Collective Mind: Core CBM+ Capability

Applying Predictive Trending within CAMEO: Exploration and Explanation of Anomalous Patterns

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The CAMEO Collective Mind Experiment



This briefing:

1. **Collective Mind Mission: To Support Proactive Approach to Fleet Health Management**
2. **Means: Collective Mind develops analytic capabilities to provide early warnings and explanation of emerging reliability issues**
3. **Targeted capabilities:**
   - Massive Screening for abnormal patterns
   - Systems Performance Monitor for identification of anomalous items

   Today's Topics
   - Exploration of identified patterns across streams
   - Explanation and prediction of patterns
4. **Taking the Collective Mind approach to other aircraft and other platforms**

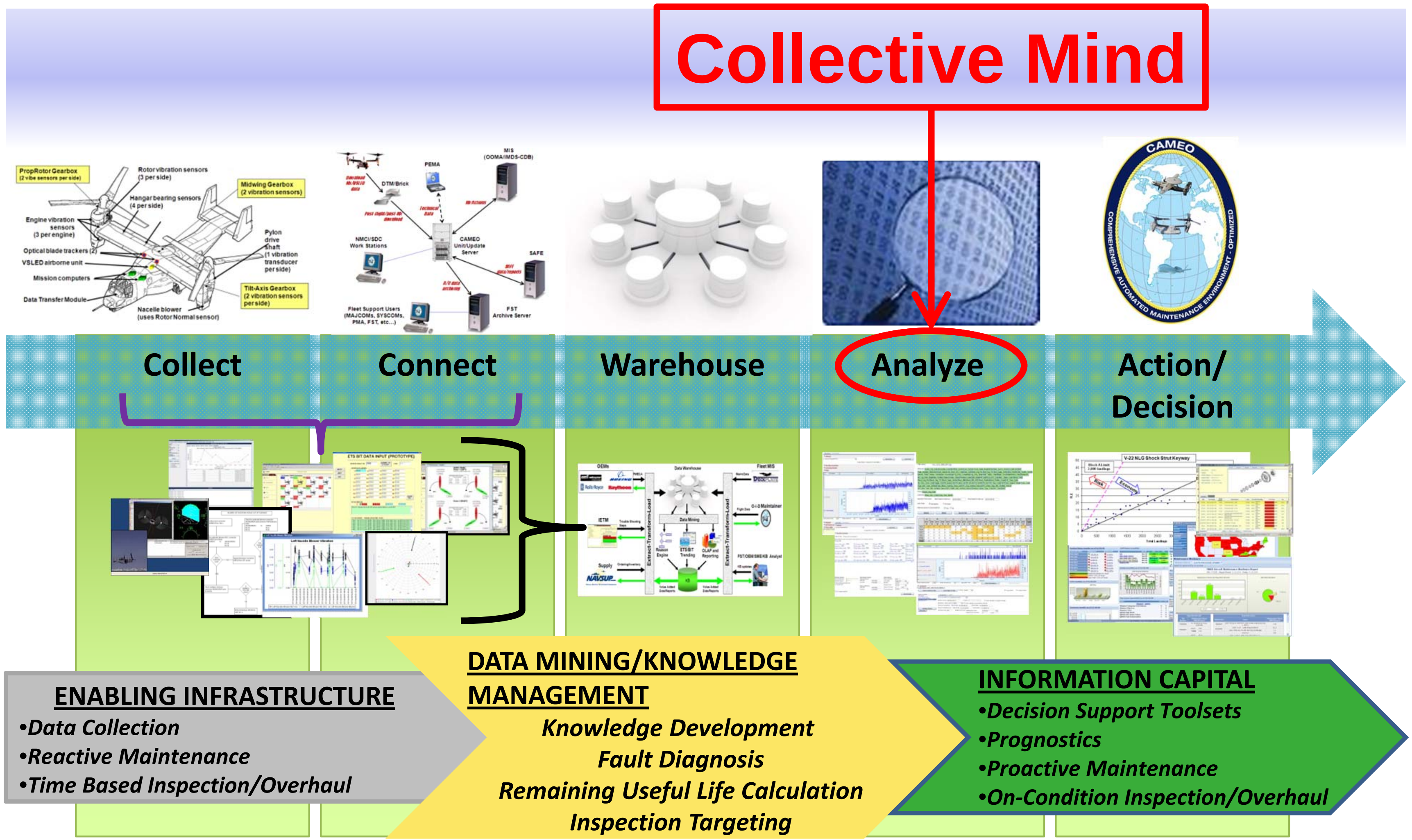
Challenges of Proactive Approach to Fleet Health Management

- **Unexpected systematic fleet-wide problems are common**
- Their **early detection** and characterization is the **key** to **proactive management**
  - Various **leading indicators** are used to (reactively) survey the status of fleet
  - **Physics-based models** are used to identify propensity of individual aircraft to **known** problems
- **Ideal capability:** **Fast and accurate detection of emerging issues, no false alarms**
- Not easy to achieve…

Ground abort rate
Air abort rate
MAF total air abort rate (home station air aborts + J diverts)
Code 3 break rate
8-/12-hour fix rate
Repeat rate
Recur rate
Logistics departure reliability
Average deferred/delayed discrepancies per aircraft
Discrepancies awaiting maintenance (AWM) or awaiting parts (AWP)
MSE rate
Functional check flight (FCF) release rate
CANN rate
Issue effectiveness rate
Stockage effectiveness rate
Bench-stockage effectiveness rate
Mission capability (MICAP) aircraft part rate
Average repair cycle days
Phase flow—a phase time distribution interval (TDI)

Forward-looking Maintenance Metrics

CAMEO: An Enabling Infrastructure to Facilitate Implementation of CBM+ Systems



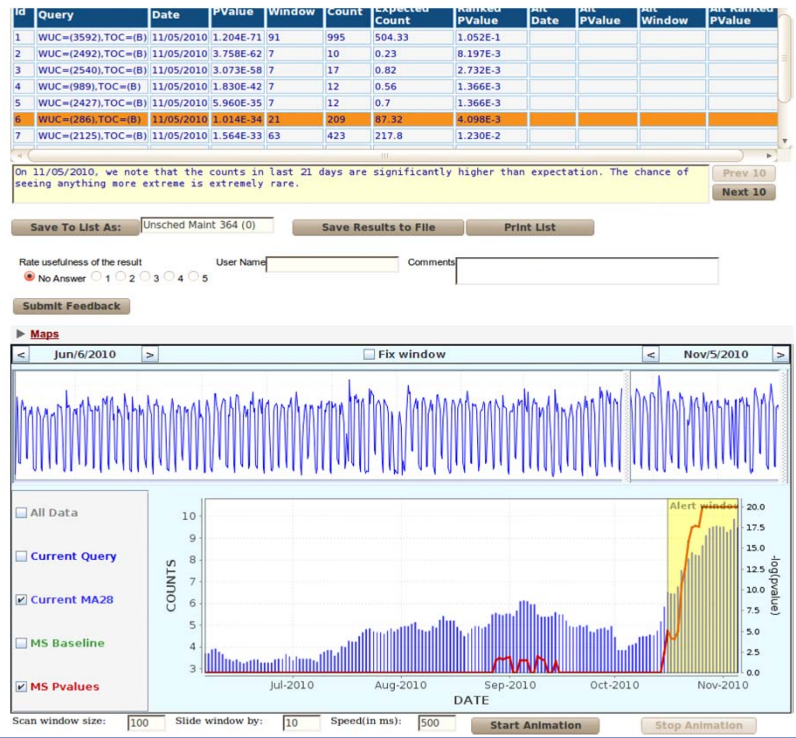
Key Capabilities of Collective Mind

- **Typical logistics data spans multiple streams and multiple dimensions**
  – Maintenance, built-in-test, vibration, configuration, flight data, supply, etc.
  – Maintenance: action taken code, when discovered, aircraft configuration, mission type, squadron, etc.
- **This leads to <u>billions</u> of potentially interesting projections of data**
- **Traditionally, data surveillance is selective and of limited sensitivity**
  – Comprehensive approach is often deemed computationally infeasible
  – Analytic resources come in short supply
  – **Risk of missing critical clues** is substantial
  – Emerging **issues identified later** than they could

<u>**CM capabilities address those challenges:**</u>

1. **Massive Screening of highly multivariate data for abnormal patterns (fleet level)**
2. **Systems Performance Monitor (detecting "<u>Bad Actors</u>")**
3. **Exploration of identified patterns across streams**
4. **Explanation and prediction of patterns**

<u>Using routinely collected data</u> (doing more without more)



Newer Collective Mind Capabilities: Multi-Stream Analysis

One type of Collective Mind cross-stream screenings:

- **Identify which maintenance activities form significantly regular sequential correlations with certain Built-In-Test (BIT) alerts**
  - Example use: Evaluating effectiveness of the existing testing protocols and need for new Built-In-Test subsystems

Other examples of Collective Mind cross-stream analysis – Explaining and predicting vibration exceedences:

- **Correlate flight conditions with vibration patterns to explain some of the observed exceedences**
  - Example use: Dismiss some exceedences as not linked with any mechanical fault to reduce investigative efforts of ground crews

- **Monitor patterns of vibrations to predict upcoming exceedences ahead of their occurrence**
  - Example use: Preemptive maintenance

Collective Mind: Underlying Technology

- **Collective Mind leverages advanced statistics, smart data structures, fast algorithms**

  Example: T-Cube - CMU-developed cached sufficient statistics data structure capable of reducing time to respond to complex count queries by 1-3 orders of magnitude when compared to alternatives

- **T-Cube efficiency enables:**
  - **Massive scale multivariate analyses** of **very large sets** of multi-dimensional data
  - **Interactive visualizations** of data
  - Automated and highly responsive manual ad-hoc analyses

- **Key practical benefits:**
  - Comprehensive searches for unusual patterns made possible

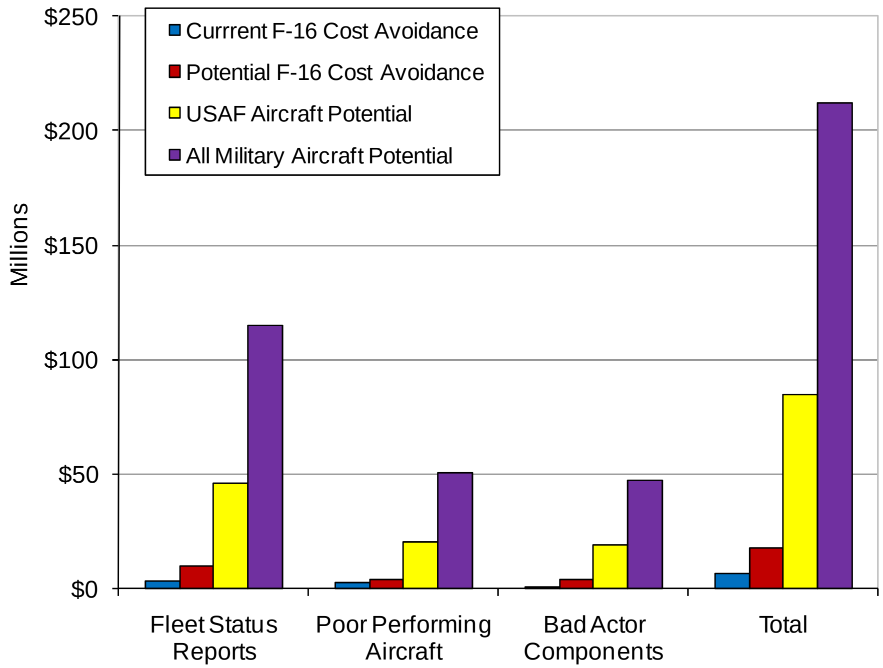
    "We don't know what we don't know" dilemma can be substantially mitigated
  - Interactive visualizations and queries boost situational awareness and understanding of the processes that produce data

Side notes on T-Cube performance

1. **Query response times do not depend on the number of records in data**
   - **Largest set loaded so far: 125M records, 15 dimensions**
   - **Minutes to screen for patterns over 4 dimensions, evaluating 4.5B hypotheses**
2. **Memory footprint varies with complexity of data**
   - **Most complex data loaded so far: 7.7M records, 19 dimensions, $5.2*10^{25}$ unique data cube cells, 478B of them with non-zero counts**
   - **Requires 10GB of memory**
3. **Speed can be traded for memory**

Quantified Task: Avoided Cost of Part Exchanges

Evidence obtained with help from the F-16 Strategic Analysis Support Section and the US Air Force Cost Analysis Directorate



- **Those savings only reflect avoided exchanges**
- **More potential, not yet estimated firmly, includes a few relatively straightforward benefits:**
  - **Improved equipment availability**
  - **Improved mission capability**
  - **Reduction of analytic efforts**
- **Costs of transition to regular use is not included in the estimates**

- **F-16 :** Return from subset analyzed from early detection and mobilization: **$6.5M** p.a.; Expected return once fully deployed: **$18.0M** p.a.
- **Scaling to all military aircraft : $212M** p.a.

Observed cost of integrating platform data into T-Cube:

- Once established with GCSS-AF, adding new aircraft type took 8hrs to setup
- Transfer of Massive Screening, System Performance Monitor and Basic Exploration and Explanation from GCSS-AF to NALCOMIS and DECKPLATE V-22 data took 1 man-month
- Larger effort to integrate into the CAMEO analysis processes
- **Modest additional investment should enable scaling Collective Mind throughout DoD aircraft fleets and throughout all DoD equipment fleets wherever logistics data warehouses exist**

Collective Mind: Summary

1. Collective Mind develops new capabilities to support a proactive approach to Fleet Health Management
2. It uses statistical data mining and predictive trending to monitor routinely collected data for early indications of reliability issues
3. Capabilities developed so far have demonstrated utility using the USAF and NAVAIR aircraft maintenance, built-in-test, and vibration data
4. Hypothesis: Applicability is not limited to USAF and NAVAIR environments -- benefits should be found in all areas of CBM+ interest

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