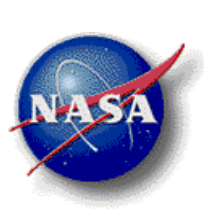

Modeling to Improve the Risk Reduction Process for Command File Errors

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Outline

- Introduction
- Probabilistic Modeling Approach
  - Analyzing Command File Error Rates
- Systems Analysis using Bayesian Belief Networks
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Introduction (1/2)

- Command Errors have been documented and studied by the Jet Propulsion Laboratory (JPL) Office of Safety and Mission Success (OSMS) and our industrial partners for well over a decade.
- Initially the effort and definitions were somewhat informal but have increased in rigor with time.
- Since a discussion with a half dozen space operations personnel will arrive at a half dozen different ideas of what a Command Error is, JPL's OSMS adopted a formal definition for a Command File Error (CFE). A CFE is now defined in JPL's Anomaly Resolution Requirements document as:
- One of the following regardless of the effect on the spacecraft:
  - An error in a command file that was sent to the spacecraft
  - An error in the approval, processing, or unlinking of a command file that was sent to the spacecraft
  - The omission of a command file that should have been sent to the spacecraft

Introduction (2/2)

- Dawn recently finished a very demanding operational period exploring the asteroid Vesta.
- The first of two initial questions was whether the CFEs encountered prior to and during the Vesta campaign were out of family with the rest of the mission and possibly the result of the high intensity activity.
- The second question was whether steps could be taken after studying Vesta to cost effectively reduce the likelihood of CFEs during the upcoming campaign at the asteroid Ceres.
- None of the CFEs Dawn encountered during the Vesta preparation and execution posed a serious threat to the mission. However, past experience has shown that there is risk from even innocuous errors in commanding a spacecraft.

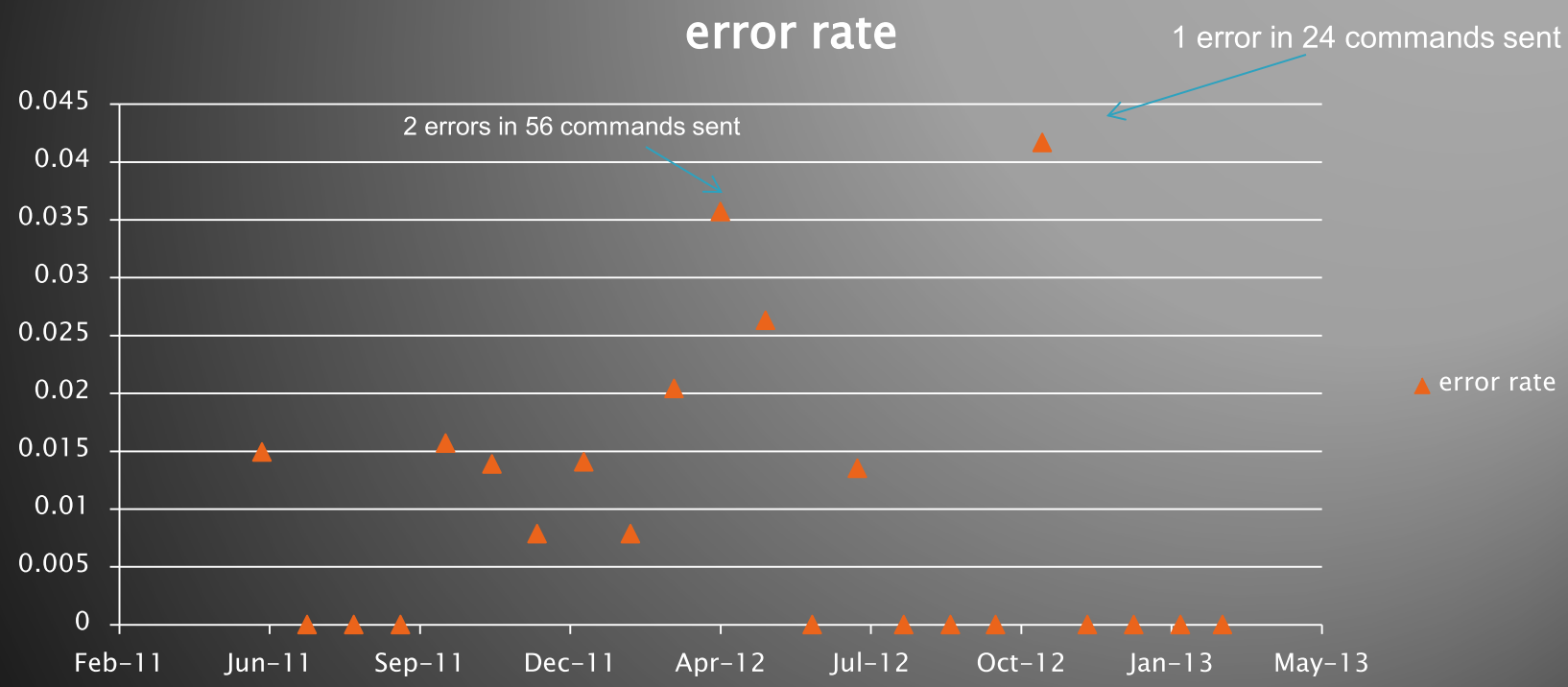
Probabilistic Modeling Approach

- Command File Errors are by nature probabilistic.
  - There is no certainty about whether or not they'll occur.
  - When they do occur, it's usually due to a sequence or combination of events.
  - Diagnosis initially involves probabilistic analysis until further evidence leads to exact cause.
  - Therefore it may be useful to represent them with probabilistic models.
  - Our approach is to build models based on observations about the system and discussions with Subject Matter Experts.
  - Current models and analyses are *very* different from the ones originally envisioned at the conception of this research task.
- Command File Errors often involve Human Errors
  - The nuclear industry has done much research in the area of Human Reliability Analysis.
  - Further, there is published research in the area of organizational/management factors as they pertain to the decision making of engineers/operators.
- Therefore, we can use statistical techniques to understand and 'manage' Dawn command file errors

Analyzing Command File Errors: Were recent increases in Dawn's CFE rates statistically significant?

- During 2012, Dawn experienced elevated command error frequencies
- (MRO, Odyssey, MGS)have an average rate of p=0.8%-1.01% in critical phases and p=0.3% to 0.5% in low activity phases. Since all projects seem to exhibit a statistical similarity, how can we evaluate the Dawn numbers?
- Let's consider that a command file radiation is a Bernoulli trial with a p probability of error.
- Therefore, we can use a Binomial distribution to determine the probability of r command file errors in n trials. This distribution will have a mean and standard deviation and we can see how much we have deviated from the mean at each interval.

DAWN CFE Rates – Monthly Bins



Note that number of commands in some months is less than 100. Therefore they have different sigma's.

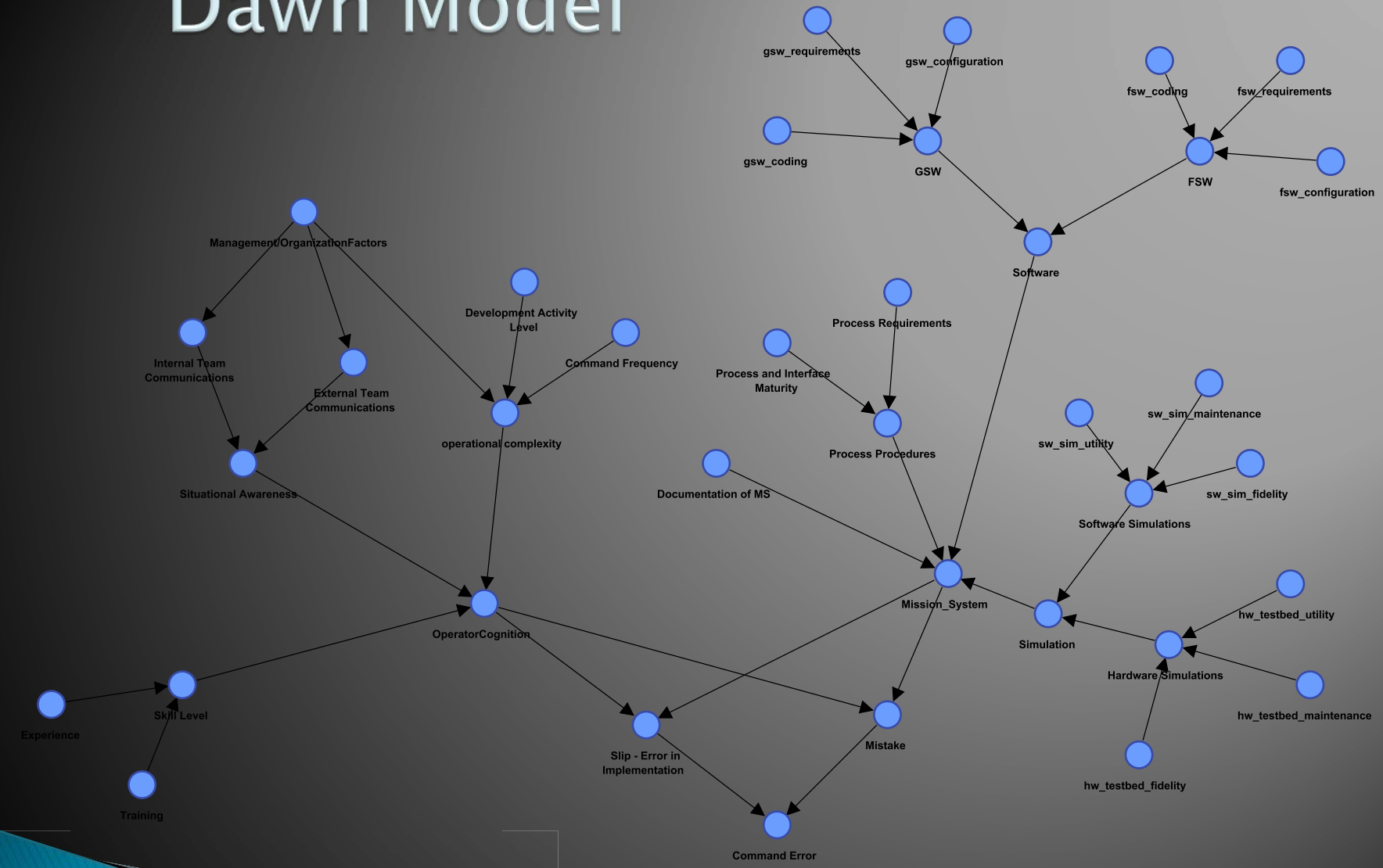
Distance from the mean in each month

Month	commands	errors	Probability of errors as occurred	mean number of errors	sigma for cfe's	distance from the mean (multiples of sigma)
11-Jun	67	1	0.35	0.67	0.81	0.41
11-Jul	124	0	0.28	1.24	1.10	-1.13
11-Aug	171	0	0.18	1.70	1.29	-1.32
11-Sep	127	0	0.27	1.27	1.12	-1.13
11-Oct	191	3	0.22	1.91	1.37	0.80
11-Nov	72	1	0.35	0.72	0.84	0.33
11-Dec	127	1	0.36	1.27	1.12	-0.24
12-Jan	142	2	0.25	1.42	1.18	0.49
12-Feb	127	1	0.36	1.27	1.12	-0.24
12-Mar	49	1	0.30	0.49	0.69	0.74
12-Apr	56	2	0.09	0.56	0.74	1.95
12-May	76	2	0.14	0.76	0.86	1.44
12-Jun	103	0	0.36	1.03	1.00	-1.03
12-Jul	74	1	0.36	0.74	0.86	0.30
12-Aug	61	0	0.54	0.61	0.77	-0.79
12-Sep	21	0	0.80	0.21	0.46	-0.46
12-Oct	22	0	0.80	0.22	0.46	-0.48
12-Nov	24	1	0.19	0.24	0.48	1.58
12-Dec	19	0	0.82	0.19	0.43	-0.44
13-Jan	14	0	0.87	0.14	0.37	-0.38
13-Feb	11	0	0.89	0.11	0.33	-0.33
13-Mar	59	0	0.55	0.59	0.76	-0.78

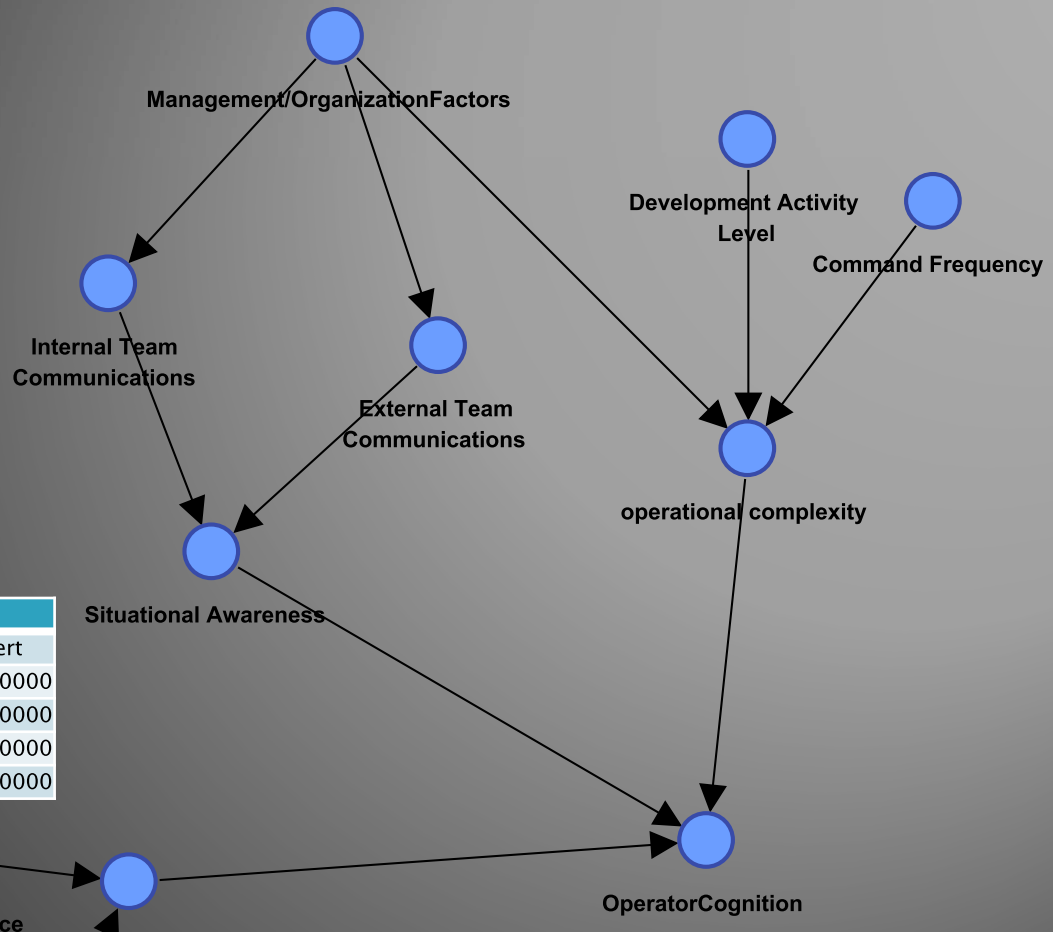
Conclusions – Analyzing Command File Errors

- In depth analysis of CFE's provides a more realistic perspective:
  - The two months that seemingly have a very high error rates, when analyzed in the context of their corresponding distributions, are well within the 2sigma levels.
  - The overall error rates are comparable to other missions.

Systems Analysis Using BBN's – Dawn Model



Process Compliance – Soft Factors

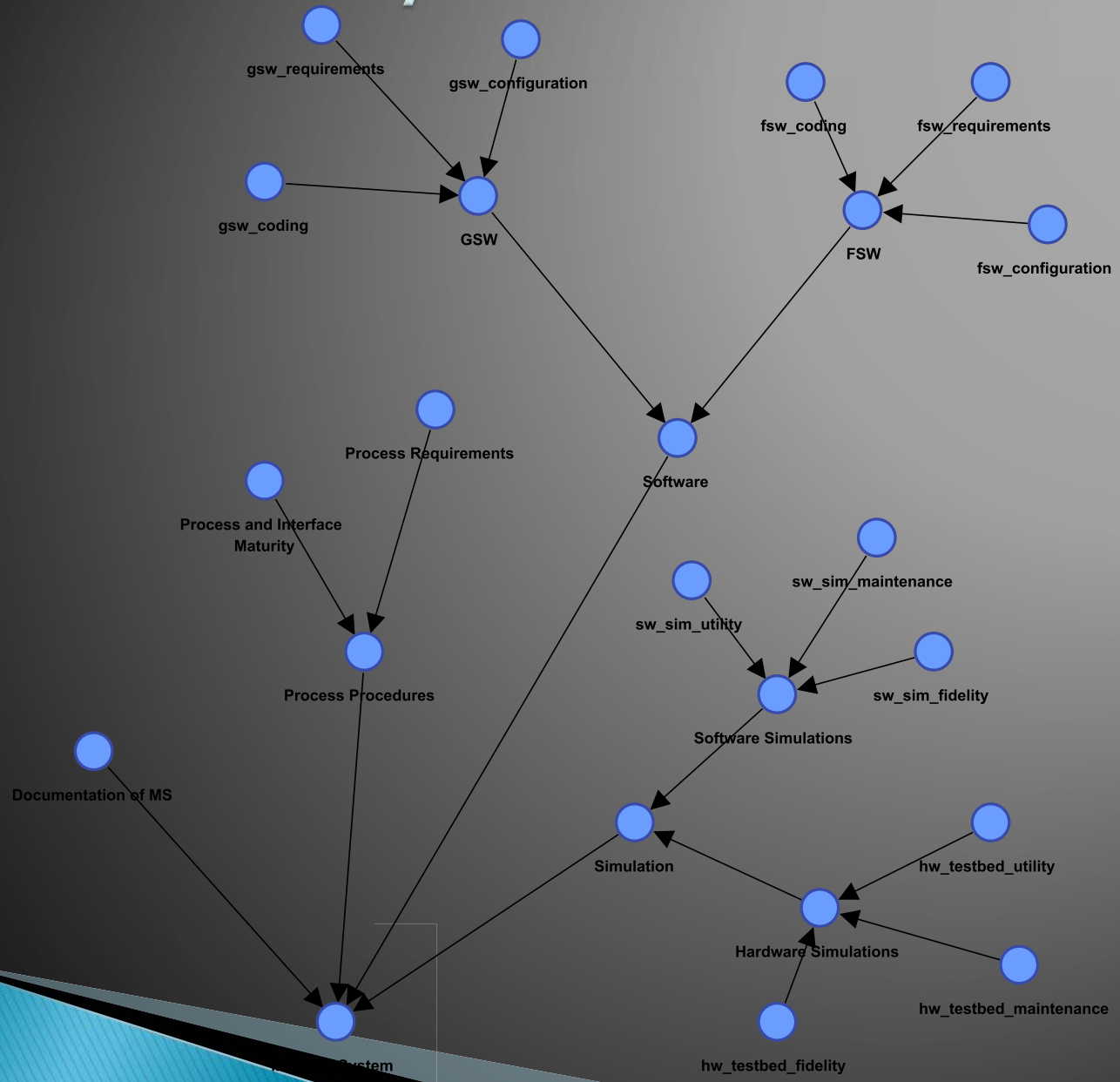


Skill Level				
Training	Experience	Novice	Journeyman	Expert
Adequate	Low	80.0000	20.0000	0.0000
	High	0.0000	10.0000	90.0000
Inadequate	Low	100.0000	0.0000	0.0000
	High	10.0000	20.0000	70.0000

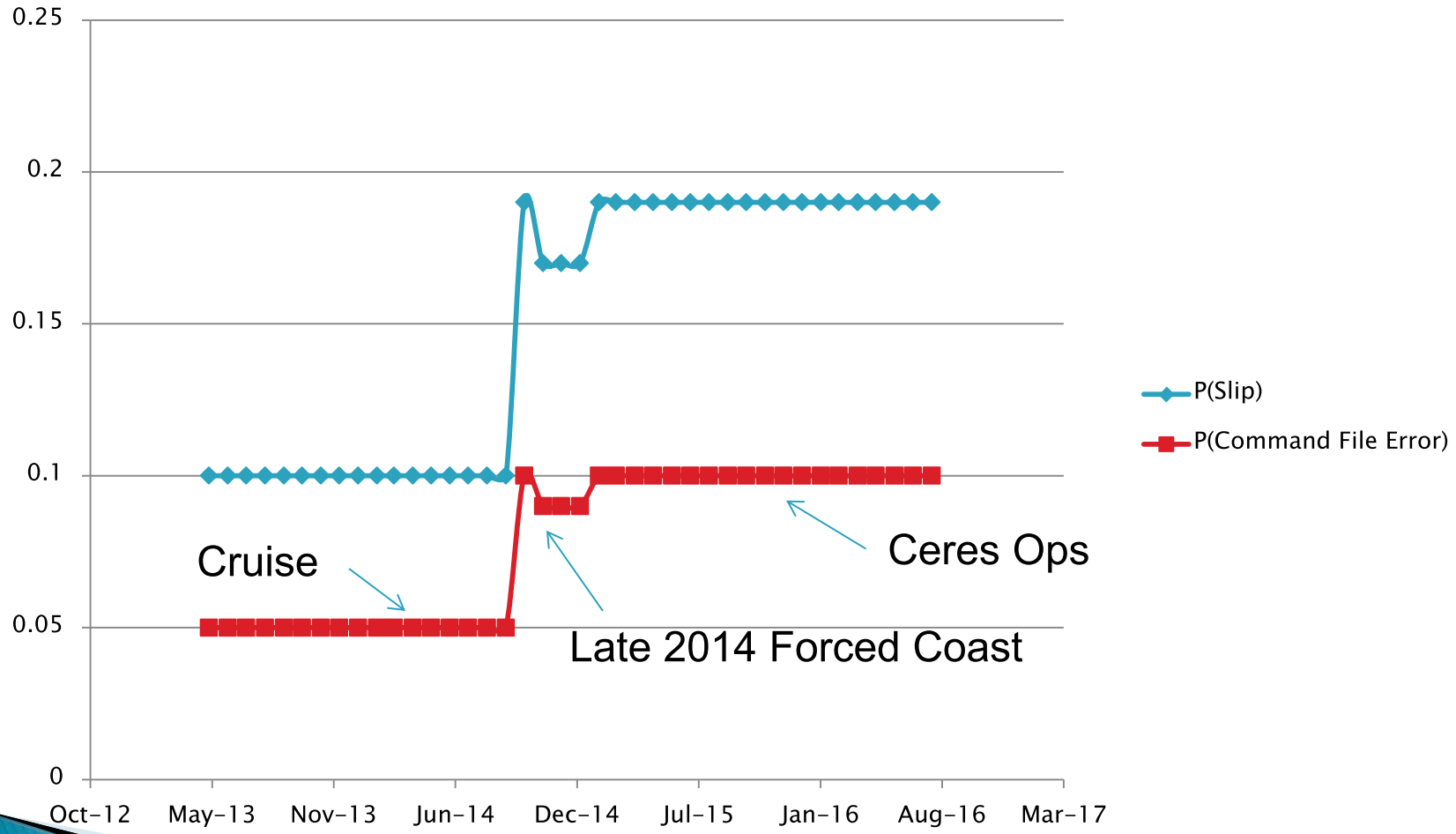
Experience	
Low	High
30.0000	70.0000

Training	
Adequate	Inadequate
90.0000	10.0000

Mission System – Hard Factors



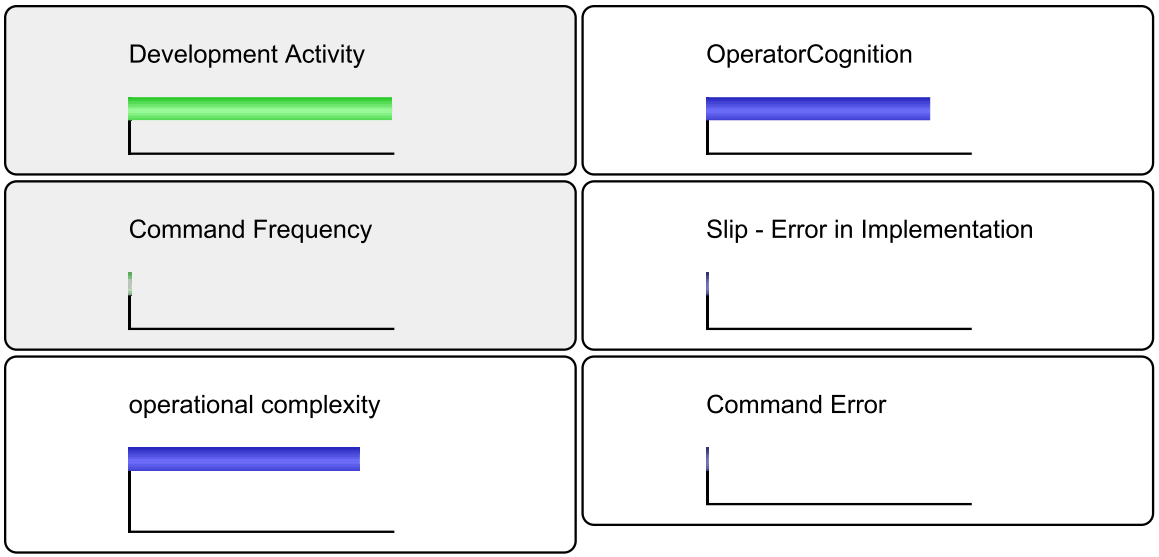
Use Case 1: Anticipating future CFE rates



Expected Error Rate for Ceres

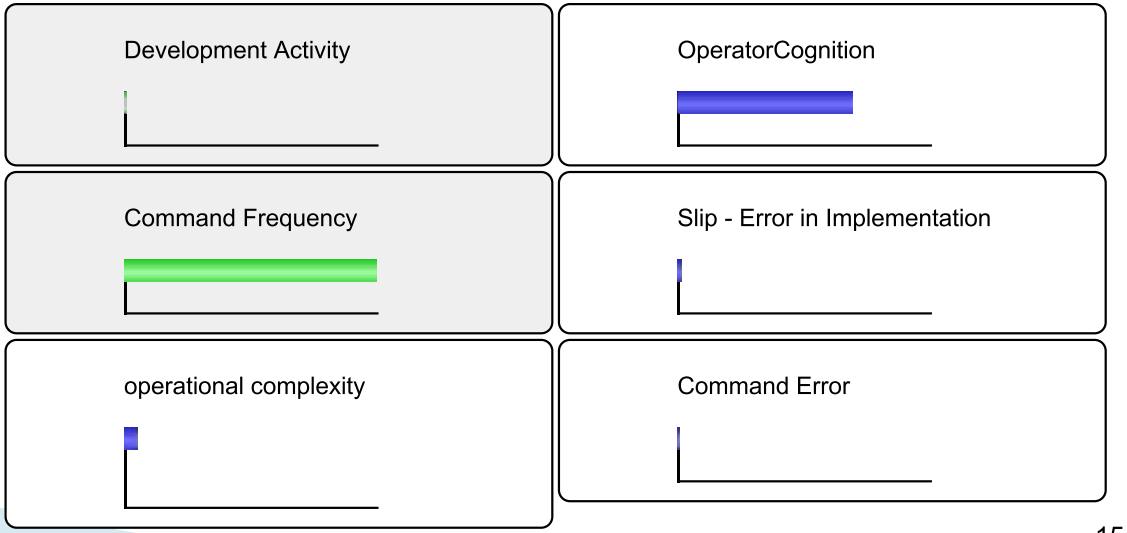
- The mission system is fixed (for the most part)
- Operator Cognition 'amplifies' the fixed Mission System signal
- There will be high activity and high command frequency
  - Probability of slip goes up to 1.89%
  - Probability of CFE goes up to 1.05% (not every slip causes a CFE).
  - A teaming management can make a big difference!
- No surprise here- we make decisions about error rates we are willing to tolerate based on the level of activity and command rate at each point in the project whether we are aware of it or not.
- In cases where we have novel activities which have large uncertainties associated with them, we use the tool to predict error rates by tweaking the probabilities of mission system components such as GSW, FSW and Simulation test-beds into account.

Use Case 1 – Anticipating future CFE rates



Low Activity,
Low Command Frequency

High Activity,
High Command Frequency



Use Case 2: Probabilistic Root Cause Analysis

- Now let's assume that we have evidence that a node has occurred.
- We can use this information to find the updated likelihood of other nodes in the mode.
- Below are sample root cause analyses and scenarios based on this concept.

Use Case 2: Probabilistic Root Cause Analysis

Mission System Inadequate?	Operator Cognition Incorrect?	Documentation of MS Inadequate?	Process Procedures	Simulation Inadequate?	Software
Yes	No	85.00%	7.00%	7.00%	8.11%

Simulation Inadequate?	Software Simulations Inadequate?	Hardware Simulations Inadequate?
Yes	31.00%	74%

HW Simulations Inadequate	Fidelity of Testbed Inadequate?	Maintanence Inadequate?	User Friendliness Inadequate?
Yes	52.00%	20.00%	75.00%

SW Simulations Inadequate	Fidelity of Testbed Inadequate?	Maintenance Inadequate?	User Friendliness/Utility Inadequate?
Yes	17%	17.00%	60.00%

Software Inadequate?	GSW Inadequate	FSW Inadequate
Yes	72%	30.00%

GSW Inadequate?	Coding Inadequate?	Requirements Inadequate?	Configuration Inadequate?
Yes	21%	44%	21%

FSW Inadequate?	Coding Inadequate?	Requirements Inadequate?	Configuration Inadequate?
Yes	9%	0%	0%

Use Case 2: Probabilistic Root Cause Analysis

Mission System Inadequate?	Operator Cognition Inadequate?	Operational Complexity High?	Skill Level Low(Novice or Journeyman)?	Situational Awareness Low?
No	Yes	78.00%	40.00%	50.00%

Operational Complexity High	Management/Org Adversarial?	Development Activity High?	Command Frequency Hi?
Yes	6.00%	67%	66%

Situational Awareness Low?	External Team Communications Inadequate?	Internal Team Communications Inadequate?	
Yes	58.00%	48.00%	

Communications Inadequate?	Management/Organizational Factors Inadequate?
Yes	51.00%

Conclusions

- There are multiple perspectives for assessing and investigating Command File Errors.
- Collecting and organizing the data associated with these errors is a first step in the direction of more in-depth statistical and probabilistic analysis.
- Statistical analysis of command file error rates can be used to determine if problems are occurring too frequently and in assessing the trends and behavior of the system.
- Systems level, probabilistic analysis leads to a more accurate understanding of the dependencies within the system and how these dependencies contribute to the CFE rates. Modeling and probabilistic analysis techniques are used as a tool to help manage the CFE error rates.
- The main take-away for the analyses presented in this paper is that by observing the system behavior and formalizing the relationship between the various parts of the system it is possible to identify the key factors that lead to CFEs and make informed decisions about the rates that the project is willing to tolerate and its associated trades.
- BBNs can be used in a number of ways to anticipate and potentially reduce command file errors on Dawn.
  - If-then scenarios to determine the sensitive variables.
  - Anticipating CFE rates based on value of parameters during different phases of the mission.
  - Incorporation of observations about the system behavior in the form of evidence to determine ripple effects on the system.
  - Root cause analysis.

Future Directions

- Future direction for DAWN includes providing the team with the software and model for use within the flight project environment on a regular basis, and increasing the fidelity of the models by incorporating confidence intervals and details about the command files that are radiated to the spacecraft.

- The module associated with the effect of management and organizational factors on the cognition of the operator was added based on the initial input of the mission manager from a different flight project. We are currently in the process of writing up that body of research in a separate paper.

- The multi-mission model that was the basis for the customized DAWN model is also being further refined to address the hard factors.

- The Multi-Mission Ground Systems and Services (MGSS) program at JPL is meant to address issues that are of interest to multiple flight projects. The goal of our study of the hard factors associated with CFE's is to provide insight to the MGSS management for this purpose.

Questions