Establishing and Using Risk Management Effectively

Singapore, IS 2009

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Attwater Consulting

SAIC, Decision and Risk Technologies

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Tutorial Schedule

13:30 – Preliminaries, Introduction

13:45 – Risk Concepts, How to Implement a Risk Management Program in an Enterprise

15:00 – Break

15:10 – Useful Risk Management Metrics, Recent Advances in Risk Assessment

16:50 – Summary and Evaluation

17:00 – You are free to go

Attendee Introductions
(Time Allowing)

- **Your Name, Employer, and Type of Business**
- **Your Job and Type of Work You Do**
- **Do You Work with Risk or Risk Management?**
- **What you are hoping to gain from today's tutorial**

Your Tutorial Instructor: Mark A. Powell

- **Director, Decision and Risk Technologies, SAIC**
- **Professor, Systems Engineering, Stevens Institute of Technology, University of Houston Clear Lake**
- **Over 35 years Experience in Systems Engineering and Project Management**
- **Former Chair, INCOSE Risk Management Working Group**
- **INCOSE Technical Leadership Team, Assistant Director for Systems Processes**
- **Contact Information at the End of Tutorial Package, Contact Welcomed**

Introduction

- **Topics**
  - **The Concept of Risk**
  - **What We do about Risk**
  - **How to Implement a Risk Management Program in an Enterprise**
  - **Useful Risk Management Metrics**
  - **Recent Advances in Risk Assessment**

The Concept of Risk

Discussion:

What is Risk?

What is Risk?

- **Simply An Uncertain Future Consequence**
  - **The Level of the Potential Consequence is Generally Uncertain**
  - **Whether or Not the Consequence *will* be Realized *may* be Uncertain**
- **Possible *Levels* of the Consequence:**
  - **Only Adverse – Asteroid Hitting the Earth**
  - **Only Advantageous – Gift of a Lottery Ticket**
  - **Or, May Range from some Adverse Level to some Advantageous Level – An Investment in a Stock or Mutual Fund**

Some Common Risk Terminology Conventions

- **Engineering**
  - ***Risks*** **have** ***Only*** **Adverse Consequences – Purely a Negative Connotation**
  - ***Opportunities*** **have** ***Only*** **Advantageous Consequences – Purely a Positive Connotation**
  - ***Rarely*** **Address Risks with Consequences that can range from Adverse to Advantageous**
- **Business (including PMI)**
  - **Risks Usually Considered to Range from Adverse to Advantageous**
  - **Both Adverse Only and Advantageous Only Consequence Risks are Simply Called** ***Risks***

Convention for This Tutorial and a Recommendation

- **Will Refer to Adverse Only and Advantageous Only Consequence Risks *AND* Risks that Range from Adverse to Advantageous as Simply *Risks***
  - **The *Math* is All the Same**
  - **Adverse Only and Advantageous Only Consequence Risks are Actually Rare, Even in Engineering**
- **Recommendation:**
  - **Conform to the convention in your Project or Enterprise**
  - ***BUT*, Be Alert to the Fact that almost all Apparent Adverse Only and Advantageous Only Consequence Risks Usually Range to *the Other Side***
    - **Be Prepared to Address this Situation**
    - **Never Ignore *the Other Side***

Quantifying Risk

- **The *Measure* of Uncertainty is Probability**
- **The *Measure* of *Risk*:**
  The Probability that the Consequence at Some Level will be Realized
  - **May be: Probability that the Consequence *Above* a Specific Level will be Realized**
  - **May be: Probability that the Consequence *Below* a Specific Level will be Realized**
  - **May be: Probability that the Consequence *in a Specific Range* will be Realized**
- **Two *Aspects* of Quantifying Risk**
  - **Consequence Level**
  - **Probability of that Consequence Level being Realized**

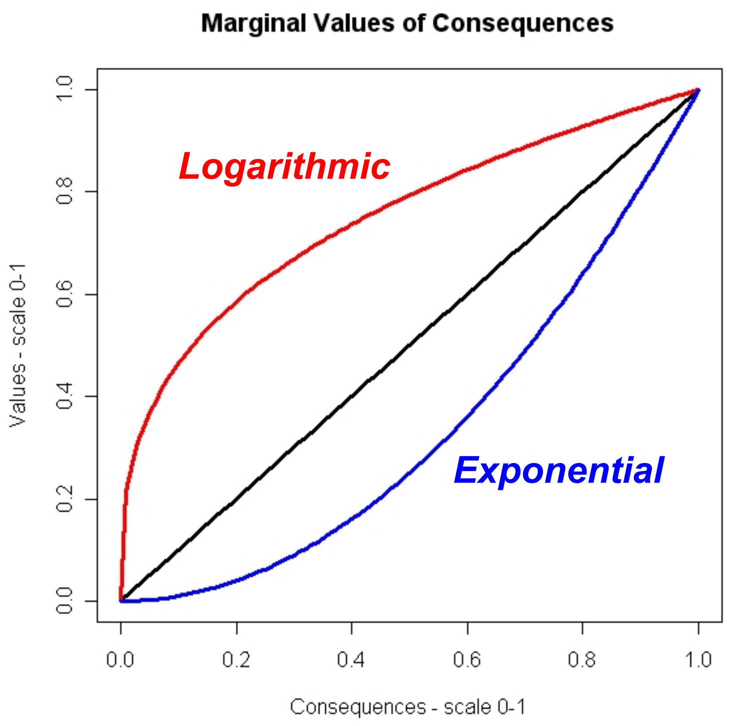
Risk Levels

- **A *Risk Level* is Always Based on a *Valuation of Consequences*, Usually Personal**
  - **Equivalently Valued Set of Probabilities for different Consequence Levels**
  - **Lottery Example: Probability of 99.9999% of losing $1 may have Same Value to You of Probability of 0.0001% of winning $1,000,000 – *The Same or Equivalent Risk Level***

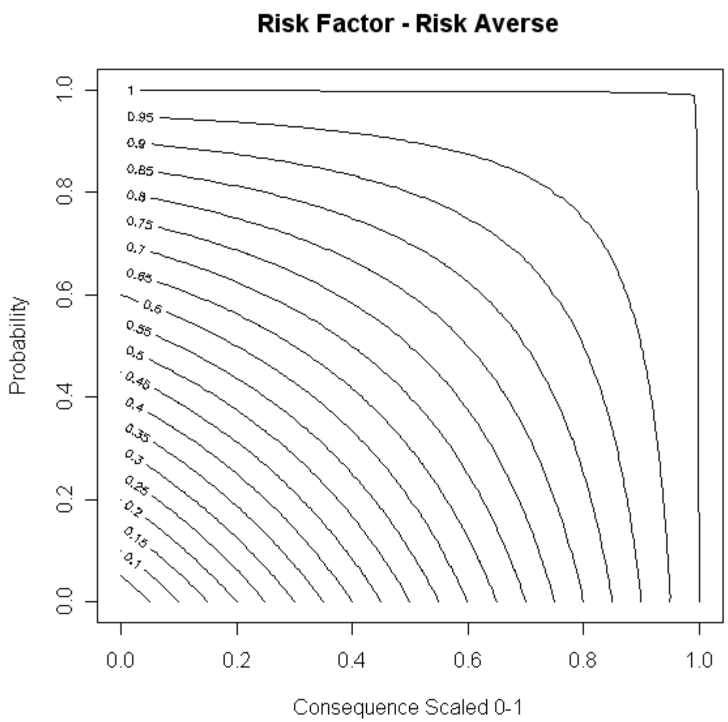
$$Value(P(-\$1)=99.9999\%) + Value(P(\$1M)=0.0001\%) \approx 0$$

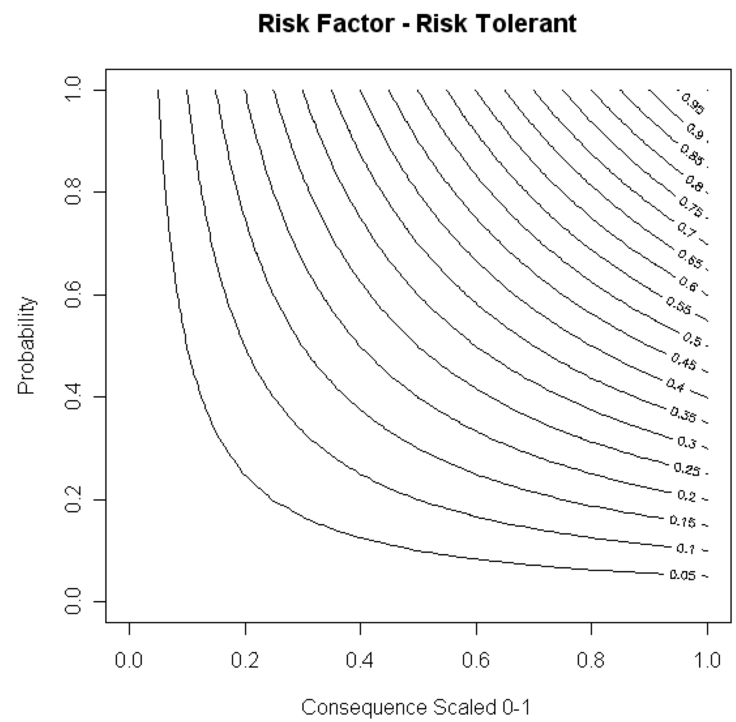
Approaches to Risk Levels

- **There are No One-Size-Fits-All Approaches – *Every Risk is Different***
  - ***Marginal* Consequence Scales for Values may be Linear, Exponential, Logarithmic, or Other**
  - **Probability Scales are Generally Linear or Logarithmic**
- **Shapes of Equivalent Risk Levels, as a functions of Consequence and Probability, are Generally *Concave* or *Convex*, but Could be Any Shape**



Risk Level Examples

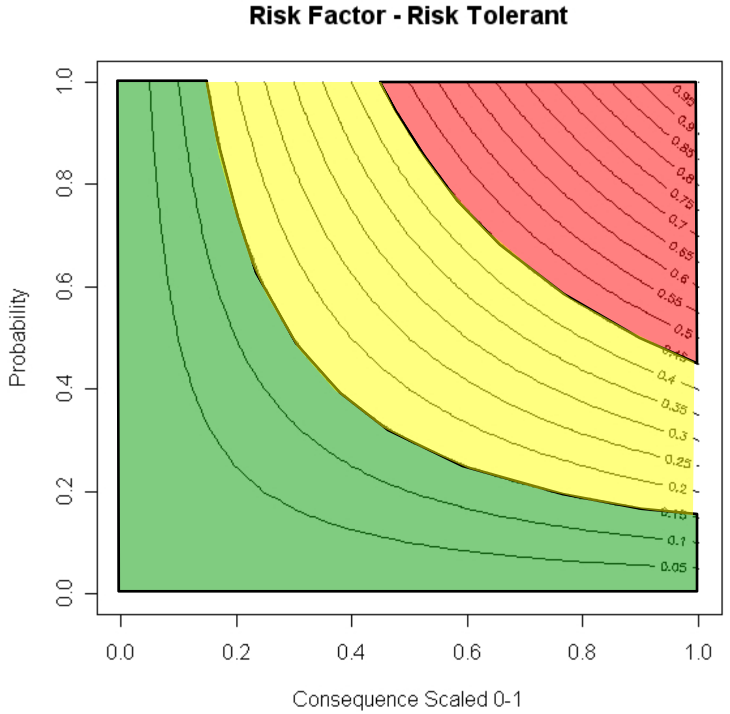




Isocontours are Equivalent Risk Levels – Lines of Constant Values for Combinations of Probabilities with Consequence Levels

The Concept of Acceptable Risk

- A Low Enough Risk Level is Acceptable – Can Live with it if Consequences are Realized
- A Too High Risk Level is Unacceptable – Cannot Live with it if Consequences are Realized
- There may be a Set of Risk Levels between Acceptable and Unacceptable



A Summary of Risk Concepts

- **Risk – An Uncertain Future Consequence**
- **The Measure of *Risk*:**
  The Probability that the Consequence at Some Level will be Realized
- **A Risk Level is an Equivalently Valued Set of Probabilities for different Consequence Levels**
  - **Acceptable**
  - **Unacceptable**
  - **Between Acceptable and Unacceptable**

What We Do About Risk

First, Where does Risk Appear in a Project?

- It's Everywhere! It's Everywhere!
  - *Schedule* – Being on Schedule is not Guaranteed
  - *Budget* – Being within Budget is not Guaranteed
  - *Performance* – Desired Performance is not Guaranteed
- Every Decision in a Project is Based on *Risk*

What Should We Want to Do About Risk?

- **If the Consequence is Only Adverse, We may want to *Expend Resources* to *Avoid it***
- **If the Consequence is Only Advantageous, We may want to *Expend Resources* to *Make it Happen***
- **If Both are Possible for a Single Consequence, We may want to *Expend Resources* to Push it from Adverse towards Advantageous**
- ***This is Just Common Sense***

Faced with Risk, We Act

- ***Analyze the Risk***
  - **Determine *Why* and *When* the Consequence Might be Realized**
  - **Determine the *Sensitivity of the Consequence Level* to Various Factors**
  - **Determine the *Sensitivity of the Probability* of a Consequence Level being Realized to Various Factors**
- ***Assess the Probability* – Statistically Process the Available Data to Obtain an Assurance Level for the Risk Level**
  - **Qualitative – Mentally Process the Data using Subjective Judgment, a Best Guess as to How Sure We can Be that the Risk Level is Acceptable, Unacceptable, or In-Between – *Only as Good as the Guesser, Pretty Risky***
  - **Quantitative – Gather Data and Information, Process Mathematically using Statistics to Provide a Quantitative Assurance Level (a Probability) that the Risk Level is Acceptable, Unacceptable, or In-Between – *Only as Good as the Data and the Statistical Process, Can be Pretty Safe***

Based on Our Risk Assessment

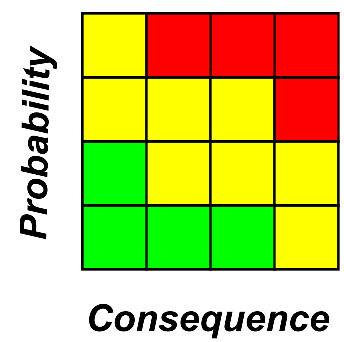
- For a Decision, Select the *Alternative* with the Highest Assurance of the *Lowest Risk Level*
- For General Risks, Set Up a Decision
  - If *Sufficiently Sure* Risk Level is Acceptable, We Do Nothing
  - If *Sufficiently Sure* Risk Level is Unacceptable, We Must Expend Resources to Mitigate (Reduce) the Risk Level to an Acceptable Level
  - Else, Plan for Mitigation, but Just Watch and Re-Assess when New Data is Obtained
- Somebody Must *Decide* What *Sufficiently Sure* is for Each Risk

The Concept of Managing a General Risk

- **At Heart, Also a Simple *Decision* Process**
  - **Three Alternatives to be Selected Based on Risk Level**
    - **High – Expend Resources to Reduce Risk Level**
    - **Moderate – Plan for Reduction and Monitor Risk Level Closely and Frequently over Time**
    - **Low – Monitor Risk Level Much Less Frequently**
  - **Must *Decide* what Combinations of Consequence Levels and Probability Levels Define High, Moderate, and Low**

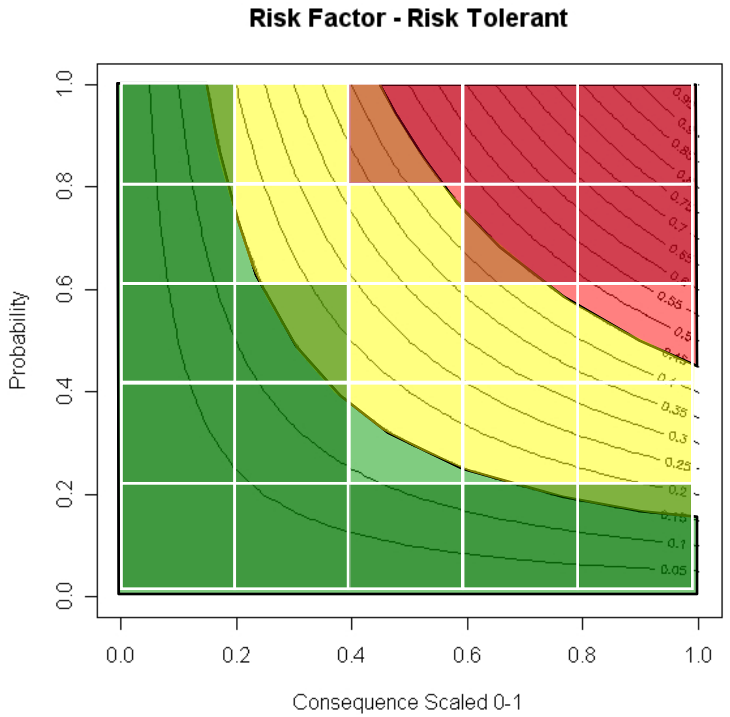
The Familiar n X m *Risk Matrix*

- ***Green* are Low or Acceptable Risks**
- ***Yellow* are Moderate Risks**
- ***Red* are High or Unacceptable Risks**



How to Create a Risk Matrix

- Develop Your Risk Level Contours based on *Values* on the Consequence (Decide)
- Decide on Acceptable and Unacceptable Risk Levels
- Quantize Consequence and Probability Scales Appropriately
- Fill in the Colors (G, Y, R) Appropriately



More on the General Risk Management Concept

- The Risk Matrix Illustrates the *Decision Structure – Risk Levels Determine Actions*
- Risk Assessment Provides the *Decision Discriminator – Assurance of the Risk Level, Based on the Data*
  - If Qualitative, Mentally Process Data to Produce an *Assurance* for the Level of Risk
  - If Quantitative, Statistically Process Data to Produce an *Assurance* for the Level of Risk
  - The Level of Assurance Required for Action is Determined by the *Project Risk Strategy*

Strategy Example: NASA Orbital Debris Avoidance

- **A Collision between a Large Piece of Orbital Debris and the Space Shuttle or Space Station would be Catastrophic**
- **If the *Risk of Collision* is Too High**
  - **The Shuttle and Station can Maneuver out of the way of the incoming Debris**
  - ***BUT*, the Maneuver ruins Microgravity Experiments and Causes Expensive Replanning**
- **NASA's *Risk Based* Decision**
  - **If P(coll) > 10^{-4}, Then Maneuver out of the Way**
  - **If 10^{-5} < P(coll) < 10^{-4}, Then Plan the Maneuver, Don't Execute, but Monitor P(coll) Frequently**
  - **If P(coll) < 10^{-5}, Just Monitor P(coll) Infrequently**

Possible NASA Strategies

- **The NASA Risk Decision:**

P(coll) >10^{-4}	(red)	***Maneuver***
10^{-5} < P(coll) < 10^{-4}	(yellow)	***Plan, Monitor Freq.***
P(coll) <10^{-5}	(green)	***Monitor Infrequently***

Catastrophic Collision

- **Debris and Shuttle/Station Tracking Data are Statistically Processed to Produce the *Assurance Level* for P(coll) > 10^{-4}**
- ***Strategy 1:*** **Maximize Protection of Vehicle and Crew**
  - **If Assurance Level (for P(coll) > 10^{-4}) > 10%, Then Maneuver**
  - **Vehicle and Crew are *More Important* than Experiments**
- ***Strategy 2:*** **Minimize Experiment Disturbance/Replanning**
  - **Don't Maneuver *Unless Assurance Level* (for P(coll) > 10^{-4}) > 90%**
  - **Experiment and Replanning Costs *More Important* than Vehicle and Crew**

Summary: What We Do with Risks

- ***Analyze*** **the Risk – Determine Root Causes and Sensitivities**
- ***Assess*** **the Risk – Determine Assurance of Risk Levels based on the Data**
- **For Decisions – Select the Alternative with the Highest Probability of the Lowest Risk Level**
- **For General Risks**
  - ***Decide*** **on Our Acceptable/Unacceptable Risk Levels**
  - ***Decide*** **on Our Risk Strategy – Assurance Levels for Action**
  - **Act (Do Nothing, Watch Closely, or Mitigate) Depending on our Assessed Risk Levels and Strategy**

How to Implement a Risk Management Program in a Project

Two Types of General Risks

- ***Anticipated* at the Start of a Project**
  - **Possible Slips/Surges in Schedule**
  - **Possible Under/Overruns in Budget**
  - **Possible Variations in Required Performance**
- ***Unanticipated* at the Start of a Project**
  - **The Problem to be Solved always Evolves**
  - **Almost Always Performance Based Risks**
  - **And *Note*: Performance Based Risks Always Produce Uncertainties in Schedule and Budget**

Handling Initially Anticipated Risks

- ***Project Management*** **Processes are** ***Risk Mitigation*** **Processes**
  - **Time-Proven** ***Lessons Learned*** **on What to do and What to NOT do to Make a Project or Enterprise a Success –** ***Reducing Risk!***
  - ***Project Management Plans*** **are** ***Risk Management Plans*** **for Initially Anticipated Risks (Mostly focused on Schedule and Budget)**
- ***Systems Engineering*** **Processes are** ***Risk Mitigation*** **Processes**
  - **Time-Proven** ***Lessons Learned*** **on What to do and What to NOT do to assure Required Technical Performance is Achieved**
  - ***Systems Engineering Management Plans*** **(and associated Plans) are** ***Risk Management Plans*** **for Initially Anticipated Technical Performance Risks**
  - **Example: Verification Reduces the Risk that Performance Requirements were not Satisfied**

The Reason for a Risk Management Program

- **To Address those Initially *Unanticipated* Risks as they are Identified and Recognized**
- **Because Most Unanticipated Risks are Performance Related or Technical, *Systems Engineering Gets the Job of Risk Management***
- **The Risk Management Program Operates *in Parallel* with Program Management and Systems Engineering to Make the Enterprise Successful, *Despite* Unanticipated Risks**

Risk Management addresses those Uncertain Future Consequences that Nobody Anticipated at the Start of the Project

How to Implement a Risk Management Program

- **Project Manager and Chief Systems Engineer Decide on *Risk Margins* for Budget and Schedule**
  - **Based on *Thoroughness* of Project Management Plan**
  - **Based on Factors related to Inherent Risks – e.g., newness of technology, complexity, size, etc.**
  - **Risk Margin Resources Primarily used for Risk Analysis, Assessment, and Mitigation**
- **Project Manager and Chief Systems Engineer Decide on a Project *Risk Strategy* (ies)**
- **Chief Systems Engineer Appoints a Risk Manager**
  - **Risk Manager Develops *Risk Management Plan* and Manages Risk Management Processes and Activities**
  - **Systems Engineering Management Plan Establishes *Risk Identification Culture* and Processes for Project Team to Identify Risks**

Risk Management Processes

- ***Risk Planning*** **– Establish Procedures for Conducting Risk Management on the Project**
- ***Risk Identification*** **– Discovery of Unanticipated Uncertain Future Consequences during the Project Life**
- ***Risk Analysis*** **– Establish Root Causes and Sensitivities**
- ***Risk Assessment*** **– Statistically Process Data to Determine Assurance of Risk Level**
- ***Risk Mitigation*** **– Plan and Execute a Project to Reduce or Eliminate Risk Level**
- ***Risk Tracking and Control*** **– Monitor and Measure Risk Management on the Project**
- ***Risk Communication*** **–** ***Explaining How Project Success is Being Assured by Managing Risk***

How to Use Risk Management in a Project

- *All* Project Personnel and Teams should be Actively Identifying Risks as *Normal Part of Job*
- Risk Manager and RM Team
  - *Review* Risks Identified by Project Personnel
  - *Assign* Risk Analysis Tasks to Engineering and Project Teams as Needed
  - *Perform* Risk Assessments as Needed (including Monitoring)
  - *Propose* Risk Mitigation Plans for Project Team to Execute
  - Track and Control All Risks
  - Prepare Risk Metrics and Risk Communications
- Project Manager and Chief Systems Engineer
  - *Communicate* Risk Metrics and Overall Risk Posture Project
  - *Decide* Upon Risk Mitigations, Assign Tasks to Project Teams
  - *Manage* Risk Margins, Release Resources *Only* when Project Risk Posture Diminishes with Time and Project Maturity

Typical Use of Risk Margins

- **95+% of Resource (Budget and Schedule) Expenditures on Risk Management**
  - **Performance of Risk Analyses by Engineering or Project Teams – *Pulled Away from Normal Job***
  - **Performance of Risk Assessments by RM Team**
  - **Performance of Risk Mitigation Plans by Project Teams – *Pulled Away from Normal Job***
  - ***Accepted Risks Commit Risk Margins Until becoming OBE***
- **< 5% of Resource Expenditures (Budget and Schedule) on Risk Management**
  - **Risk Planning**
  - **Risk Tracking and Control**
  - **Risk Communications**
- **Risk Identification Should be Part of Normal Job and thus not Use Risk Margin Resources**

Summary: Risk Management Program

- **Risk Management Program is for Risks *Unanticipated* at Start of Program (PMP and SEMP should address All Anticipated Risks)**
- **Operates *in Parallel* with Project Management and Systems Engineering**
- **PM and CSE Must Make Some *Tough Decisions* on Risk Margins, Risk Strategies, and Mitigations**
- **Risk Identification *Culture* Must be Innate**
- **Management Message: *Risk Management Saves Enterprises from Failure***

Short Break

Please Be Back in 10 Minutes

Useful Risk Metrics

The Problem with Risk Management

- **A good risk management process results in nothing happening – *the Project Succeeds!***
- **How does one *measure* RM performance?**
- **Multiple choice:**
  - **If a project meets its performance goals, then …**
    - **A. It's risk management process was successful**
    - **B. The project had a run of good luck**
    - **C. The project was under-constrained**
    - **D. All of the above**
  - **If a project overruns its cost commitments, then …**
    - **A. Its risk management process failed**
    - **B. The project got a bad roll of the dice**
    - **C. The project was over constrained**
    - **D. All of the above**

Risk Management Metrics?

- ***What* do you measure?**
- ***How* do you measure it?**
- **How do we know what is a *good* measurement, or a *bad* measurement?**
- **The International Council on Systems Engineering (INCOSE) Chartered Risk Management Working Group (RMWG) to Investigate RM Metrics**

INCOSE RMWG
RM Metrics Proposal

- **RM Metrics Classified by Usage Frequency**
  - ***Infrequent* Metrics**
    - **Usually before or after a project**
    - **When significant performance issues are noted**
    - **During the development of a Risk Management process**
  - ***Continuous* Metrics**
    - **Measure the process during execution**
    - **Measure the quality of the products during execution**
    - **Attempt to make interim corrections if needed**
  - ***On-demand* Metrics**
    - **When a measurable result is available, compare to expectations**
    - **Ad Hoc or Periodic**

Infrequent Metrics and Measurements

- *Compliance* to organization's standards
  - Build a compliance matrix – extract "Shall" statements
  - Compare project's process against the organization's standards

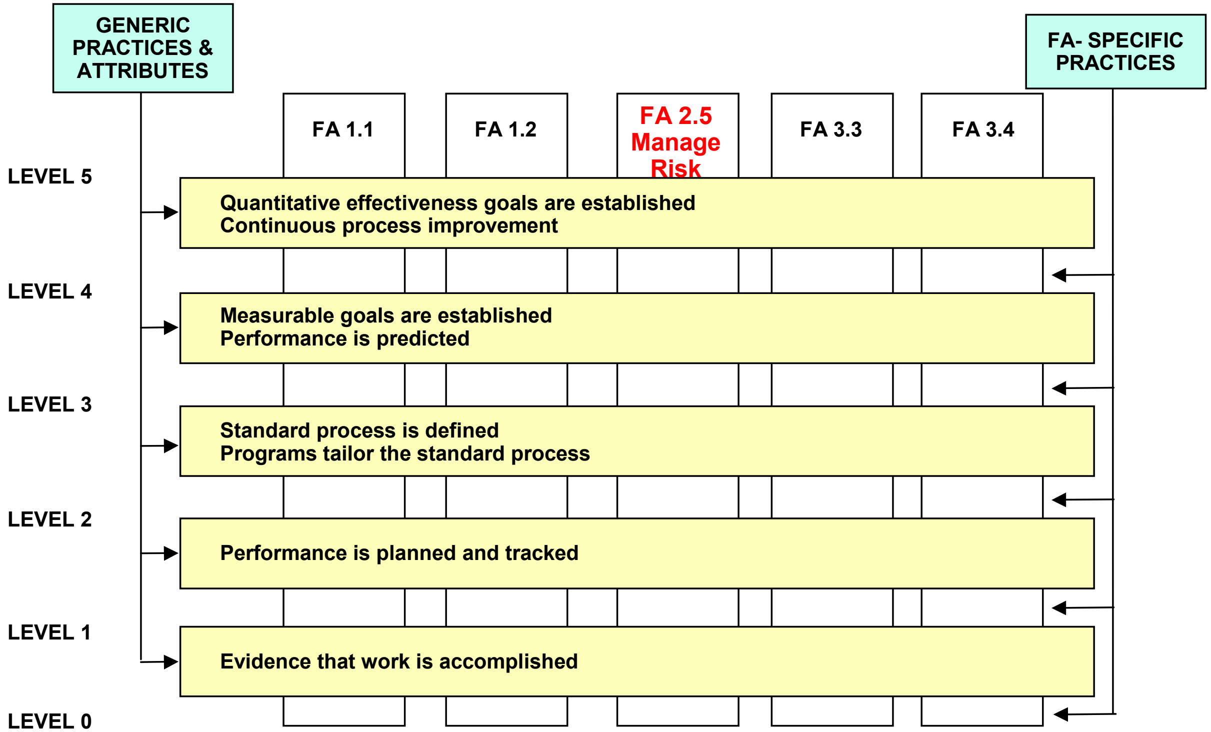
Project Compliant?	"Shall" Statement	Project RM Plan Paragraph
5	The identification of risk shall be actively encouraged at all levels in the Project Team	Pg. 2, Section 1.6
4	Risk identification shall be accomplished by entering the information into the Kepler Risk Database through the Kepler Risk Tracking Tool.	Pg. 2, Section 1.6
	…fied risks shall be reviewed by Project …ent on a cyclical basis and accepted, assigned to a …er for action, rejected or retired.	Pg. 2, Section 1.6

A scale of 1 to 5 indicating level of compliance

Corrective Action?

Infrequent Metrics and Measurements

- ***Compliance*** **to "Best Practices"**
- **No consensus on what are "Best Practices"**
- **Use CMMs as a substitute**



Continuous Metrics

- **Compliance to Plan**
- **Performance**
  - **Effectiveness**
  - **Efficiency**
  - **Staleness**
- **Trending**

Continuous Metrics: Compliance to Plan

- ***Compliance*** **to RM Plan**
  - **Is the project actually doing what it said it would do?**
  - **A simple compliance matrix**
  - **Shall statements from the RM Plan for the project versus evidence that the activities are actually performed**
  - **Determine corrective action**

Continuous Metrics: Performance

- **Performance – measure the performance of the process**
  - ***Effectiveness***
    - **Effective: No or very few unforeseen *problems* occur**
    - **Approach: How many *problems* occurred that were never identified as risks**
  - ***Efficiency***
    - **Efficient: Catching risks *early* when it is more cost effective to mitigate them**
    - **Approach: Measure the time between when a risk was identified and when it became a problem**
  - ***Staleness***
    - **How many risk products are "stuck" in a process step**
    - **And, how long have they been there**

The Effectiveness Metric

- **Performance – *Effectiveness***
  - **Premise: An effective risk management system will prevent unexpected problems**
  - **P_E, Process Effectiveness is the ratio of problems encountered, N_p, that were not identified as risks, to the total of risks identified, N_r *, and problems encountered***

    $$P_E = 1 - N_p/(N_p + N_r)$$
  - **Measure of goodness: 90% = good; 80% = watch; 70% = Action**
  - **Action: causal analysis and process improvement**

The Efficiency Metric

- **Performance – *Efficiency***
  - **Premise: An efficient risk management system is one in which the planning and mitigation of risks occurs well before they become problems**
  - **For n realized risks, P_e, Process efficiency, is the average time lapse between all risks' identification date, T_{ID}, and the time that it is realized, T_R,**

$$P_e = \sum (T_{R,i} - T_{ID,i})/n,$$

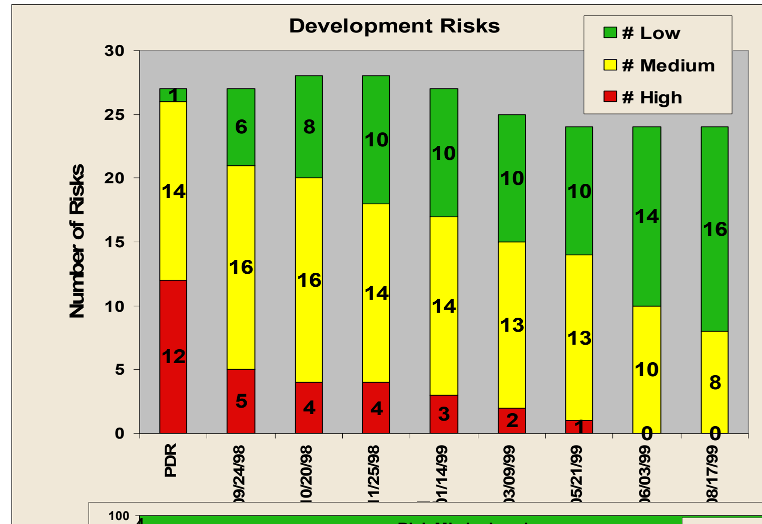
  - **Measure of goodness: the larger the better**
  - **Action: causal analysis and process improvement**
  - **Potential Improvements: Look at 90th percentile time lapse**

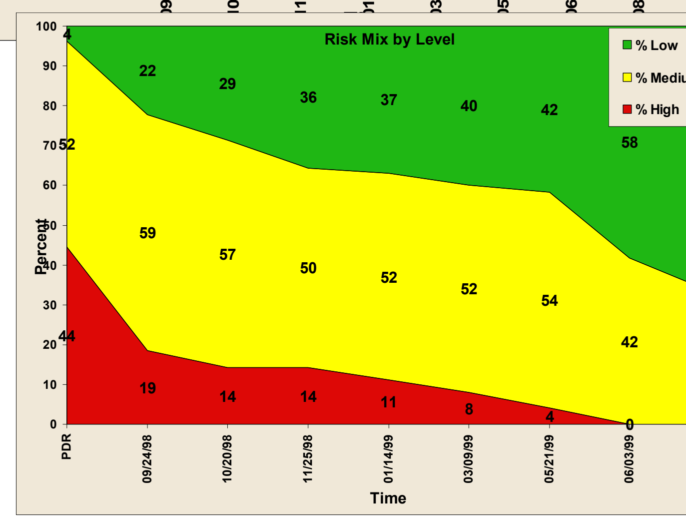
The Staleness Metric

- **Performance – *Staleness***
  - **Residence time for risks in major steps**
  - **Short residence times: < ~30 days, are "Excellent"; long residence times: ~180 are "Very Poor"**
  - **Measure of goodness: 90% short = good; 80% short = watch; < 70% short = Action**
  - **Action: direct project management attention to insure actions on stale risks**
- **Example measures:**
  - ***First Latency*: Time identified to time first action by project management**
  - ***Second Latency*: Time from assignment to a Risk Owner to time the project *Accepts* risk mitigation plan**
  - ***Subsequent Latencies*: Lateness tracked against dates on the steps in the risk mitigation plan**

Trending Metrics

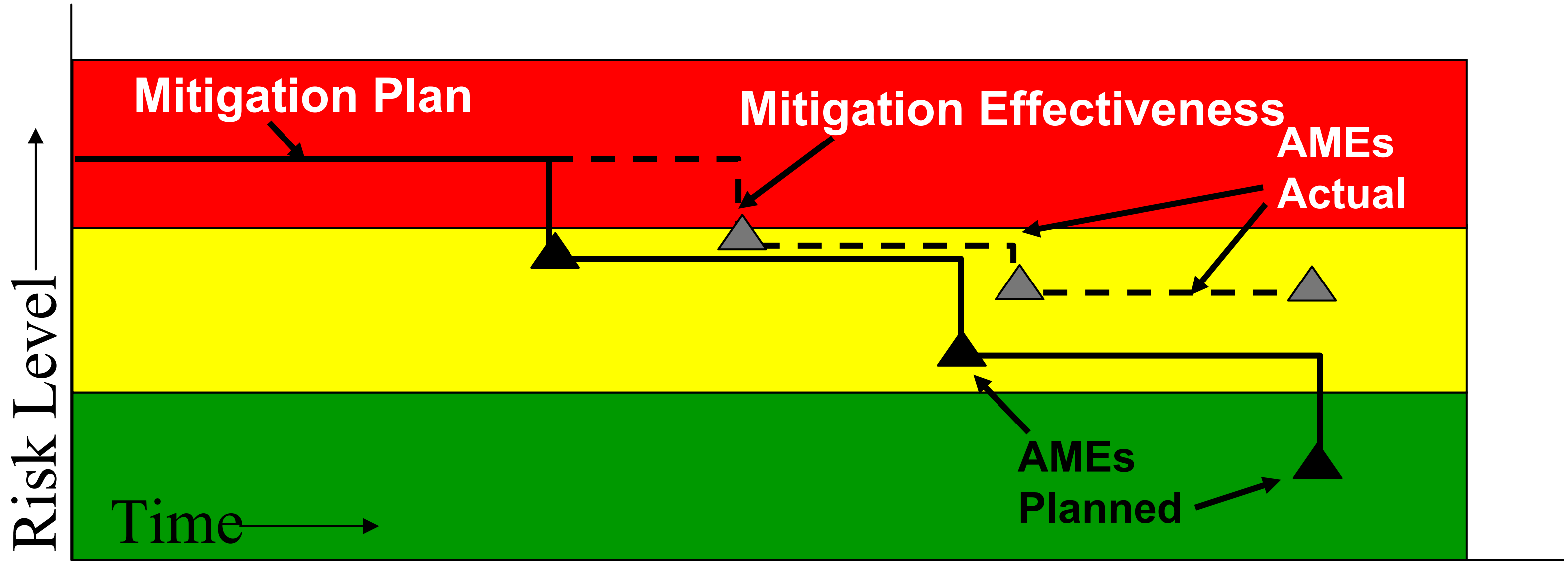
- Body Count versus time
- Measure Risk Level Changes
- *Goodness* is more vague on this one
  - No change is *bad*
  - Increasing risk numbers may be *bad*
  - A decreasing trend in the red and yellow is *good*
- Action: direct project management attention to insure actions





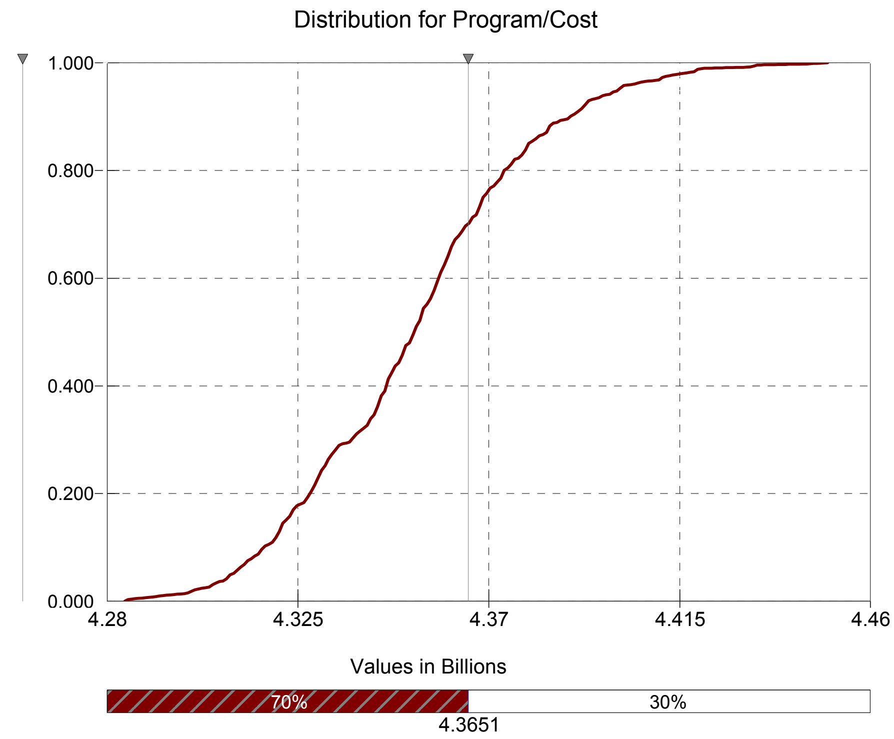
More Trending Metrics

- **Waterfall charts**
- **Measure**
  - **Latency (Calculated elsewhere)**
  - **Errors in prediction of impact or effectiveness of mitigation**
- **Goodness: Miss residual risk by *half a color***
- **Action: direct project management attention to correct**



On-Demand Metrics: Results

- Based on risks that have been accepted by the project either with or without mitigation
- Should those risks be realized, the impact is measured
- Compare the measured impact with the predicted impact
- Action: causal analysis and process improvement



Summary of Metrics

- ***Infrequent***
  - **Measure the quality of the process**
  - **Compliance to the organization's standards**
  - **Comparison with Best Practices**
- ***Continuous***
  - **Compliance to plan**
  - **Performance**
    - **Effectiveness**
    - **Efficiency**
    - **Staleness**
  - **Trending**
- ***On-demand***
  - **Results - for *accepted* risks that are realized, compare actual risk outcomes with predictions**

INCOSE RMWG Recommendation

- **A *Proper Combination* of Metrics should be Selected**
  - **Individual Metrics are Not Sufficient**
  - **Should Include Each Frequency Type**
- **Risk Management Performance is Measurable, and Hence Manageable**
- **Risk Management Can be *Justified***

Recent Advances in Risk Assessment

Risk Assessment

- ***Risk Assessment*** **is** ***Absolutely Key*** **to a Successful Risk Management Program, and Hence,** ***Absolutely Key*** **to a Successful Enterprise**
- **Risk Assessment Answers a Simple Question:**

Based on the Available Data, How Sure can we be that the Risk Level is Unacceptable?

- ***Typical*** **Available Data Types**
  - **Actual Observed Events or Measurements**
  - **Observations that Events Have *NOT* Occurred (Censored data)**
  - **Heuristics and Professional Opinion**

Qualitative Risk Assessments

- **Risk Assessment Can be Purely *Qualitative***
  - ***Mentally* Processing (Mentally doing the Statistics) the Available Data with a lot of Subjectivity thrown in (assumptions) to get an Estimate (SWAG) of Assurance**
  - **This Assurance Estimate is only as good as:**
    - **The Brain: Mental Algorithms and Statistical Processing**
    - **The Assumptions that were used, *if even Known***
- **Often Referred to as:**
  - ***Seat of the Pants***
  - ***Shoot from the Hip***
  - ***Best Engineering Judgment***
  - **Or, just a *Guess***
- **Sometimes Good Enough, But Usually *Very Dangerous to Use for Serious Risks***

Quantitative Risk Assessments

- ***Mathematically*** **Models Uncertainty, Consequence Root Causes, and Sensitivities**
- **Process All Available Data using *Statistical Methods* to Obtain Quantitative Measures of Assurance of Risk Levels**
- **Proper Quantitative Risk Assessments Use *No Assumptions*, are *Very Reliable* and *Repeatable***
- ***Why Don't We Use Quantitative Risk Assessments?***
  - **Proper Risk Assessment Formulations *for Real World Problems* using All Available Data without Assumptions almost always become *Analytically Intractable***
  - **Even Numerical Approaches (Monte Carlo Methods) almost always *Impossible* to Use for the Proper Assessment**
  - **Classical Statistical Methods do not use Censored Data or Heuristics very Well, if at All, Nor Outliers**
  - **Classical Statistical Methods use Many (Usually Unstated) Assumptions**

The State of Risk Assessment Practice Today

- **For Real World Risk Assessment Problems**
  - ***Cannot do Proper*** **Quantitative Risk Assessments**
  - **Because of** ***Futility*****, Proper Formulations Not Taught in most College Engineering Programs**
- ***Current*** **Quantitative Risk Assessment Practices**
  - **Use of Classical Statistics, if Possible, Usually** ***Ignoring Good Data*** **(Censored and Heuristic) with** ***Many Assumptions***
  - **Use of** ***Assumptions*** **in Monte Carlo (numerical approximation) Simulations (often called** ***Probabilistic Risk Assessment*****)**
  - ***Impossible*** **to use Classical Statistics or Probabilistic Risk Assessment with** ***only*** **Censored and/or Heuristic Data**
  - ***Oversimplifications*** **of Problem Formulations to Enable Use of Classical Statistics and/or Assumptions, Reduced Dimensions**
  - ***Must Ignore Outlier Data***
- **Almost Universally,** ***Overconservative*** **Assurances for Risk Levels Obtained with Associated Costs**

The Recent Advancement

- **Not Really an Advancement in Quantitative Risk Assessment**
- **New Numerical Methods Allow *Proper* Quantitative Risk Assessment to be Done**
  - **In the Mid 1990's, European Biomedicine Began Using New *Markov Chain Monte Carlo* Methods to Produce Quantitative Risk Assessments**
  - ***Markov Chain Monte Carlo* Methods provide very good numerical approximations for Real World Analytically Intractable Risk Assessment Formulations**
    - ***No Assumptions Necessary*, Models of Objectivity Can be Used Instead**
    - ***All Data Types* can be Fused into the Assessment and Used Effectively, *including Censored and Heuristic***
    - ***No Need to Ignore Outlier Data***

Markov Chain Monte Carlo

- **A *More General* Version of Monte Carlo Methods**
  - **Does *Not* Require Defined Sampling Models**
  - **Does *Not* Require Assumptions, *Completely Objective***
  - **Will Work with Analytically Intractable Formulations**
  - **Can work for *Very High Dimensional Problems* (up to 20,000 related sources of uncertainty)**
  - ***Simple Algorithms* to Code, but Not Amenable to Packaging as a Computational Tool**
- **When Used in Risk Assessment, Provides *Full Quantitative Assurance of Risk Levels* for the Most Complicated Real World Risk Assessment Problems**

Example: Space Shuttle Cargo Transfer Bag Test

- **Cargo Transfer Bags (CTB) to be Carried on Shuttle to Space Station**
- **Required Zipper Cycle Life – 2,000 Cycles**
- **If CTB Zipper Fails During Launch or Descent, Loose Object could Penetrate the Hull (Rare Event with Extreme Consequences)**
- **Performed a Single Test**
  - **One CTB Only**
  - **8,000 Successful Zipper Cycles**
- **Relevant Question**

How Sure can we be from the ONE Test Result that the TRUE Risk of CTB Zipper failure by 2,000 Cycles is below some Acceptable Level?

Synopsis for the CTB Test

- **Test Datum:**
  Successful 8K Cycles without a Failure on One CTB Zipper
- **Assumptions (*outrageous*):**
  - **Zipper Cycling Cannot Improve Reliability of the CTB Zipper**
  - **At Least 62.4% of CTB failures will occur before 30,000 Cycles**
- **No Stated Minimum Acceptable Risk – So Parameterize**

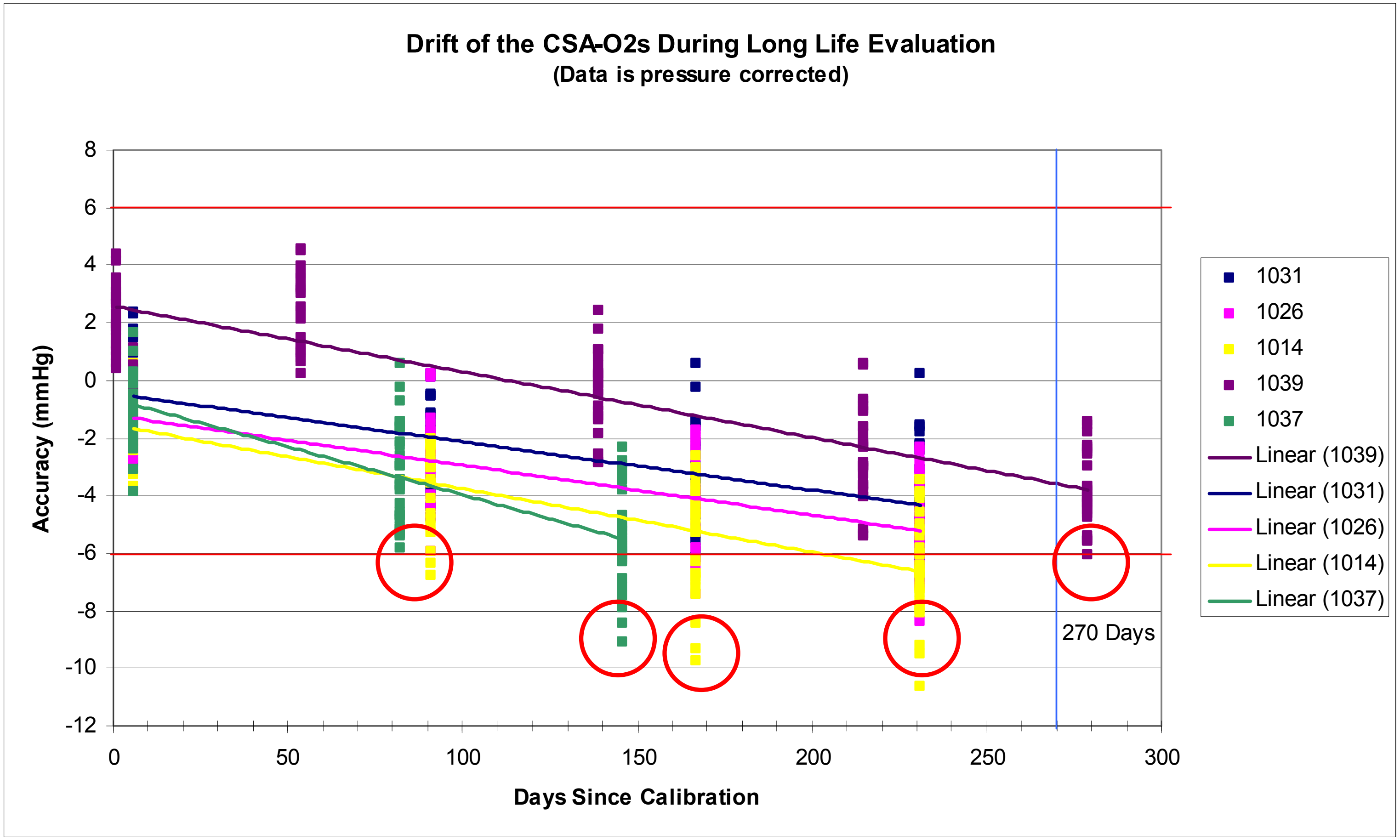
Risk of CTB Zipper Failure by 2K Cycles (R_{2K})	Assurance Provided by Test Results P(True $R_{2K} < R_{2K}$)
1%	75%
5%	88%
10%	94%
20%	98%

Could Not be Solved Without Markov Chain Monte Carlo Methods!

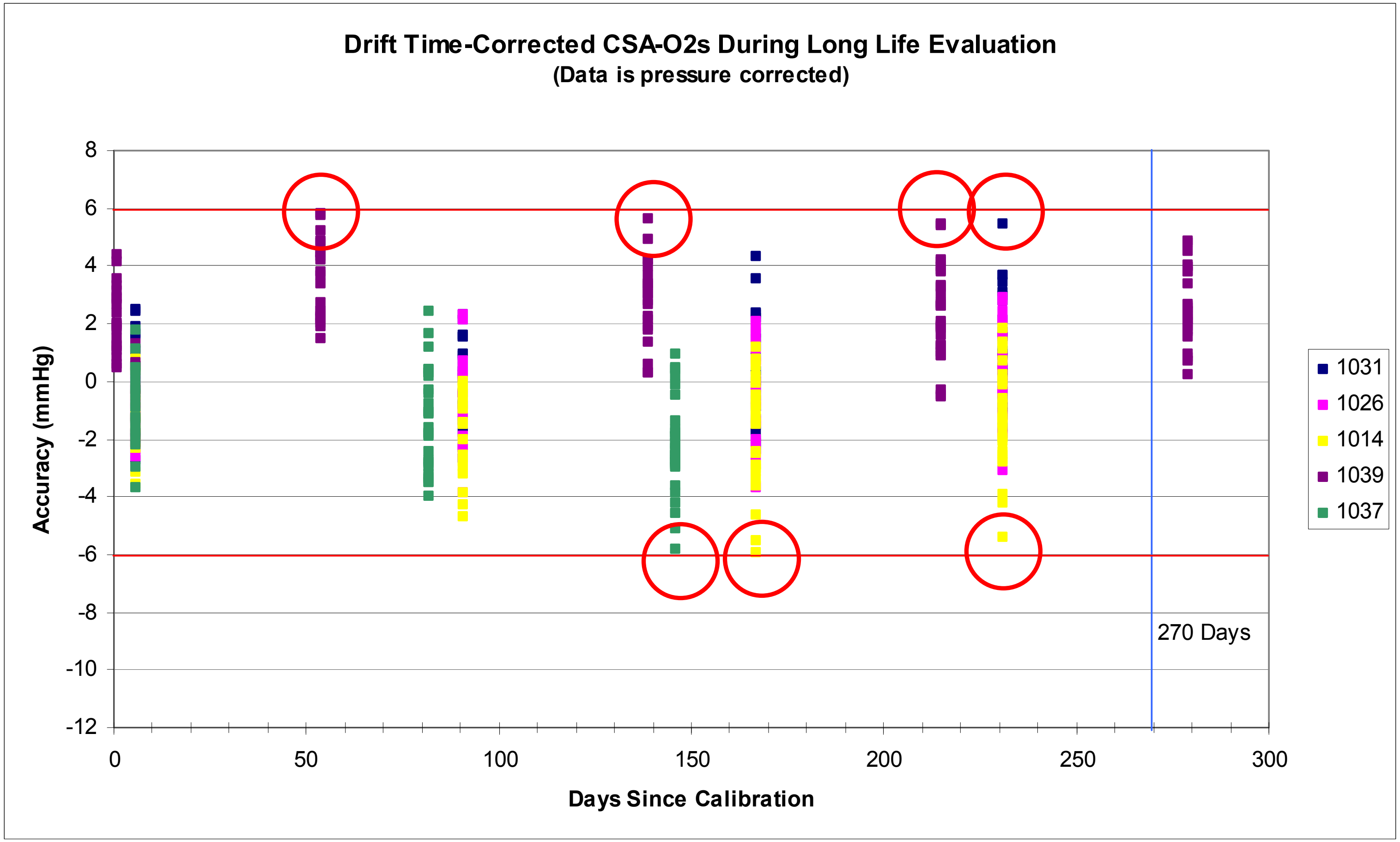
Example: ISS O2 Sensor Drift

- **Problem: Space Station Oxygen Sensor Measurement Accuracy is Observed to *drift* with Time**
  - **If the Measured O_2 is in Error by more than $\pm$6mmHG within 270 days since Calibration, it could *Kill* an Astronaut**
  - **Already Compensating for Pressure Variations in Measurement Accuracy (Successful)**
- **Proposed Solution Options:**
  - **Test for Drift rates and Compensate for Drift; *OR,***
  - **Redesign O_2 Sensor and Ship Up to ISS**
- **Questions:**
  - **What is the *Existing* Risk of Sensor Accuracy Drift Beyond Acceptable Limits?**
  - **What is the Risk *After* the Proposed Drift Compensation?**

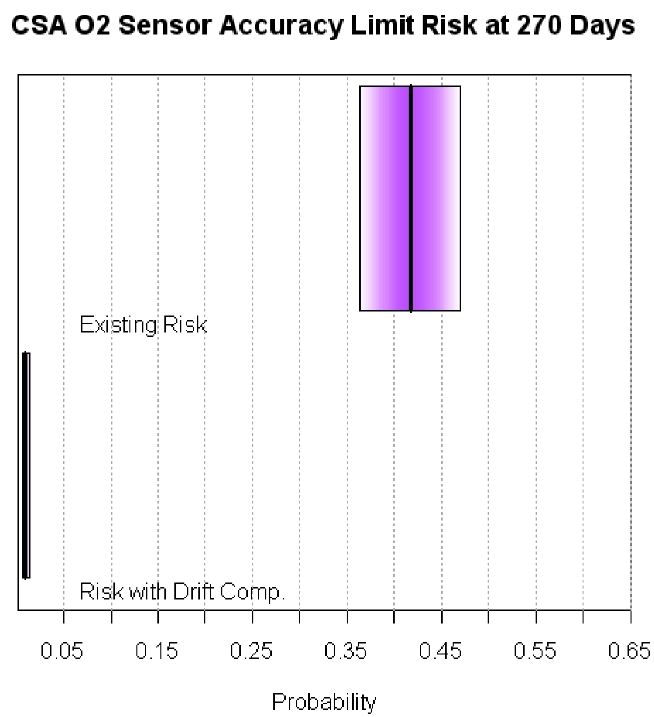
O2 Sensor Test Data



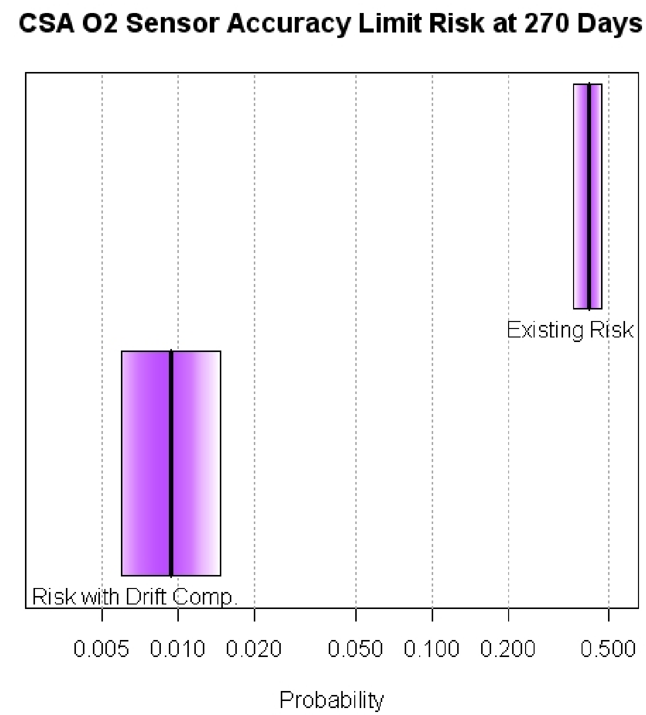
Drift Corrected O2 Sensor Data



Before and After Drift Correction Risk Results



Linear Scale



Logarithmic Scale

O2 Sensor Risk Summary

- **Without Drift Compensation, Risk of Exceeding Accuracy Limits at 270 Days is 36-46% (with *90% Assurance*)**
- **With Drift Compensation, *95% Sure* Risk of Exceeding Accuracy Limits at 270 Days is < 1.5%**
- **Additional O2 Level Compensation could Reduce Risk Further**
- ***No Assumptions Needed***

Could Not be Solved Without Markov Chain Monte Carlo Methods!

Example: RSR Loose Screw Risk

- **Problem: Screws Holding Locker Door in Place in Shuttle Bay are Too Short**
  - **If Door Looses Integrity, or Falls off, Something could Penetrate the Shuttle Hull during Launch or Descent**
  - ***What is The Risk of having a Loose Screw, that could then Lead to a Risk of Losing a Door, and Losing a Shuttle and Crew?***
  - **Data: 8 screws of 273 observed Loose, but not Lost**
- **Decision:**
  - **Replace and Retighten All Screws, *OR***
  - **Delay Flight**

Risk of Panel Door Loss

- **Complex Risk Question**
  - **Loss of any Latch or Hinge Plate on Door will cause Loss of Door Integrity**
  - **Loss of a Latch or Hinge Plate requires Loss of One or More Screws**
  - **How many lost screws, in what patterns for Latch or Hinge Plate will Cause Loss of Door?**
  - **The Answer Defines Failure Modes**
- **Potential Failure Modes**
  - **Any One to Six Screws Lost in a Latch or Hinge Plate Causes Door Integrity Loss - *Conservative***
  - **Specific Pattern of One to Six Screws Lost in a Latch or Hinge Plate Causes Door Integrity Loss – *Realistic* Engineering, and Less Conservative**

The Probability Equations for Risk of Panel Door Loss

- **The Complete Probability Equations are usually Neglected, Usually a Mistake**
- **The Probability Statements for this Risk**
  - **P(loss of any door)**
    = 1-(1-P(loss of single panel door))^(# of single panel doors)
    *** (1-P(loss of double panel door))^(# of double panel doors))**
    *** (1-P(loss of triple panel door))^(# of triple panel doors))**
  - **P(loss of door)**
    = P(loss of any Latch OR loss of any Hinge Plate on the door)
    = 1-(1-P(loss of latch))^(# of latches and hinge plates on door)
  - **P(loss of latch) = P(loss of Hinge Plate)**
    = P(M screws lost of Pattern of 6) – the failure mode

$$= \sum_{j=0}^{6} \left[\mathbf{P}\left(\textbf{M Lost} \,|\, j \textbf{ Loose}\right) \mathbf{P}\left(j \textbf{ Loose}\right) + \mathbf{P}\left(\textbf{M Lost} \,|\, 6-j\,\textbf{Tight}\right) \mathbf{P}\left(6-j\,\textbf{Tight}\right) \right]$$

Predicted Risk of RSR Panel Door Failure

- **Consider All Conservative Failure Modes (1 to 6 screws may be needed to Retain Each Latch and Each Hinge Plate)**
- **Worst Case – Specific Screw Patterns will Reduce Risk**
- **Table of Predicted Risks for Failure due to Lost Screws**

Failure Mode Definition (# Lost Screws in Pattern of 6)	P(Loss Single Door|Data)	P(Loss Double Door|Data)	P(Loss Triple Door|Data)	P(Loss Any Door|Data)
1 or more	1.91%	3.78%	5.62%	29.34%
2 or more	2.35e-2%	4.69e-2%	7.04e-2%	0.422%
3 or more	2.57e-4%	5.14e-4%	7.71e-4	4.63e-3%
4 or more	2.23e-6%	4.47e-6%	6.70e-6%	4.02e-5%
5 or more	1.34e-8%	2.68e-8%	4.02e-8%	2.41e-7%
6	4.11e-11%	8.23e-11%	1.23e-10%	7.41e-10%

Actually, One of those Very Rare Quantitative Risk Assessment Problems Solvable Analytically, But Shuttle Engineers Did not Know How to Properly Formulate it

For More Information on Proper Quantitative Risk Assessment and MCMC

- Numerous Texts, Check Amazon
- I Welcome Contact
  - Articles
  - Examples
- Stevens Courses
  - SYS 601: *Probability and Statistics for Systems Engineers*
  - SYS 660: *Decision and Risk Analysis for Complex Systems*
  - Webcampus: http://webcampus.stevens.edu

Summary and Conclusions

- **Risk Management Programs *Insure Against Project Perils* to *Ensure Project Success***
- **Proper Risk Management and Risk Communications *Improve Customer and Line Management Confidence***
- **A Good Set of Risk Management Metrics Enable Effective Management of the RM Process, and *Good Communications***
- **New Numerical Methods Enable Proper *Quantitative Risk Assessment* without Assumptions to Make Risk Management More *Effective* and *Efficient***

Risk Management Can be Established and Used Effectively

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