Empirical Analysis of Safety-Critical Software Anomalies Post-Launch

Burton Sigal (JPL)

Robyn Lutz and Carmen Mikulski (JPL)

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Topics

- **Overview**
- **Results**
  - Quantitative analysis
  - Evolution of requirements
  - Visualization tools
- **Work-in-progress**
- **Contribution**

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.

Overview: *Approach*

- **Analyzed anomaly data using *Orthogonal Defect Classification (ODC)* method**
  - Developed at IBM; widely used by industry
  - Quantitative approach
  - Used here to detect patterns in anomaly data
- **Evaluated ODC using *Formalized Pilot Study***
  - R. Glass ['97] detailed rigorous process to get valid results
  - 35 steps divided into 5 phases
  - Used here to evaluate ODC for NASA use

Overview: *What is ODC?*

- **ODC is a measurement technology for software engineering that uses defects found as a source of information to understand and improve:**
  - The software product
  - The software process
- **Defect is described as a required change, necessary to fix the program or product**

More information can be found at http://www.research.ibm.com/softeng

Overview: *ODC Defect Classification*

- **Activity: what was taking place when anomaly occurred?**
  - Based on the activity performed when the defect was recorded
- **Trigger: what was the catalyst?**
  - Catalyst that causes defect to manifest itself as a failure
  - Different triggers for each activity
- **Target: what was fixed?**
  - The highest-level identity of the entity that was fixed
- **Type: what kind of fix was done?**
  - The actual correction that was made to fix the problem

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Results: *Summary of Activities*

- **Started with a small set of 89 critical Incident/Surprise/Anomaly reports (ISAs)**
  - Adapted ODC classification scheme for **post-launch** ISAs
  - Preliminary results indicated post-launch software requirements evolution
- **Expanded set and analyzed 199 of high criticality ISAs**
  - 7 spacecraft: Cassini, Deep Space 1, Mars Global Surveyor, Galileo, Mars Polar Lander, Mars Climate Orbiter, Stardust
- **Institutional defect database → Access database of data of interest → Excel spreadsheet with ODC categories → Pivot tables with multiple views of data**
- **2-D and 3-D frequency counts of Activity, Trigger, Target, Type, Trigger within Activity, Type within Target, etc.**
- **Found patterns→formulated hypotheses→provided recommendations**

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Results: *ODC Adaptation to JPL*

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

Activities	Triggers
System Test	Software Configuration Hardware Configuration Start/Restart, Shutdown Command Sequence Test Inspection/Review
Flight Operations	Recovery Normal Activity Data Access/Delivery Special Procedure Hardware Failure
Unknown	Unknown

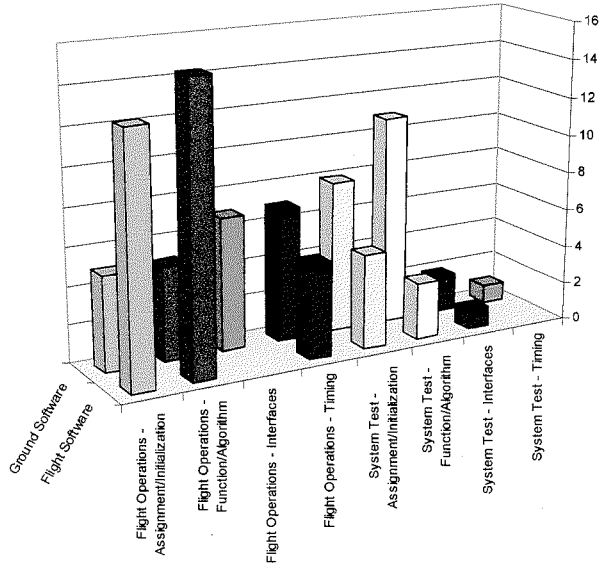
Targets	Types
Ground Software	Function/Algorithm Interfaces Assignment/Initialization Timing
Flight Software	Function/Algorithm Interfaces Assignment/Initialization Timing Flight Rule
Build /Package	Install Dependency Packaging Scripts
Ground Resources	Resource Conflict
Info. Development	Documentation Procedures
Hardware	Hardware
None/Unknown	Nothing Fixed Unknown

Results: *Profiling Analysis*

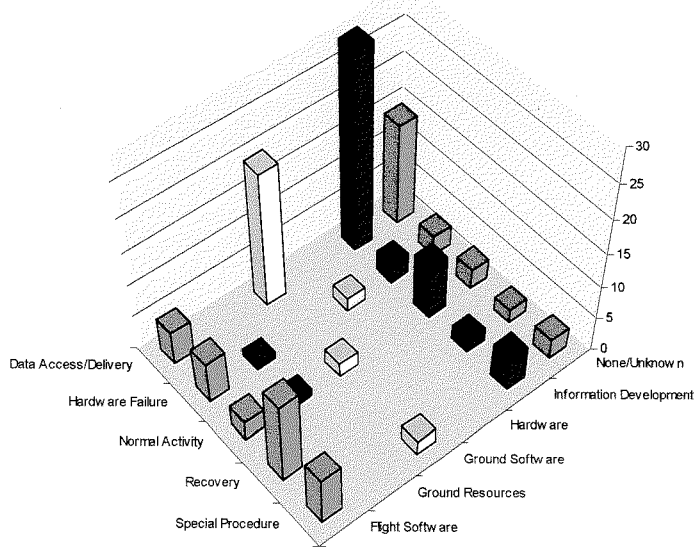
- **Sample Question: What is the typical signature of a post-launch critical software anomaly?**
- **Metrics:**
  - Activity = Flight Operations
  - Trigger = Data Access/Delivery
  - Target = Information Development
  - Type = Procedures
- **Example: Star Scanner anomaly**
  - Activity = occurred during flight
  - Trigger = star scanner telemetry froze
  - Target = fix was new description of star calibration
  - Type = procedure written

Results: *Sample Analyses*

Ground/Flight S/W vs. Type within Activity



Trigger vs. Target



Results: *Evolution of Safety-Critical Requirements Post-Launch*

- **Anomalies sometimes result in changes to software requirements**
- **Found that requirements changes are not due to earlier requirement errors**
- **Instead, requirements changes are due to:**
  - Need to handle rare event or scenario (software adds fault tolerance)
  - Need to compensate for hardware failure or limitations (software adds robustness)
- **Metrics:**
  - Activity = Flight Operations
  - Trigger = Hardware failure
  - Target = Flight Software
  - Type = Function Algorithm
  - **Example: Damaged Solar Array Panel cannot deploy as planned**
    - Activity = occurred during flight
    - Trigger = Solar Array panel incorrect position (broken damper which had rotated into the SAM hinge-line which prevented latching)
    - Target = Changes to flight software
    - Type = Add a solar array powered hold capability in the FSW

Results: *Evolution of Safety-Critical Requirements Post-Launch*

- Confirms value of requirements completeness for fault tolerance
- Confirms value of contingency planning to speed change
- Contradicts assumption that "what breaks is what gets fixed"
- Suggests need for better requirements engineering for maintenance
- Results presented at IFIP WG 2.9 Workshop on Requirements Engineering, Feb, 2001; at 5th IEEE International Symposium on Requirements Engineering, Aug, 2001.
- "Operational Anomalies as a Cause of Safety-Critical Requirements Evolution," to appear, *The Journal of Systems and Software*

Results:
Web-based Visualization Tool

- Results of Peter Neubauer (ASU), Caltech/JPL Summer Undergraduate Research Fellow, 2001
- Developed alternative visualizations of data results to support users' analyses
- Web-based tool assists distributed users
- Sophisticated tool architecture builds on existing freeware
- Demo at QA Section Manager's meeting (FAQ: Would this work for our project?)
- Demo to D. Potter's JPL group developing next-generation Failure Anomaly Management System

Work-In-Progress

- **Assembling process recommendations tied to specific findings and unexpected patterns**
  - Ex: Create checklist of "missing" procedures that were needed during operations in previous, similar missions
  - Ex: Use early Contingency Planning to anticipate and support requirements evolution
- **Incorporate standardized ODC classifications into next-generation problem-failure reporting database to support automation and visualization**
- **Profile by mission phase: are there more anomalies during critical mission phases?**
- **Pursuing funding for FY'03 extension of ODC work to pre-launch and additional applications**

Work-In-Progress

- **Collaborating with Mars Exploration Rover to experimentally extend ODC approach to pre-launch software problem reports**
  - Adjusting ODC classifications to testing phase
  - Feedback from Project has been noteworthy
  - Analyzing Problem Reports per ODC classification
  - Results can support tracking trends and progress:
    - Graphical data summaries will be delivered to Project
  - Results can support better understanding of typical problem signatures:
    - Hypothesis testing results will be delivered to Project

Contribution

- User selects preferred representation (e.g., 2-D bar graph) 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 unexpected patterns and focus on problem areas
- Provides rapid quantitative foundation for process improvement
- Equips us with a methodology to continue to learn as projects and processes evolve