Formalized Pilot Study of Safety-Critical Software Anomalies

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Topics

- Overview
- Results
  - Quantitative analysis
  - Evolution of requirements
  - Pattern identification & unexpected patterns
- Work-in-progress
- Benefits
Overview

- **Goal:** To reduce the number of safety-critical software anomalies that occur during flight by providing a *quantitative analysis* of previous anomalies as a foundation for process improvement.

- **Approach:** Analyzed anomaly data using adaptation of *Orthogonal Defect Classification (ODC)* method
  - Developed at IBM; widely used by industry
  - Quantitative approach
  - Used here to detect patterns in anomaly data

- **Evaluated ODC for NASA use using a Formalized Pilot Study** [Glass, 97]
Overview: Status

- Year 3 of planned 3-year study
  Plan → Design → Conduct → Evaluate → Use
- FY’03 extension proposed to extend ODC work to *pre-launch and transition to projects* (Deep Impact, contractor-developed software, Mars Exploration Rover testing)
- Adapted ODC categories to operational spacecraft software at JPL:
  - Activity: what was taking place when anomaly occurred?
  - Trigger: what was the catalyst?
  - Target: what was fixed?
  - Type: what kind of fix was done?
Results: ODC Adaptation

- Adapted ODC classification to post-launch spacecraft Incident Surprise Anomalies (ISAs)

<table>
<thead>
<tr>
<th>Activities</th>
<th>Triggers</th>
</tr>
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<tbody>
<tr>
<td>System Test</td>
<td>Software Configuration</td>
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<td></td>
<td>Hardware Configuration</td>
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<td></td>
<td>Start/Restart, Shutdown</td>
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<td>Command Sequence Test</td>
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<td></td>
<td>Inspection/Review</td>
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<tr>
<td>Flight Operations</td>
<td>Recovery</td>
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<td></td>
<td>Normal Activity</td>
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<tr>
<td></td>
<td>Data Access/Delivery</td>
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<tr>
<td></td>
<td>Special Procedure</td>
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<td>Hardware Failure</td>
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<tr>
<td>Unknown</td>
<td>Unknown</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Targets</th>
<th>Types</th>
</tr>
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<tbody>
<tr>
<td>Ground Software</td>
<td>Function/Algorithm</td>
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<tr>
<td></td>
<td>Interfaces</td>
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<td>Assignment/Initialization</td>
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<td>Timing</td>
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<td></td>
<td>Flight Rule</td>
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<tr>
<td>Build /Package</td>
<td>Install Dependency</td>
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<td>Packaging Scripts</td>
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<tr>
<td>Ground Resources</td>
<td>Resource Conflict</td>
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<td>Info. Development</td>
<td>Documentation</td>
</tr>
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<td></td>
<td>Procedures</td>
</tr>
<tr>
<td>Hardware</td>
<td>Hardware</td>
</tr>
<tr>
<td>None/Unknown</td>
<td>Nothing Fixed</td>
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<tr>
<td></td>
<td>Unknown</td>
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</tbody>
</table>
Results: Quantitative Analysis

- Analyzed 189 Incident/Surprise/Anomaly reports (ISAs) of highest criticality from 7 spacecraft
  - Cassini, Deep Space 1, Galileo, Mars Climate Orbiter, Mars Global Surveyor, Mars Polar Lander, Stardust
- Institutional defect database → Access database of data of interest → Excel spreadsheet with ODC categories → Pivot tables with multiple views of data
- Frequency counts of Activity, Trigger, Target, Type, Trigger within Activity, Type within Target, etc.
- User-selectable representation of results
- User-selectable sets of spacecraft for comparison
- Provides rapid quantification of data
Results: Quantitative Analysis

Distribution of Triggers within Activity
Results: Quantitative Analysis

Ground/Flight S/W vs. Type within Activity

Trigger vs. Target
Results: *Evolution of Requirements*

- Anomalies sometimes result in changes to software requirements

- **Finding:**
  - Change to handle rare event or scenario (software adds fault tolerance)
  - Change to compensate for hardware failure or limitations (software adds robustness)

- **Contradicts assumption that “what breaks is what gets fixed”**

**Example:** Damaged Solar Array Panel cannot deploy as planned

- Activity = Flight Operations (occurred during flight)
- Trigger = Hardware failure (Solar Array panel incorrect position—broken piece rotated & prevented latching)
- Target = Flight Software (Fixed via changes to flight software)
- Type = Function/Algorithm (Added a solar-array-powered hold capability to s/w)
Results: *Pattern Identification*

- **Sample Question:** What is the typical signature of a post-launch critical software anomaly?

- **Answer:**
  - Activity = Flight Operations
  - Trigger = Data Access/Delivery
  - Target = Information Development
  - Type = Procedures

- **Example:** Star Scanner anomaly
  - Activity = occurred during flight
  - Trigger = star scanner telemetry froze
  - Target = fix was new description of star calibration
  - Type = procedure written
# Results: *Unexpected Patterns*

## Examples of Unexpected ISA patterns:

<table>
<thead>
<tr>
<th>Example (from spacecraft):</th>
<th>Process Recommendation:</th>
<th>Example (from spacecraft):</th>
</tr>
</thead>
<tbody>
<tr>
<td>22% of critical ISAs had ground software as Target (fix)</td>
<td>Software QA for ground software</td>
<td>Unable to process multiple submissions. Fixed code.</td>
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<tr>
<td>23% of critical ISAs had procedures as Type</td>
<td>Assemble checklist of needed procedures for future projects</td>
<td>Not in inertial mode during star calibration. Additions made to checklist to prevent in future.</td>
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<tr>
<td>Of these, 41% had Data access / delivery as Trigger</td>
<td>Better communication of changes and updates to operations</td>
<td>Multiple queries for spacecraft engineering and monitor data failed. Streamlined notification to operators of problems.</td>
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<tr>
<td>34% of critical ISAs involving system test had software configuration as Trigger (cause); 24% had hardware configuration as Trigger</td>
<td>Additional end-to-end configuration testing</td>
<td>OPS personnel did not have a green command system for the uplink of two trajectory-correction command files. Problems resulted from a firewall configuration change.</td>
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Work-In-Progress

- **Assembling process recommendations** tied to specific findings and unexpected patterns; in review by projects

- **Working to incorporate ODC classifications** into next-generation problem-failure reporting database (to support automation & visualization)

- **Disseminating results**: invited presentations to JPL Software Quality Improvement task, to JPL Mission Assurance Managers, to MER, informal briefings to other flight projects; at Assurance Technology Conference (B. Sigal), included in talk at Metrics 2002 (A. Nikora), at 2001 IFIP WG 2.9 Workshop on Requirements Engineering; papers in 5th IEEE Int’l Symposium on Requirements Engineering and The Journal of Systems and Software (to appear).
Collaborating with Mars Exploration Rover to experimentally extend ODC approach to pre-launch software problem/failure testing reports

- Adjusted ODC classifications to testing phases (build, integration, acceptance)
- Delivered experimental ODC analysis of 155 Problem/ Failure Reports to MER
- Feedback from Project has been noteworthy
- Results can support tracking trends and progress:
  - Graphical summaries
  - Comparisons of testing phases
- Results can support better understanding of typical problem signatures
ODC Analysis (preliminary)
MER Testing Problem/Failure Reports: 
*Trigger by Activity*

- Capability Invocation
- Command Execution
- Data Access/Delivery
- HW Configuration
- HW-SW Interaction
- Inspection/Review
- Recovery
- Special Procedure
- Start/Restart
- SW Configuration
- Unknown
- Workload & stress
ODC Analysis *(preliminary)*
MER Testing Problem/Failure Reports: *Trigger by Target*
Benefits

- User selects preferred representation (e.g., 3-D bar graphs) and set of projects to view
- Data mines historical and current databases of anomaly and problem reports to feed-forward into future projects
- Uses metrics information to identify and focus on problem areas
- Provides quantitative foundation for process improvement
- Equips us with a methodology to continue to learn as projects and processes evolve