Risk Identification and Mitigation through Process Potential Failure-Modes-Effects Analysis

Ed Kestel
Director, Manufacturing
Orbital Sciences
Agenda

- Introduction to Orbital Sciences
- Lean Practices
- What is the “Bill of Process” and its Benefits?
- Elements of Bill of Process
- Process Mapping (PM)
- Process Failure Mode and Effects Analysis (PFMEA)
- Process Characterization Report (PCR)
- Additional Resources
Orbital Overview

- Leading Developer and Manufacturer of Small- and Medium-Class Space Systems
  - 30-Year Record of Reliable, Rapid and Affordable Development and Production
  - Serving Customers in Commercial, National Security and Civil Government Markets
- Over 1,000 Satellites and Launch Vehicles Built or Under Contract for Customers
  - 205 Satellites and Space Systems
  - 165 Space and Strategic Launch Vehicles
  - 635 Target Vehicles and Sounding Rockets
- 3,900 Employees and 1.7 Million Square Feet of State-of-the-Art Facilities
- Revenues of About $1.5 Billion Expected in 2012
- Contract Backlog Totals $5.2 Billion for Delivery Through 2018
- Conservative Balance Sheet With Strong Liquidity
Diversified Multi-Market Customer Base

38% Department of Defense & Intelligence Agencies
25% Commercial & International Satellite Operators
37% NASA, Other Civilian Agencies & Universities

2012 Revenues by Customer Type
Well-Balanced Business Segments

Launch Vehicles

Satellites and Space Systems

- 38%
- 32%
- 30%
Program Managers
General Managers, Marketing Managers
Business Support Specialists
Manufacturing/Test/QA Specialists
Technical Staff
System Engineers
Designers
Mechanical Engineers
Software Engineers
Electrical Engineers
Other Engineers (GN&C, RF/Optical, Aero, Mission Ops)

3,900 Employees*
2,000 Engineers/Scientists*

*As of July 1, 2012

*As of July 1, 2012
State-of-the-Art R&D and Production Facilities

Dulles, Virginia
- Headquarters and Satellite Development and Production
  - 1,850 Employees

Chandler, Arizona
- Launch Vehicle Development and Production
  - 1,325 Employees

Gilbert, Arizona
- Satellite Development and Production
  - 300 Employees

Greenbelt, Maryland
- Space Technical Services
  - 400 Employees
Over 735 Space Missions Since 1982*

71 Commercial Satellites

67 Government Satellites

40 Space Payloads

70 Space Launch Vehicles

186 Interceptor & Target Vehicles

303 Sounding Rockets

*April 1982-March 2012
Satellite and Space Systems Experience

**Commercial Satellites**
- GEO Communications
- LEO Communications
- LEO Imaging

**Mission Record**
- 71 Launches Since 1982
- 97% Mission Success

**Production Backlog**
- 8 Units in Backlog

**Science & Exploration Spacecraft**
- LEO Earth & Space Science
- ISS Cargo Logistics
- Deep-Space Exploration

**Mission Record**
- 28 Launches Since 1982
- 96% Mission Success

**Production Backlog**
- 14 Units in Backlog

**National Security Satellites**
- LEO Missions
- GEO Missions

**Mission Record**
- 39 Launches Since 1982
- 97% Mission Success

**Production Backlog**
- 3 Units in Backlog

77 Satellites in Current Operations… Over 975 Satellite-Years of Experience
Launch Systems Experience

**Space Launch Vehicles**
- Small Payloads (Up to 2 Tons)
- Medium Payloads (3 to 7 Tons)
- Special Purpose Vehicles

**Mission Record**
- 70 Launches Since 1982
- 92% Mission Success

**Production Backlog**
- 5 Units Delivered
- 15 Units in Backlog

**Strategic Launch Vehicles**
- Interceptor Vehicles
- Global Strike Vehicles
- ICBM/IRBM-Class Targets

**Mission Record**
- 22 Launches Since 1982
- 100% Mission Success

**Production Backlog**
- 40 Units Delivered
- 14 Units in Backlog

**Target Vehicles**
- Short-Range Targets
- Medium/Intermediate Targets
- Special Purpose Vehicles

**Mission Record**
- 160 Launches Since 1982
- 95% Mission Success

**Production Backlog**
- 28 Units Delivered
- 52 Units in Backlog

108 Launches With 96% Success in Last 10 Years
**Orbital’s Space System Capabilities**

<table>
<thead>
<tr>
<th>LEO Systems</th>
<th>GEO Systems</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mission Capability</strong></td>
<td><strong>Launch Vehicle</strong></td>
</tr>
<tr>
<td><strong>Satellite Bus</strong></td>
<td><strong>LEOSTar-1</strong></td>
</tr>
<tr>
<td><strong>Launch Vehicle</strong></td>
<td><strong>Pegasus</strong> or <strong>Minotaur I</strong></td>
</tr>
<tr>
<td><strong>Ground Software</strong></td>
<td><strong>Spacecraft Control</strong></td>
</tr>
<tr>
<td><strong>All-in Price Range</strong></td>
<td><strong>$45-70M</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>LEO Systems</strong></th>
<th><strong>GEO Systems</strong></th>
</tr>
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<tbody>
<tr>
<td><strong>Mini</strong></td>
<td><strong>Small</strong></td>
</tr>
<tr>
<td><strong>Medium</strong></td>
<td><strong>Medium</strong></td>
</tr>
<tr>
<td><strong>Mini</strong></td>
<td><strong>Small</strong></td>
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</tbody>
</table>

**Mini**
- 150 kg/500W Payload
- Low Attitude Control
- 3-Year Life
- 24-27 Month Delivery

**Small**
- 150 kg/1.5kW Payload
- Med Attitude Control
- 5-7 Year Life
- 30-36 Month Delivery

**Medium**
- 2,000 kg/4.0 kW Payload
- High Control/Agility
- 7-10 Year Life
- 33-39 Month Delivery

**Mini**
- 100 kg/1.5 kW Payload
- High Stability/Control
- 5-7 Year Life
- 27-30 Month Delivery

**Small**
- 500 kg/5.0 kW Payload
- High Stability/Control
- 15-18 Year Life
- 24-27 Month Delivery

**Medium**
- 700 kg/7.5 kW Payload
- High Stability/Control
- 15-18 Year Life
- 27-30 Month Delivery

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*Includes Spacecraft Bus, Launch Vehicle, Ground Control Software and System I&T; Excludes Mission-Unique Payload(s) and Ground Control/Processing Services

*Overview July 2012*
Lean Practices

- **Continuous improvement philosophy** – Focus on eliminating Non-Value Added (NVA) activities
- **Teams** *(Mentorship, Career Development Objective)*
  - With rotation of highly specified job skills
  - Using a disciplined problem-solving process
- **Cross-trained and multi-skilled employees**
  - Who can work many operations within a work group and operations in different groups (or capacities, as well) *(Design for Manufacturability)*
  - Process quality, not inspection *(RCCA / Bill of Process)* – We cannot inspect Quality into our products- We build it in.
- **5S Principles**
- **Use of participatory decision-making**
  - Facilitator-led, team-based problem-solving, suggestion systems, etc. *(Rapid Improvement Events, A3, Peer Reviews)*
Process Characterization & Optimization utilizing Bill-of-Process methodologies

Process Mapping, PFMEA, and Characterization Reporting
Definition:

BoP characterizes production and test process steps by using mathematical analysis to prevent and predict potential failure modes in the workplace.

Benefits:

- Detection of potential and current failure modes
- Helps teams identify the potential failure’s causes and effects to production and test
- A vehicle for preventative measures for mitigation
- Promotes problem prevention / problem solving
- Promotes best practice sharing to improve processes
Elements of a ‘Bill of Process’

- Process Map (Lean 202)
- PFMEA (QS 4)
- Process Characterization Report

Other analytical tools:

- Gage R&R (QS 16)
- Cp/ Cpk (QS 16)
- Process Trouble Shooting Guide (QS 5, QS 8)
- Process Control Plan (QS 16)
- Out of Control response Plan (QS 16)
- Control Charts/ Logs (QS 16)
- Calibration – Control by QSP / TM
- Preventative Maintenance Plan (Lean 207)
- Refer to TM or Lean Quick Start modules for more tools as required
**Description**

- Hierarchical method for displaying processes that illustrates how a product or transaction is processed
- It is a visual representation of the work-flow either within a process – or an image of the whole operation
- Comprises a stream of activities that transforms a well defined input or set of inputs into a pre-defined set of outputs
- Allows people unfamiliar with the process to understand the interaction of causes during the work-flow
- May contain additional information about the process such as input and output variables, time, cost, NC count, etc.

**Participants**

- Cross-functional team comprised of anyone that regularly works with the process (i.e., Technicians, Engineers, Quality, etc.)
Process Failure Modes and Effects Analysis (PFMEA)
- A systemized group of activities intended to:
  - Address *before hand* the potential failure modes and their effects
  - Recognize and evaluate the potential failure of a product/process and its effect
  - Identify actions which could eliminate or reduce the potential causes for failure
  - Document the process and Track changes to process- to avoid failures

Failure Modes and Effects Analysis (FMEA)
- A procedure and tools that help to identify every possible failure mode of a process or product, to determine its effect on other sub-items and on the required function of the product or process
- The FMEA is also used to rank & prioritize the possible causes of failures as well as develop and implement preventative actions, with the accountability to ensure that these actions are carried out.
- FMEA is a disciplined approach used to identify possible failures of a product or service and then determine the frequency and impact of the failure
Process Map Exercise

- **Participants**
  - Cross-functional team comprised of anyone that regularly works with the process (i.e., Technicians, Engineers, Quality, etc.)

- **Rejection History**
  - List non-conformances, rate of occurrence, cause type

- **Process Map Exercise**
  - Construct a process map
  - List all steps in the process
  - List all sub process steps (if required)
PFMEA Exercise

- PFMEA Exercise:
  - Conduct a PFMEA (Process Failure Mode and Effects Analysis)
  - Define all failure modes, effects and causes of the effects of the steps on the process map
PFMEA Exercise – PFMEA Template

<table>
<thead>
<tr>
<th>PROCESS (STEPS)</th>
<th>POTENTIAL FAILURE MODE</th>
<th>POTENTIAL EFFECTS OF FAILURE</th>
<th>POTENTIAL CAUSES OF FAILURE</th>
<th>CURRENT CONTROLS</th>
<th>OCCUR</th>
<th>SEVERITY</th>
<th>DETECTION</th>
<th>RISK PRIORITY NUMBER (RPN)</th>
<th>CRITICALITY FACTOR</th>
<th>RECOMMENDED ACTIONS AND STATUS</th>
<th>ACTIONS TAKEN</th>
<th>OCCUR</th>
<th>SEVERITY</th>
<th>DETECTION</th>
<th>RISK PRIORITY NUMBER (RPN)</th>
<th>CRITICALITY FACTOR</th>
<th>RESPONSIBLE PERSON OR PROCESS</th>
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</tbody>
</table>
Suggested Evaluation Criteria:
The team should agree on an evaluation criteria and ranking system, which is consistent, even if modified for individual product analysis.

<table>
<thead>
<tr>
<th>Probability of Failure</th>
<th>Possible Failure Rates</th>
<th>Ranking</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very High: Failure is almost inevitable</td>
<td>Greater than or equal to 1 in 2</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>1 in 3</td>
<td>9</td>
</tr>
<tr>
<td>High: Repeated failures</td>
<td>1 in 8</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>1 in 20</td>
<td>7</td>
</tr>
<tr>
<td>Moderate: Occasional failures</td>
<td>1 in 80</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>1 in 400</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>1 in 2000</td>
<td>4</td>
</tr>
<tr>
<td>Low: Relatively few failures</td>
<td>1 in 15,000</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>1 in 150,000</td>
<td>2</td>
</tr>
<tr>
<td>Remote: Failure is unlikely</td>
<td>Less than or equal to 1 in 1,500,000</td>
<td>1</td>
</tr>
</tbody>
</table>
Suggested Evaluation Criteria:
The team should agree on an evaluation criteria and ranking system, which is consistent, even if modified for individual product analysis.

<table>
<thead>
<tr>
<th>Effect</th>
<th>Criteria: Severity of Effect</th>
<th>Ranking</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hazardous-without warning</td>
<td>Very high severity ranking when a potential failure mode affect safe vehicle operation and or involves noncompliance with government regulation without warning.</td>
<td>10</td>
</tr>
<tr>
<td>Hazardous-with warning</td>
<td>Very high severity ranking when a potential failure mode affect safe vehicle operation and or involves noncompliance with government regulation with warning.</td>
<td>9</td>
</tr>
<tr>
<td>Very High</td>
<td>Vehicle/item inoperable, with loss of primary function.</td>
<td>8</td>
</tr>
<tr>
<td>High</td>
<td>Vehicle/item inoperable, but at a reduced level of performance.</td>
<td>7</td>
</tr>
<tr>
<td>Moderate</td>
<td>Vehicle/item inoperable, but comfort/Convenience item(s) inoperable. Customer experiences discomfort.</td>
<td>6</td>
</tr>
<tr>
<td>Low</td>
<td>Vehicle/item operable, but comfort/convenience item(s) operable at reduced level of performance. Customer experience some dissatisfaction.</td>
<td>5</td>
</tr>
<tr>
<td>Very Low</td>
<td>Fit and Finish, item, or end product does not conform to maximum, perfect, or optimum condition. Defect noticed by most customers.</td>
<td>4</td>
</tr>
<tr>
<td>Minor</td>
<td>Fit and Finish, item, or end product does not conform to maximum, perfect, or optimum condition. Defect noticed by average customers.</td>
<td>3</td>
</tr>
<tr>
<td>Very Minor</td>
<td>Fit and Finish, item, or end product does not conform to maximum, perfect, or optimum condition. Defect noticed by discriminating customers.</td>
<td>2</td>
</tr>
<tr>
<td>None</td>
<td>No Effect</td>
<td>1</td>
</tr>
</tbody>
</table>
Suggested Evaluation Criteria:
The team should agree on an evaluation criteria and ranking system, which is consistent, even if modified for individual product analysis.

<table>
<thead>
<tr>
<th>Effect</th>
<th>Criteria: Likelihood of Detection be Design Control</th>
<th>Ranking</th>
</tr>
</thead>
<tbody>
<tr>
<td>Absolute Uncertainty</td>
<td>Design control will not and/or can not detect a potential cause/mechanism and subsequent failure mode; or there is no design control.</td>
<td>10</td>
</tr>
<tr>
<td>Very Remote</td>
<td>Very remote chance the Design Control will effect a potential cause/mechanism and subsequent failure mode.</td>
<td>9</td>
</tr>
<tr>
<td>Remote</td>
<td>Remote chance the Design Control will detect a potential cause/mechanism and subsequent failure mode.</td>
<td>8</td>
</tr>
<tr>
<td>Very Low</td>
<td>Very Low chance the Design Control will detect a potential cause/mechanism and subsequent failure mode.</td>
<td>7</td>
</tr>
<tr>
<td>Low</td>
<td>Low chance the Design Control will detect a potential cause/mechanism and subsequent failure mode.</td>
<td>6</td>
</tr>
<tr>
<td>Moderate</td>
<td>Moderate chance the Design Control will detect a potential cause/mechanism and subsequent failure mode.</td>
<td>5</td>
</tr>
<tr>
<td>Moderately High</td>
<td>Moderate High chance the Design Control will detect a potential cause/mechanism and subsequent failure mode.</td>
<td>4</td>
</tr>
<tr>
<td>High</td>
<td>High chance the Design Control will detect a potential cause/mechanism and subsequent failure mode.</td>
<td>3</td>
</tr>
<tr>
<td>Very High</td>
<td>Very High chance the Design Control will detect a potential cause/mechanism and subsequent failure mode.</td>
<td>2</td>
</tr>
<tr>
<td>Almost Certain</td>
<td>Design Control will almost certainly detect a potential cause/mechanism and subsequent failure mode.</td>
<td>1</td>
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</tbody>
</table>
Elements of a Process Characterization Report (PCR)

- Process Map of Short Description of Process
- Findings / Concerns
- Recommended Action(s)
• Process Map or Short Description of Process
  ➢ This summarizes the process mapping exercise, which may be used with a process flow chart using Visio, Power Point or equivalent. It should allow the reader to fully understand the process, without going into great detail.

➢ Example:
Findings / Concerns

- Describe items that were found during the characterization process that have a significant negative effect on the process. These findings will be addressed in the Recommended Action(s) table. Provide data (if necessary) to support findings.

- Example:

  Shrink tubing/Sleeving: RPN = 200 for wrong location (tubing shifted from one location of wire to another) and RPN = 250 for insufficient tubal length that causes easy shifting of tubing after heat. Action needed to resolve movement of tubing.
**Elements of a PCR – Summary and Recommendations**

- **Recommended Action(s)**
  - List actions recommended to alleviate the processes that are negatively affecting product.
  - Example:

<table>
<thead>
<tr>
<th>Item No.</th>
<th>Failure Mode</th>
<th>Prod Area</th>
<th>RPN Value</th>
<th>Action Item</th>
<th>Action Taken</th>
<th>Responsible</th>
<th>Estimated Completion</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Shrink tubing- wrong location (shifting of tubing to another part of wire) and insufficient length</td>
<td>Cable</td>
<td>200 and 250</td>
<td>TM-8575 update to increase length of tubing and require half of shrink tubing length to cover insulation. This will decrease opportunities for the shrink tubing to move to another location and require a sufficient length increase for processing.</td>
<td>1. Update TM-8575 to increase length of tubing and require half of shrink tubing length to cover insulation. 2. Training on new process.</td>
<td>Arteaga</td>
<td>01/14/12</td>
<td>Training completed, TM update in</td>
</tr>
</tbody>
</table>
**Bill of Process** is a term used to characterize and optimize operational steps through systematic analysis of process monitoring using Lean Enterprise and mathematical (statistical) techniques.

Mapping the process flow helps cross-functional teams understand key inputs and outputs of significant processes. By evaluating the severity, occurrence and ability to detect a potential failure mode, the PFMEA process helps teams identify the potential failure impact (effect) due to variables acting upon the process. Product yield data and cycle time data are important in validating the occurrence and detection values. Through the expertise of the cross-functional team, actions can be taken characterizing the process and implementing preventive measures (i.e., tooling) to mitigate opportunity of possible defects. Click here for guidance on how to perform Bill of Process here at Orbital.

Mathematical models such as Gauge Repeatability and Reproducibility (Gauge R&R), Process Failure Mode and Effects Analysis (PFMEA), Process Mapping and Process Capability Analysis are used if it is determined that a process needs to be monitored more closely to ensure further variation reduction. Actions may include Statistical Process Control (SPC), control and response planning and/or mistake-proofing interventions including visual management techniques and/or directed automation.

Click here for quick view of matrices, click here for updating PFMEAs (Click here for updating LSG Chandler I & T)
What Do We Do To Ensure Success?

- Always **follow the process** and **never deviate without approved paperwork**

- Set the **tone** and establish **values** for the organization based on **Hoshin and Process Control Standards**

- **Provide** the correct tools, training, techniques and strategies for making the organizations work more effectively and efficiently

- **Continually evaluate** the performance and personality of the team and when necessary, “re-arrange the people on the bus and ensure the right people are in the right seats”

“The pessimist complains about the wind. The optimist expects the wind to change. The leader adjusts the sails.” - John Maxwell

“Quality means doing it right when no one is looking.” - Henry Ford

“We can’t solve problems by doing the same kind of thinking we used when we created them.” Albert Einstein

EVERYONE IS RESPONSIBLE TO ENSURE MISSION SUCCESS!
Question & Answer

Please fill out your session feedback and leave it at the back of the room!

This Session Is: 01-06-02 Kestel

Are you a future presenter?
Contact Jeff Fuchs, jfuchs@choosemaryland.org
About presenting at next year’s Mid-Atlantic Lean Conference.