool in the National Airspace System

*Bruce Normann – CSSI Inc.*

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# Outline

- There is both a need and an opportunity to extend the T&E discipline deeper into the operational portion of the lifecycle.
- Systems of Systems generate emergent behavior that can't be reliably triggered by normal test inputs
- Continuous monitoring is the only way to detect emergent behaviors
- Existing DOE methods can be extended to big data
- Some monitoring elements are in place already, but feedback loops are not fully formed

# Thesis

- Tools, techniques and data are all available to solve the challenge of detecting, identifying and analyzing emergent behavior in a SoS.
- Rigorous T&E methods can now be extended into the operational portion of the lifecycle by actively monitoring system-wide data streams.
- Increasing levels of autonomy in the SoS will dictate a more active monitoring approach
- Data-mining emergent behaviors (+/-) will provide richer feedback to system owners and builders

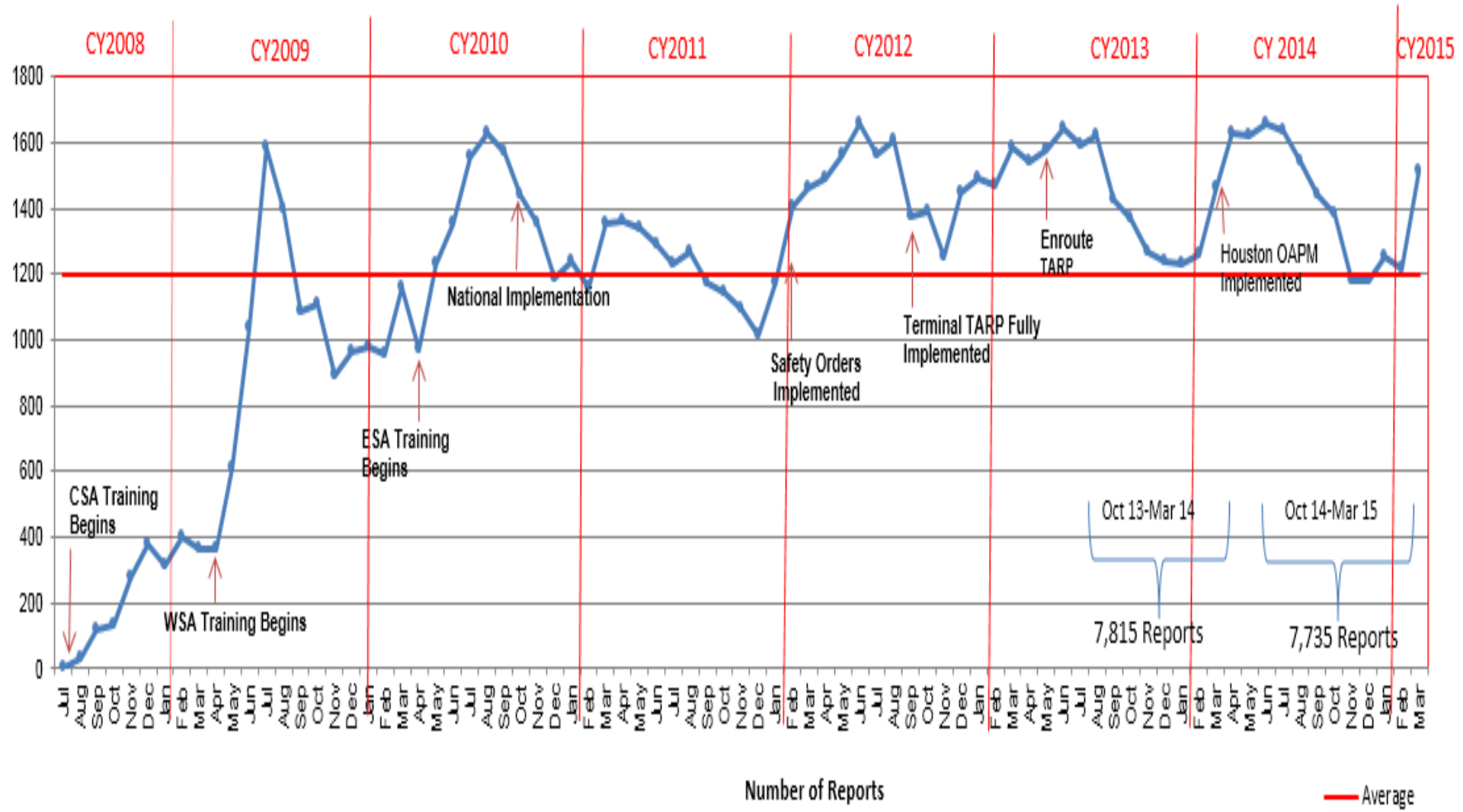
# Foundation Concepts

- A System of Systems (SoS) will exhibit unique, continuing, emergent behaviors during the normal operational lifecycle.[1]
- Emergent behavior is the cumulative effect of the actions and interactions among constituents of complex systems which cannot be predicted through analysis at any level simpler than that of the system as a whole, and is unavoidable in the presence of autonomous constituents.[2,3]

# Emergent Behavior Is Real

- This is not an insignificant portion of the overall system behavior.
- **>**2,000 voluntary **safety event** reports are filed each month for NAS operations, by ATC personnel and aircraft operators. (*event*<*incident*<*accident*)
- Every event is not caused by emergent behavior, but many are mitigated, interrupted or resolved by human intervention (= emergent behavior).

# Emergent behavior is persistent

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# Does it matter to T&E…?

- Several consistent themes in T&E industry discourse point to a sub-optimal solution for T&E of SoS.

- **How much testing is enough?**
- **Test As We Fight (*or Operate…*)**
- **Testing for Capabilities: *The Importance of Mission Accomplishment in T&E***

# The Root Problem

***"You can't know everything, at one time."***

- A good deal of thought and effort goes into more and better forms of DOE to mitigate this fact.[4,5]

- System sustainment teams don't have a T&E mentality, particularly the STAT formalism that is becoming the norm for modern T&E practice.

# The Normal T&E Charter

## **FAA** - *T&E Programs should be structured to:*

- Provide essential information to support decision making
- Provide essential information for assessing technical and acquisition risk
- Verify the attainment of technical performance specifications and objectives
- Verify that systems are operationally effective and suitable for intended use

# The T&E Charter

**The 80/20 rule supports the charters…[6]**

| Lifecycle Activity (Phase) | Errors Introduced | Errors Found |
|---|---|---|
| Requirements Analysis | 55% | 18% |
| Design | 30% | 10% |
| Testing | 10% | **50%** |
| Operational Support | 5% | **22%** |

# The How….

- T&E today is still fundamentally based on inputs and outputs, i.e. applying a forcing function and measuring the system response.
- A key semantic gap is shown by how the T&E industry parsed this phrase in 2011:
  - Test **As** We Fight.

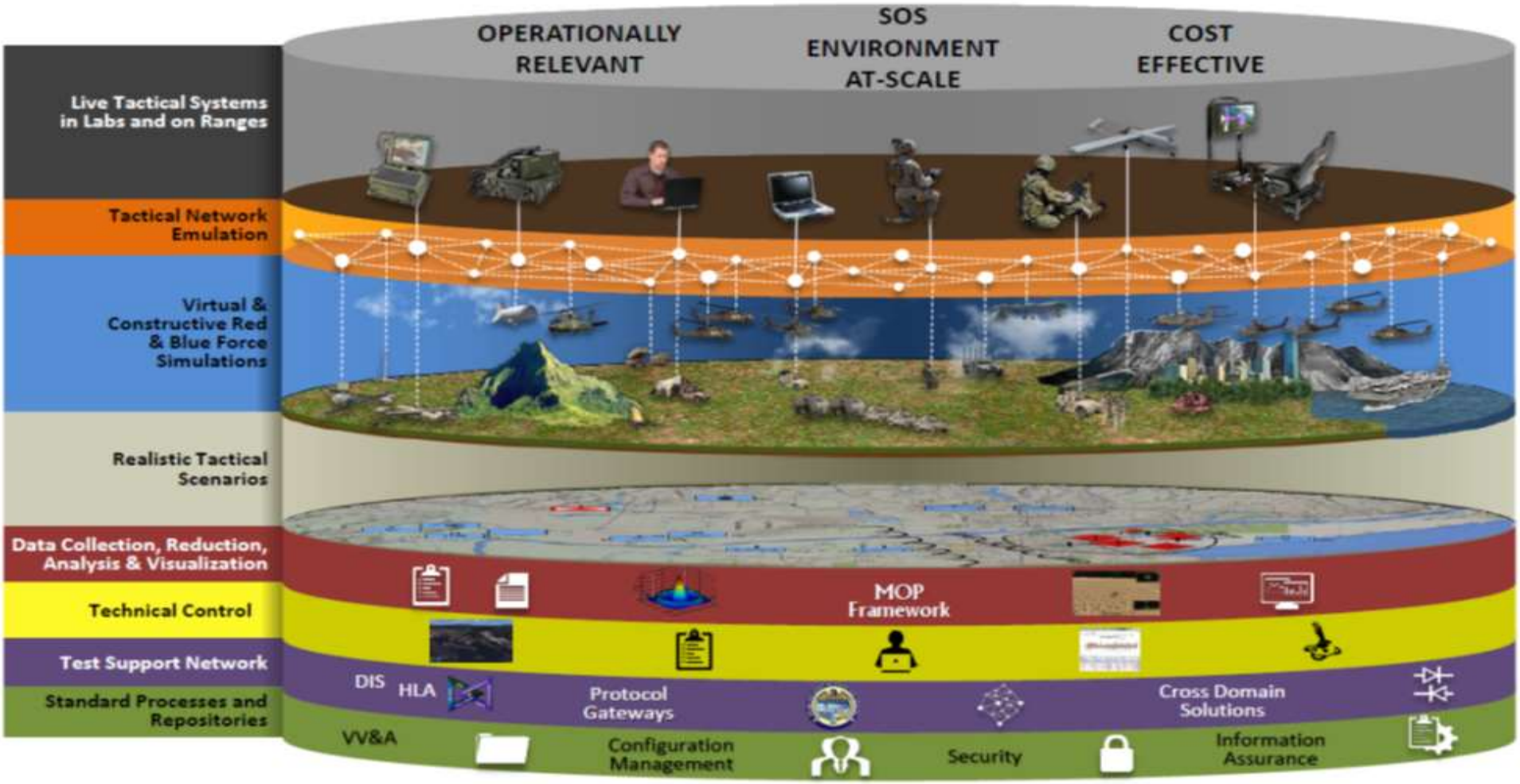
    "…. 'in the same manner' **as** we fight"

    *NOT*

    "…. 'at the same time' **as** we fight"

# How, Exemplified….

Example of "Test **in the same manner** as we fight" [7]



# An Inconvenient Truth

*"You can't force unpredictable behavior; A+B = C+δ"*

*"Anything less than total war is just a test."*

Examples:

- Stress Testing v. Continuous Monitoring for Detecting Cardiac Arrhythmia[8]
- Testing of auto emissions - Inspection v. OBD-II
- Black box driver behavior monitoring v. driving test

# The InfoSec Battle

*Impact of inadequate monitoring for IT networks* [9]

- Median age of data breech is **>** 6 months before detection
- 2/3 are **not** detected by in-house monitoring
- Usually detected by law enforcement investigation (after losses occurred...)

# Leveraging the Data

- Data that describes and documents emergent behavior is increasingly available; SWIM, VSRP, all forms of big data, unstructured data, etc.
- Finding the emergent behavior is more difficult, because it often depends on context. The challenge is to separate out the unpredicted behavior.
- Small-scale, point solutions are becoming more common, with advent of big data tool sets. *Example:* On-line monitoring of the emergent behavior and characteristics of a product to improve product design.[10]

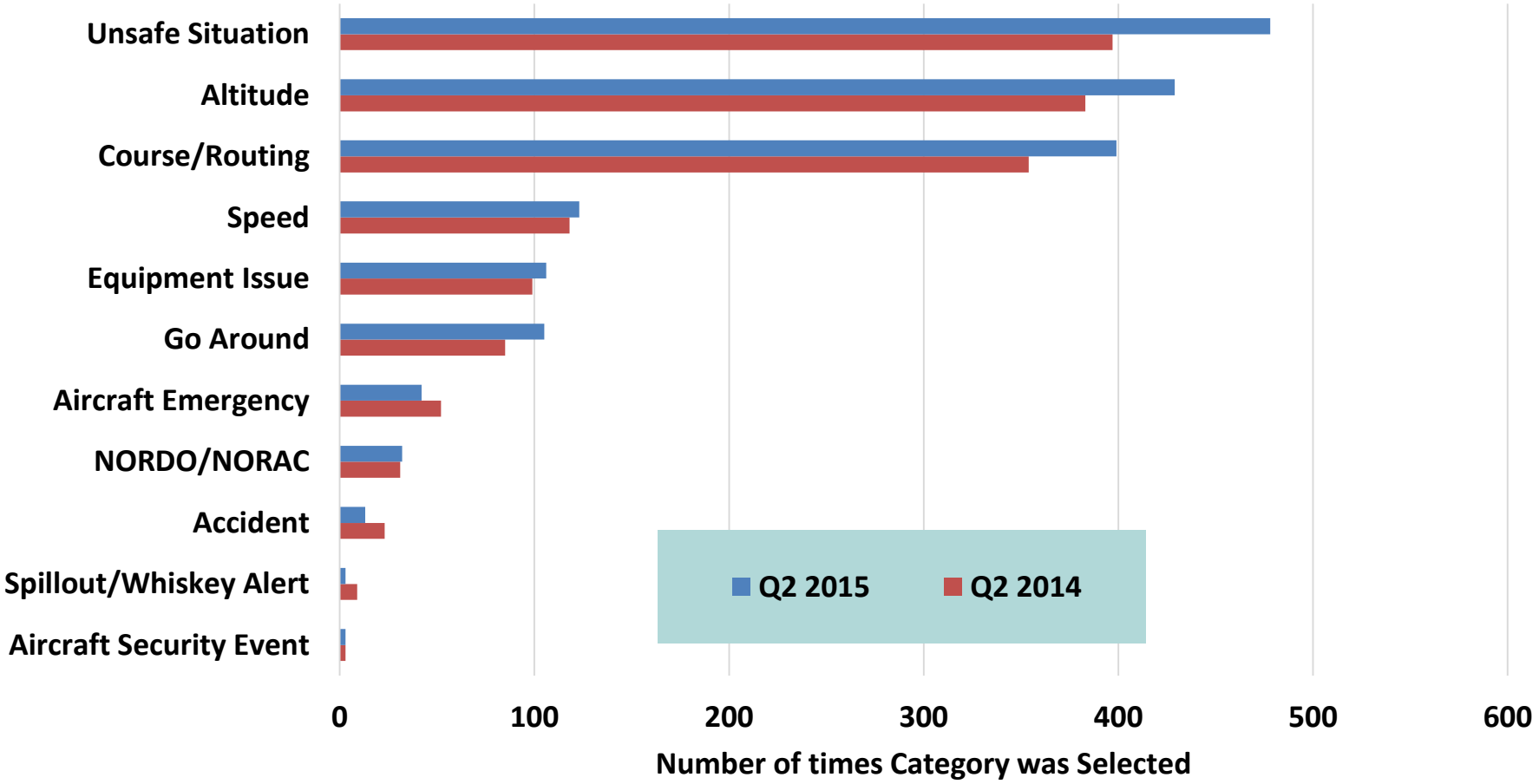
# Tools on the Shelf

A variety of network analysis methods can be used or adapted to identify, select, and order the critical relationships that will yield the most information from continuously monitored operational data.

- Multi-dimensional dependency (MDD) analysis[11]
- Systems Geometry[12]
- Bayesian Networks, Probabilistic Causal Modeling[13]
- ……

# Where We Are Today

VSRP data has untapped potential for analysis:[14]



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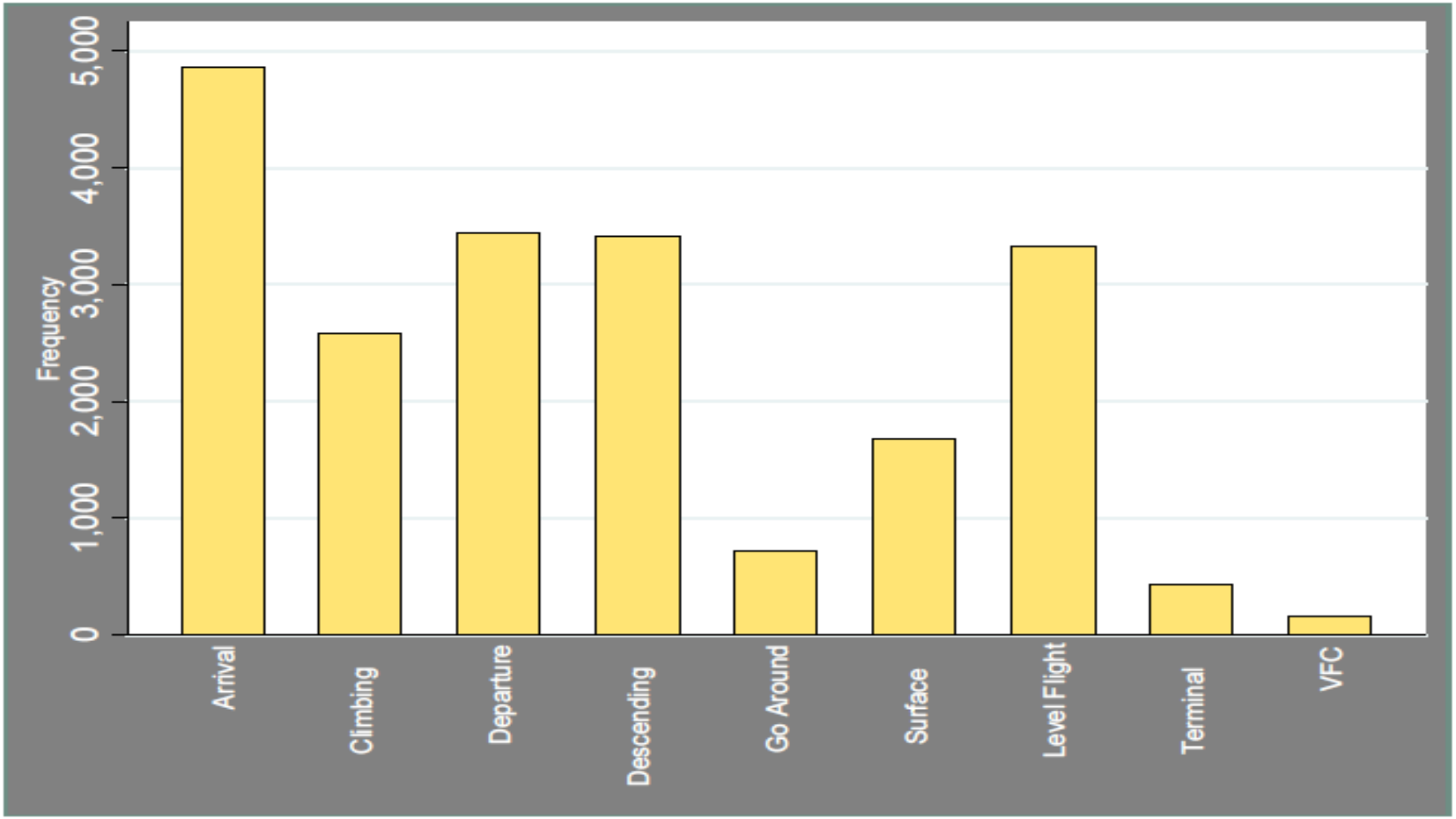
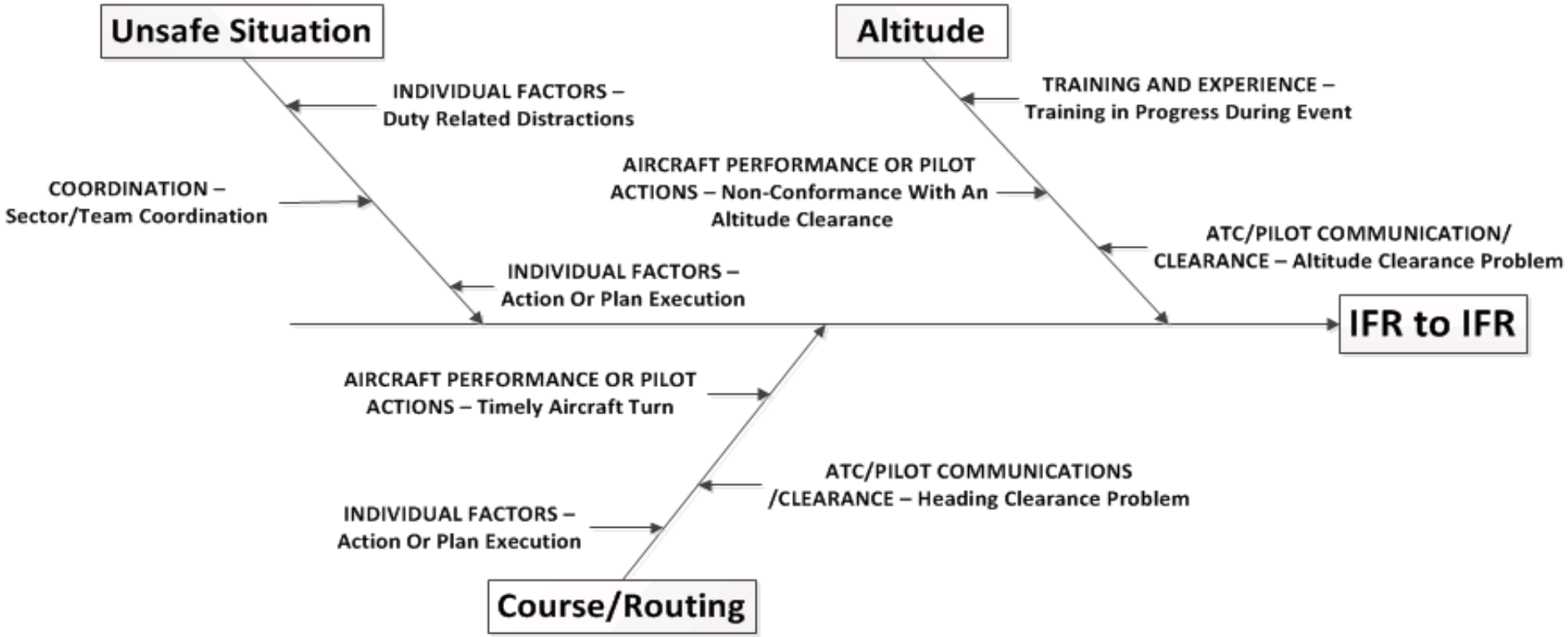


# Where We Are Today

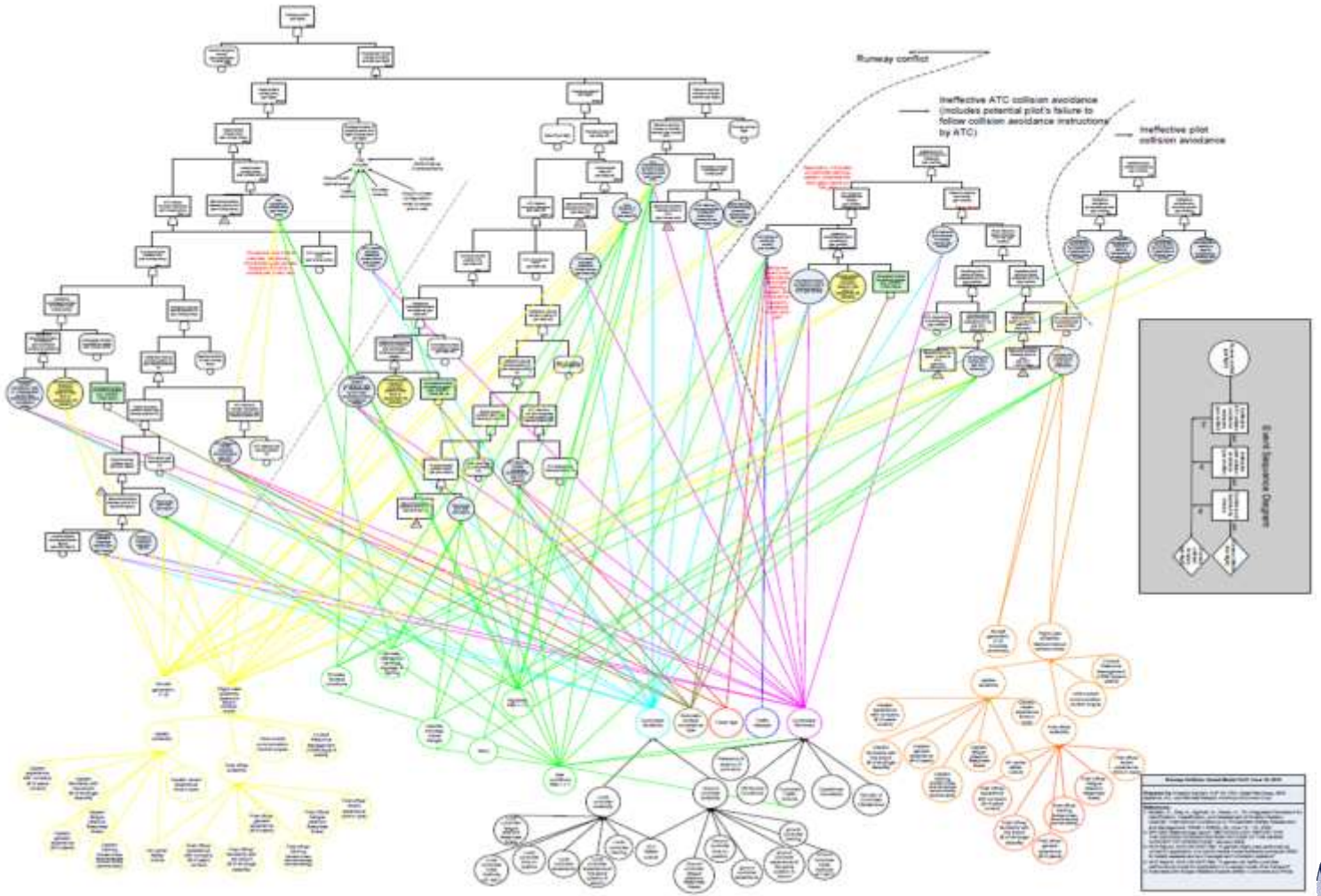
VSRP data has untapped potential for analysis:[16]

**Most Common Causal Categories and Factors Leading to a Conflict between IFR Aircraft**



# Where We Are Today

Bayesian networks can simplify the analysis



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# Next Steps - Opportunities

- Continuing research into data analysis techniques for large, operational data sets
- Establishing feedback to system and SoS design
- Enabling the move from Safety-I to Safety-II
  - Understanding '**+** *and* **–**' safety events
- Designing continuous monitoring components based on optimized interaction networks
- Integrating continuous monitoring into the concept development phase - moving up the chain again…

# Next Steps - Challenges

- Not all SoS have extensive data collection, storage, & distribution
- Techniques may be viewed as 'reactive' in nature, since they don’t solve for all unknowns before deployment and integration.
- May be viewed as adding unnecessary resources to sustainment phase of program
- Data generation may be 'slow'
- SoS are constantly evolving

# Wrap Up

- The T&E discipline can be a relevant force during the operational portion of the lifecycle, continuously reducing risk and increasing system performance.
- A new 'CTE' toolset is required, and all the basic components are available to build it.
- Existing DOE methods can be leveraged as-is
- CTE supports modern product delivery methods
- Increasing levels of autonomy in the SoS will dictate a more active monitoring approach

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