Practical Risk Management for Technical Projects

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Tutorial Outline

Introduction

Concepts: ***Just What are We Talking About Here?***

RM Processes: ***Let's Get Practical!***

RM Metrics: ***Measuring and Communicating How the Project is going to be a Success***

Advanced Methods: ***Assessing Risk Distributions and Mitigation Effectiveness Distributions***

Review, Summary, Evaluation: ***Then, You are Free to Go.***

Introduction: Your Tutorial Instructor, Mark Powell

- **Over 40 years Experience in Systems Engineering and Project Management**
- **Former Chair, INCOSE Risk Management Working Group**
- **INCOSE Technical Leadership Team, Former Assistant Director for Systems Processes**
- **Professor, Systems Engineering**
  - **Stevens Institute of Technology**
  - **University of Houston Clear Lake**
  - **University of Idaho**
- **Contact Information at the End of Tutorial Presentation, Contact Welcomed**

Introduction: Where to get the Slides

- **Go to www.attwaterconsulting.com/TutSEmPres.htm**
- **First presentation, with the tutorial title**
- **In this live presentation, I use slide animations that do not show in the printable slides.**
- **If you follow my presentation using these printable slides, please don't steal my thunder.**

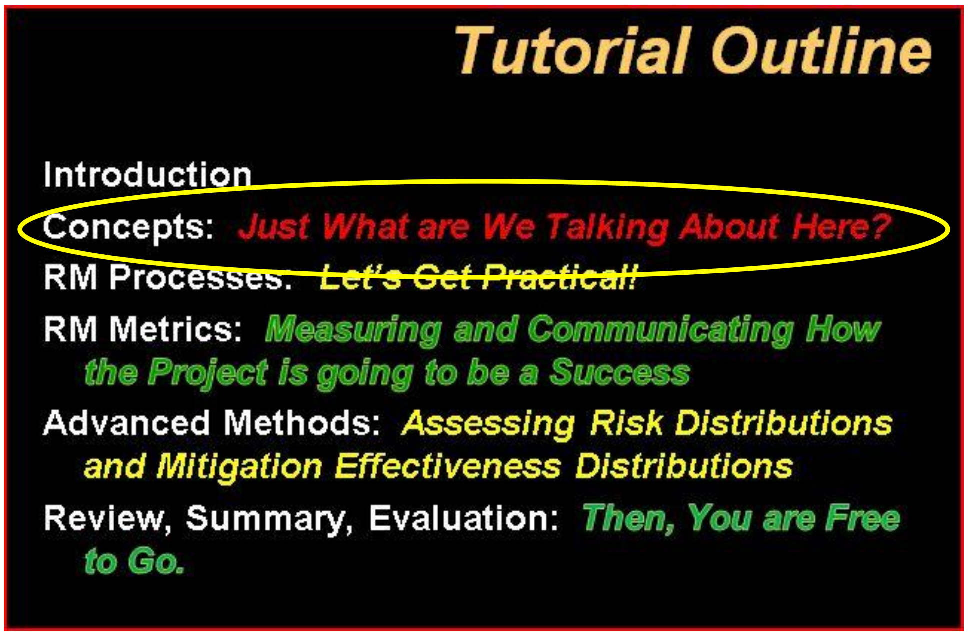
Thanks!

Introduction to the Tutorial

- **What do we mean *Practical*?**
  - **Better Conceptual Understanding**
  - **Techniques you Can Implement**

    within your existing Standards or Company Policies
  - **An Aside: *No Standard or Company Policy Precludes You doing the Right Thing.***

Concepts: Just What are We Talking about Here?



- ***risk* vs. *Risk***
- **Unacceptable *risks* and Acceptable *risks***
- **To Mitigate, or Not to Mitigate**

risks vs. *Risks*

- **All *Risks* are *risks*, but not all *risks* are *Risks.***
- **Every decision ever made on (or off) planet Earth was based on an assessment of *risk.***
- **Definitions Abound for the word.**
- **For this Tutorial: *risk* is simply an uncertain future consequence.**
- **The measure of *risk* is the probability that a consequence above or below a specified level will be realized.**

Now to Risks

- **Before project start, all projects are Awash in a Sea of Uncertainty and *risks.***
- **At project start, *good* project management has plans and processes in place to address the pre-start identified uncertainties and *risks.***
  - **Depending on project size, perhaps 50 plans**
  - **PMP, SEMP, CMP, RMP, SIVP, EVMP, TPMP, etc.**
- **All PM processes and plans exist to monitor and mitigate *risks* identified before project start.**
- ***risks* identified after project start are *Risks.***

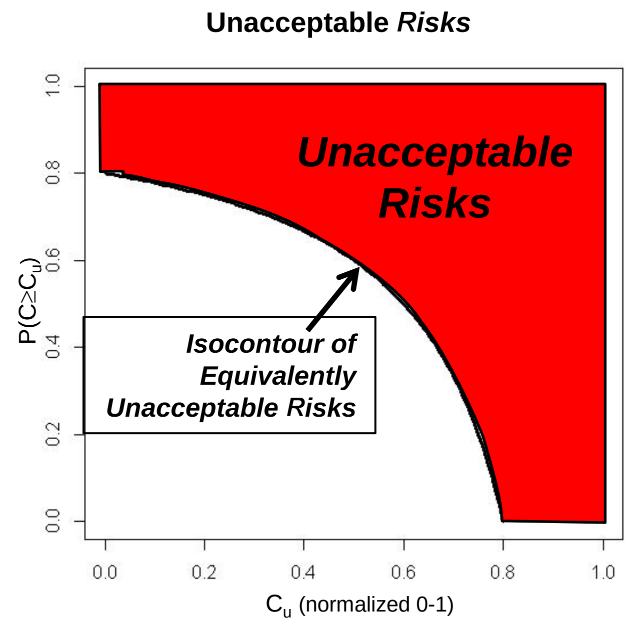
More on Risks

- **The primary *risk* that all projects face –**
  the risk of not being Successful
- **Success?**
  - **Delivering required performance**
  - **On Schedule**
  - **On Budget**

  (On Schedule, On Budget) ***Importance varies by contract type***
- **All management plans focus on this *risk.***
- **All *Risks* ultimately contribute to this *risk.***
- **We Formally Manage *Risks* using Risk Management Processes*.***
- **The measure of a *Risk* is the probability that a consequence above or below a specified level will be realized during the life of the project.**

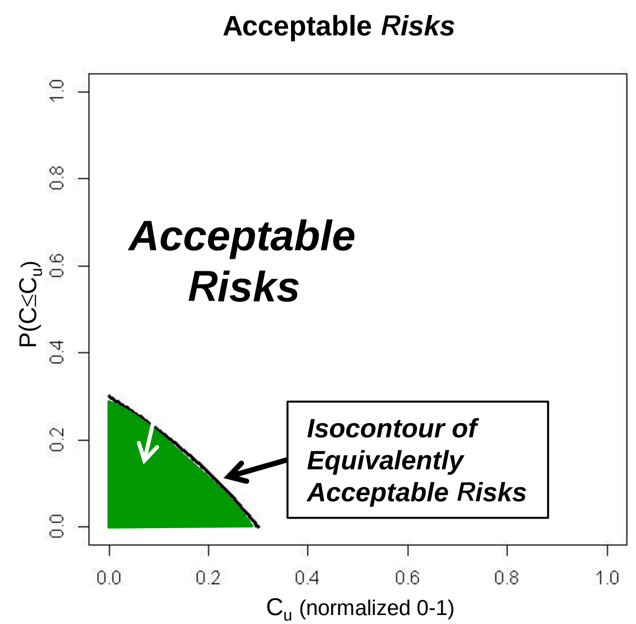
Unacceptable risks (or Risks)

- **Maybe, the consequences that might be realized might be too high or too low.**
- **But, we are talking about Unacceptable *risks***
  - **Let's do an experiment.**
  - **The minimum unacceptable probabilities change for different consequence thresholds.**
  - **We end up with an isocontour of equivalently unacceptable *risks.***



Acceptable risks (or Risks)

- **Maybe, the consequences that might be realized are so low or so high, that you don't care if they are realized.**
- **But again, we are talking about Acceptable *risks*.**
  - **The maximum acceptable probabilities change for different consequence thresholds.**
  - **We end up with an isocontour of equivalently acceptable *risks.***



Unacceptability and Acceptability of risks

- **It's personal!**
  - **Every consequence type will be valued differently by the same person, and differently between different persons.**
  - **Unacceptable/Acceptable isocontours will be different by consequence type, and between different persons.**
- **There are always threshold ranges of equivalently unacceptable and acceptable *risks* (isocontours).**
- **A given probability of realizing a higher good consequence may not be valued as much as the same probability of realizing a lower bad consequence.**
- **The Unacceptable and Acceptable *Risk* isocontours are never Stationary – *they vary during the life of the project*.**

To Mitigate, or Not to Mitigate

- **The *almost* universal convention:**
  - **We mitigate Unacceptable risks.**
  - **We do not mitigate Acceptable risks.**
- **Would you mitigate if you were *sufficiently sure* that a *risk* was unacceptable?**
- **Would you Not mitigate if you were *sufficiently sure* that a *risk* was acceptable?**

Well, Maybe.

To Mitigate

- **Suppose you were *sufficiently sure* that the cost (consequences) of mitigation would be more than the consequences if the Unacceptable *risk* were realized?**
- **Suppose you were *sufficiently sure* that the amount of *risk* reduction for the cost (consequences) of mitigation was just too little?**

That Unacceptable risk might become Acceptable!

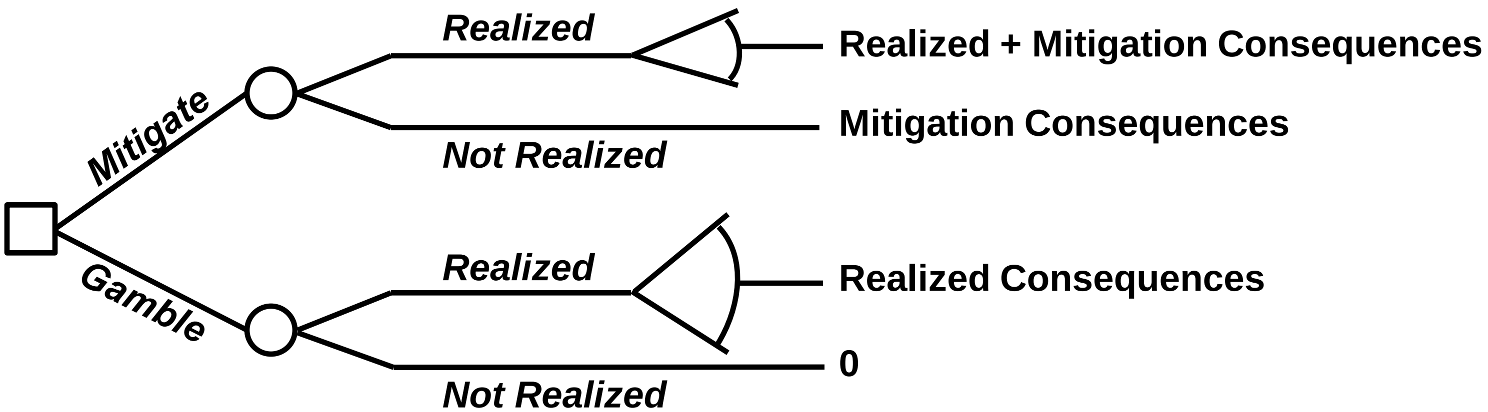
To Not Mitigate

- **Suppose you were *sufficiently sure* that the cost (consequences) of mitigation of an Acceptable *risk* was so trivial and low to be essentially *free*?**

That Acceptable risk might become Unacceptable!

"The" Decision

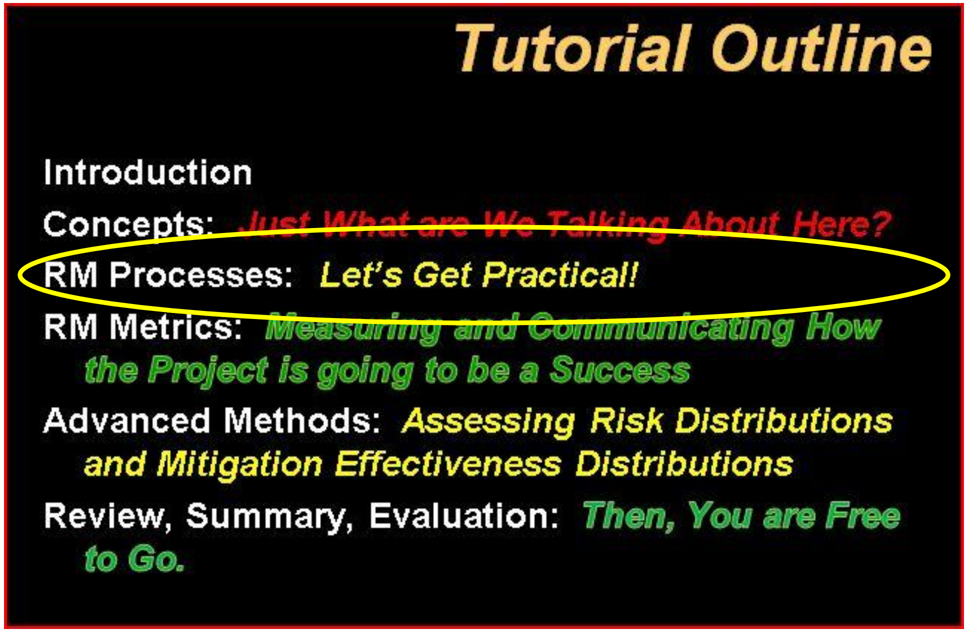
- When a *Risk* is identified, a decision must be made:
  - Do we expend resources to mitigate the *Risk*?
  - Or, do we gamble that no consequences will be realized, and if they are then expend the resources to deal with the problem?



More on “The” Decision

- **Dirty Little Secret:**
  Any time a Risk is identified,
  resources will be expended.
- **How *sure* the decision maker can be about the changes between the distributions of realizable consequences, with and without mitigation, is key to this decision.**
- **After mitigation, may have to repeat “The” Decision**
- **Today, it is possible to quantify “How *sure* the decision maker can be” for every *Risk*!**

RM Processes: Let's get Practical!



- **Seven *Risk* Management Processes**
- **How to Implement a Formal RM Program.**
- **Where does all the Time and Money Go?**

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* – Record and document *Risk* Management activities on the Project**
- ***Risk Communication – Explaining How Project Success is Being Assured by Managing Risks***

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 Plans**
  - **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) – Repeat as needed**
- **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***

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 ← *Knows all Plans by Heart***
  - **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* – Formal Project Records**
  - **Prepare *Risk* Metrics and *Risk* Communications**
- **Project Manager and Chief Systems Engineer**
  - ***Communicate Risk* Metrics and Overall Project *Risk* Posture**
  - **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**

Tips for the Risk Manager

- **Put all management plans in a database for easy identification of new *Risks*.**
- **Only Close a *Risk* if:**
  - **Realized and becomes a problem**
  - **Becomes OBE (overcome by events)**
  - **Or, found addressed in the management plans.**
- **Require a formal project record to close a *Risk.***
- **Distinguish between Open and Active *Risks***
  - **Open means that it has not been Closed**
  - **Active means "The" Decision has not been made, or that it is actively being monitored and/or mitigated.**
  - **Revisit all Open *Risks* at major milestones**

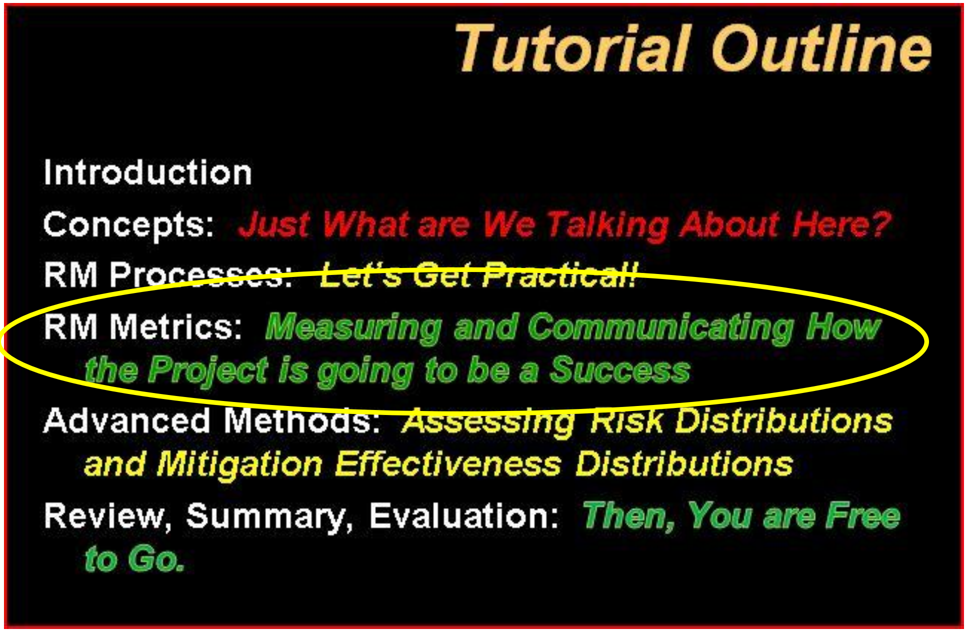
Where does All the Time and Money Go?

- **95+% of Resource (Budget and Schedule) Expenditures on *Risk* Management (all from allocated *Risk* Margin)**
  - **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 by Project Teams – *Pulled Away from Normal Job* (90+%)**
  - **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 Programs are for *risks Unanticipated* at Start of Program (management plans should address all anticipated *risks*)**
- **Operate *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**
- **Message to upper management and customers: *Risk Management Saves Projects from Failure***

RM Metrics:
Measuring and Communicating How the Project is going to be a Success



- **The Problem with *Risk* Management**
- **INCOSE RMWG Proposal**
- **Selected RM 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 succeeds, 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 fails, 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**

(Contact me for 2005 Paper)

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**

Selected Metrics

- **Effectiveness**
- **Efficiency**
- **Trending**

The Effectiveness Metric

- **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**

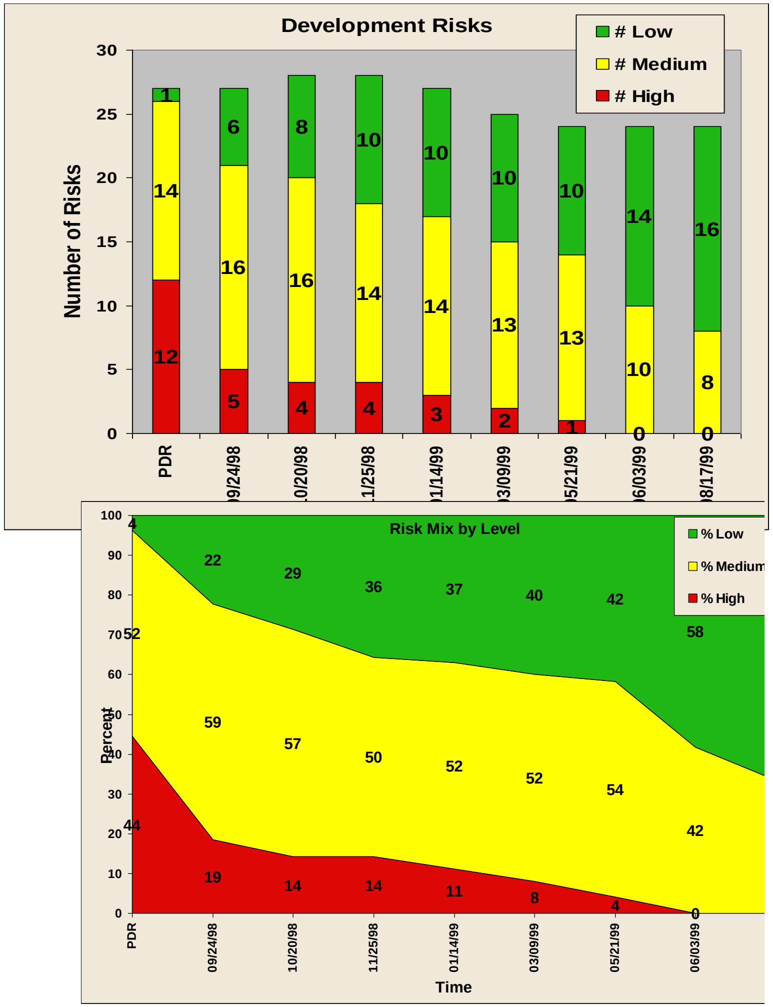
The Efficiency Metric

- **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 (or OBE) *Risks*, P_e, Process efficiency, is the average time lapse between all *Risks*' identification date, T_{ID}, and the time that it is realized or becomes OBE, T_R,**

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

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

Trending Metrics



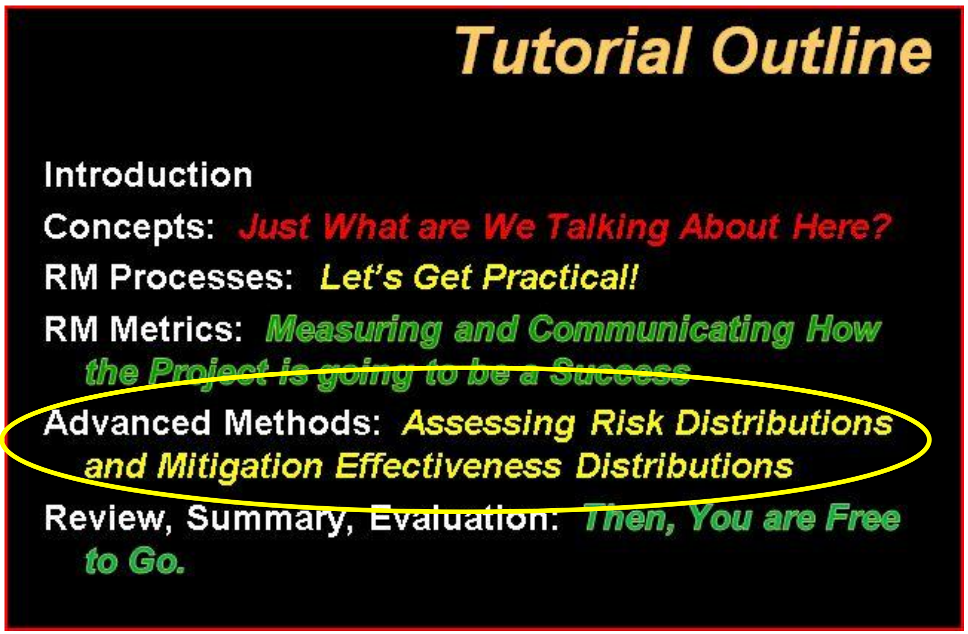
- Body Count versus time
- Reflects *Risk* Level changes with time
- *Goodness* is more vague on this one
  - No change is *bad*
  - Increasing *Risks* numbers may be *bad*
  - A decreasing trend in the red and yellow is *good*
- Action: direct project management attention to insure actions

Important Heuristic on Trending Metrics

- **Active Body Count: Any project that has more than 12 Active *Risks* is in Trouble.**
- **What do we mean by Active?**
  - **A *Risk* has been identified as new, and open, but "The" Decision has not been made.**
  - **Actively being Monitored and/or Mitigated**
  - **Accepted Risks are Open but not Active**
- **Open Body Count: Charts on previous slide should be swamped by Green.**

Advanced Methods:

Assessing Risk Distributions and Mitigation Effectiveness Distributions



- ***Risk*** **Assessment Distributions**
- **Predictive Mitigation Effectiveness Distributions**
- **Some Examples**

What is a Risk Assessment?

- ***Risk*** **Assessment always answers one simple question:**

> ***Based on the available data, how sure can we be that the Risk is Unacceptable (or Acceptable)?***

- ***Risk*** **Assessment is almost always practiced as purely Qualitative (can be calculated *Mentally*)**
  - **Points from Seat of the Pants, Shoot from the Hip, Best Engineering Judgment (SWAG), or just a guess (WAG)**
  - **Usually, Points are Mean Estimates, but may be any Point Estimate (*Medians* or *Modes* are common)**
  - **Assurance is always Shoot from the Hip, Best Engineering Judgment (SWAG), or just a Guess (WAG), and Almost Always ad Hoc – a guess at Just HOW Sure**
- **Qualitative *Risk* Assessment may be appropriate - if the decision maker (Project Manager, Chief Systems Engineer, IPT Lead, etc.) is *very experienced* in the field of the *Risk* (the consequence)**

> ***Qualitative always equates to Personal.***

Why Not Quantitative Risk Assessments?

- **Quantitative *Risk* Assessments**
  - **Statistically process the available data to produce a probability distribution for the *Risk* level**
  - **The *Assurance* that the *Risk* is Unacceptable (or Acceptable) can be calculated from this distribution.**
  - **Unfortunately, no COTS stats packages can produce Quantitative *Risk* Assessments, definitely *not without a lot of very questionable assumptions*.← *Now Qualitative!***
  - **Up until about 1995, *Impossible* to do Quantitative *Risk* Assessments properly for real world problems, *especially not without a lot of very questionable assumptions*. ← *Made them Qualitative!***
  - **Skills to perform Quantitative *Risk* Assessments correctly are difficult to find.**

Quantitative Risk Assessment: Auto Example

- **Soon to be available Zeus 5000 SUV – 100,000 mile drivetrain warranty already announced**
- **Sales price still TBD**
- **How much we add to the sales price to cover warranty repairs depends on how sure we can be of the number of Zeus 5000's that will fail in 100,000 miles.**
- **Designed for 95% reliability at 100,000 miles**
- **How sure can we be that the Zeus 5000 SUV will have 95% reliability at 100,000 miles?**

Classic Problem!!!

That Rascally Zeus 5000

- **We can run a test and collect failure and survivor data for the Zeus 5000.**
- **We can use that data to answer the question Quantitatively.**
  - **If very very sure Zeus 5000 reliability is 95% or higher, can keep the price low.**
  - **If not so sure, then price may have to increase.**

The equation we have to solve:

$$Risk \text{ that } R(T) < R_c(T) \mid data = P\left(R(T) < R_c(T) \mid data\right)$$

$$= \int_0^{R_c(T)} pd\left(R(T) \mid data\right) dR(T) \qquad \mathbf{= f(data)}$$

$$\propto \int_0^{R_c(T)} pd\left(\int_T^{\infty}\left\{\int_0^{\infty}\int_0^{\infty}\left[\left(\frac{\beta}{\eta}\right)\left(\frac{t_f}{\eta}\right)^{\beta-1} e^{-\left(\frac{t_f}{\eta}\right)^{\beta}}\right]\left[\prod_{i=1}^{N}\left(\frac{\beta}{\eta}\right)\left(\frac{t_{f_i}}{\eta}\right)^{\beta-1} e^{-\left(\frac{t_{f_i}}{\eta}\right)^{\beta}}\right]\right.\right.$$

$$\left.\left. * \left[\prod_{j=1}^{M} e^{-\left(\frac{t_{s_j}}{\eta}\right)^{\beta}}\right]\left(\frac{1}{\eta}\right)\left(\frac{1}{\beta}\right) d\eta\, d\beta\right\} dt_f\right) dR(T)$$

where: $R_c(T)$ is the critical reliability at service life T, and

$data$ is the set of product failure service lives $\left\{t_{f_1}, t_{f_2}, \cdots, t_{f_N}\right\}$ and

the set of service lives for products that have not failed $\left\{t_{s_1}, t_{s_2}, \cdots, t_{s_M}\right\}$

Full derivation of the equation can be found at:

http://nomtbf.com/2012/07/whats-all-the-fuss-about-bayesian-reliability-analysis-2/

Full Disclosure

- **I cannot solve that equation analytically.**
- **I am not alone.**
- **Nobody else on planet Earth (or in LEO space), not even with ordinary numerical methods, including ordinary Monte Carlo, can either.**
- **But it can be solved numerically using Markov Chain Monte Carlo methods (coming up).**

Qualitative or Quantitative Risk Management?

- **Unless Quantitative *Risk* Assessments are used, it *IS* Qualitative *Risk* Management**
- **Qualitative RM may be good enough!**
- **However –**
  - **If there exists a *lot* of data, or**
  - **If the consequences can be *severe***

Quantitative Risk Management may be Worth the Effort!

Predictive Mitigation Effectiveness Distributions

- **A very important question is how much *risk* reduction will the proposed mitigation produce?**
  - **Uncertain of course, the mitigation is not done**
  - **But distribution of mitigation effectiveness is predictable, even without getting data.**
- **Future mitigation data is of course uncertain, but we can do a Quantitative *Risk* Assessment on what that mitigation data might turn out to be!**
- **Feed those mitigation data distributions into a Quantitative *Risk* Assessment for our *Risk*, and we can see how sure we can be that mitigation will achieve a specified level of *risk* reduction.**

Does that sound a bit Incestuous?

- **Formally called developing a Pre-Posterior distribution**

  The result is the Preposterous distribution!
- **The basis for Value of Information analyses – EVPI, EVII, EVIU, etc.**
- **But with the full Quantitative Preposterous distribution, we can calculate how sure we can be that we will get a specified level of mitigation effectiveness.**

Would that help making "The" Decision?

Why doesn't anybody predict Risk Mitigation Effectiveness?

- **Remember that rather nasty equation for the Quantitative *Risk* Assessment for the reliability for the Zeus 5000 SUV?**
- **The equations for Quantitative Predictive Mitigation Effectiveness add another couple of layers of integrals.**
  - **These equations cannot be solved analytically either.**
  - **These equations cannot be solved with ordinary numerical methods, including ordinary Monte Carlo.**
  - **But they can be solved numerically using Markov Chain Monte Carlo methods (coming up).**

A Recent Advancement: Markov Chain Monte Carlo

- **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, can keep it Quantitative instead of going Qualitative, purely *f(data)***
  - **All data types can be fused into the assessment and used effectively, *including Censored data and Heuristics***
  - ***No need to ignore outlier data***

An Aside: Monte Carlo

- **Monte Carlo is nothing more than a numerical method to obtain an approximate solution for a definite integral.**
- **In general, can be used to obtain approximate solutions for integral transforms.**
- **Remember that rather nasty equation for the Quantitative *Risk* Assessment for the reliability for the Zeus 5000 SUV?**
  - **Lots of integrals and integral transforms**
  - **Impossible to solve analytically, and with ordinary Monte Carlo**
- **Monte Carlo requires joint samples from the integrand over the full domain in frequencies proportional over the range of the integrand.**
- **Ordinary Monte Carlo gets these samples from built-in random number generators. Very Limited.**
- **If the integrand does not have a built-in random sampler, cannot use ordinary Monte Carlo to solve the integral.**

Markov Chain Monte Carlo

- **A *More General* version of Monte Carlo**
  - **MCMC does *not* require recognizable defined sampling models – uses a Markov Chain to sample the integrand**
  - **Will work with analytically intractable integrals**
  - **Can work for *Very High Dimensional Integrals* (up to 20,000 related sources of uncertainty)**
  - ***Simple Algorithms* to code, but not amenable to packaging as a commercially available tool – requires manual interactions to tune the Markov chain**
- **When used in *Risk* Assessment, provides Full Quantitative Assurance of *Risk levels* for the most complicated real world *Risk* Assessment problems**

A Second not-so-recent Advancement

- **Models of Objective Uncertainty – derivable three ways for every *risk* problem by finding the uncertainty model that:**
  - **Minimizes the Fisher information (Jeffreys, 1930's)**
  - **Maximizes the information entropy (Lindley and Savage, 1960's)**
  - **Or, Maximizes the EVPI (Bernardo and Smith, 1990's)**
- **All three methods produce the same models for the same problem. – *is that ever comforting!!!***
- **Use instead of assumptions**
  - **Keeps personal values out of the equations**
  - **Avoids compounding personal *risk* averseness and *risk* tolerances**

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)
- NASA 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
- **Full Disclosure of Assumptions (*not really questionable*):**
  - **Zipper cycling cannot improve reliability of the CTB zipper**
  - **At least 62.4% of CTB failures will occur before 30,000 cycles**
- **No stated maximum acceptable *Risk* – so Parameterize**

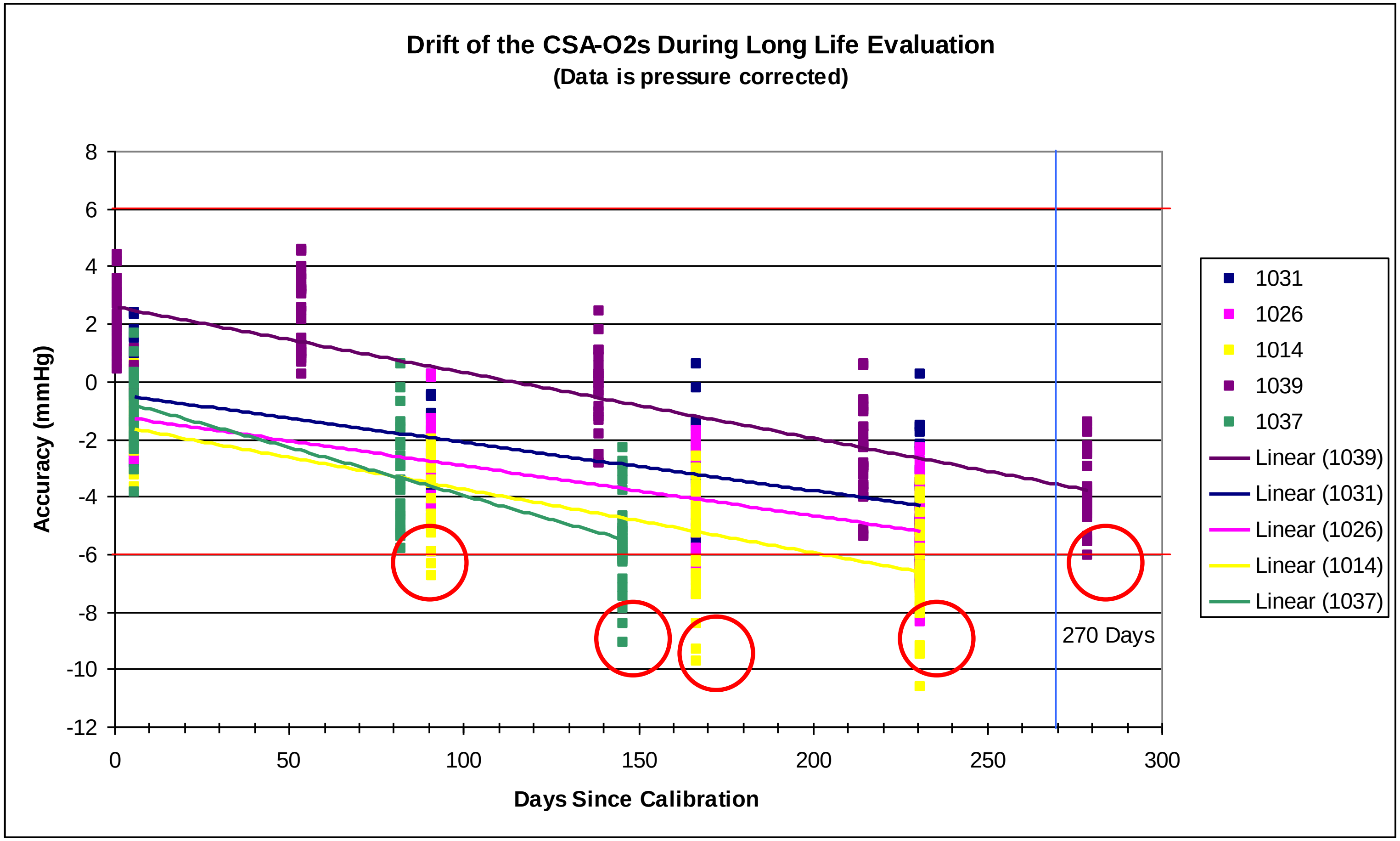
***Risk* of CTB Zipper Failure by 2K Cycles (R_{2K})**	**Assurance Provided by Test Results P(True $R_{2K} < R_{2K}$)**
1%	**75%**
5%	**88%**
10%	**94%**
20%	**98%**

Could Not be Solved Without Markov Chain Monte Carlo Methods!

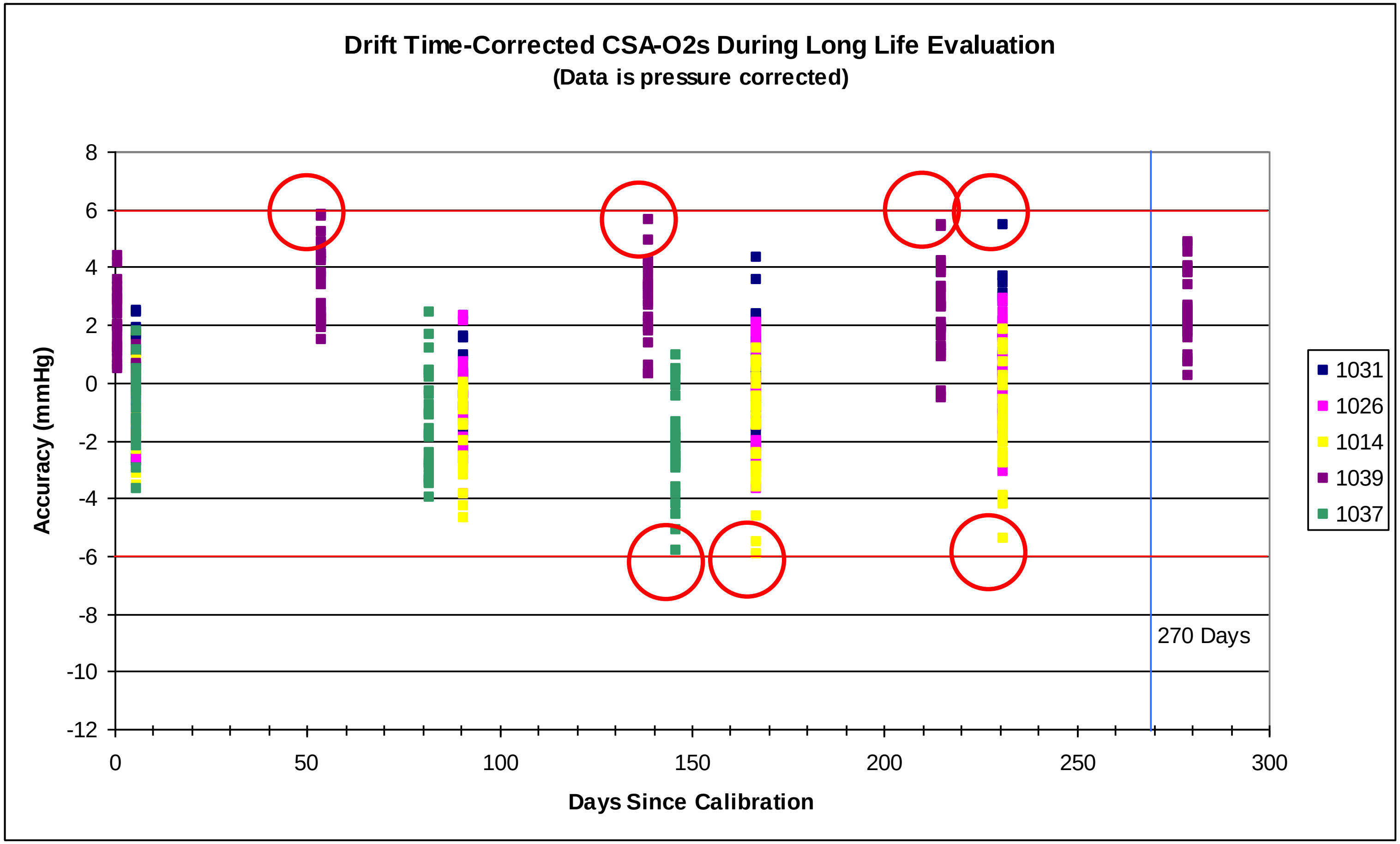
Example: ISS O_2 Sensor Drift

- **Problem: Space Station EVA Prep oxygen sensor measurement accuracy is observed to *drift* with time**
  - **If the measured O_2 is in error by more than ±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?**

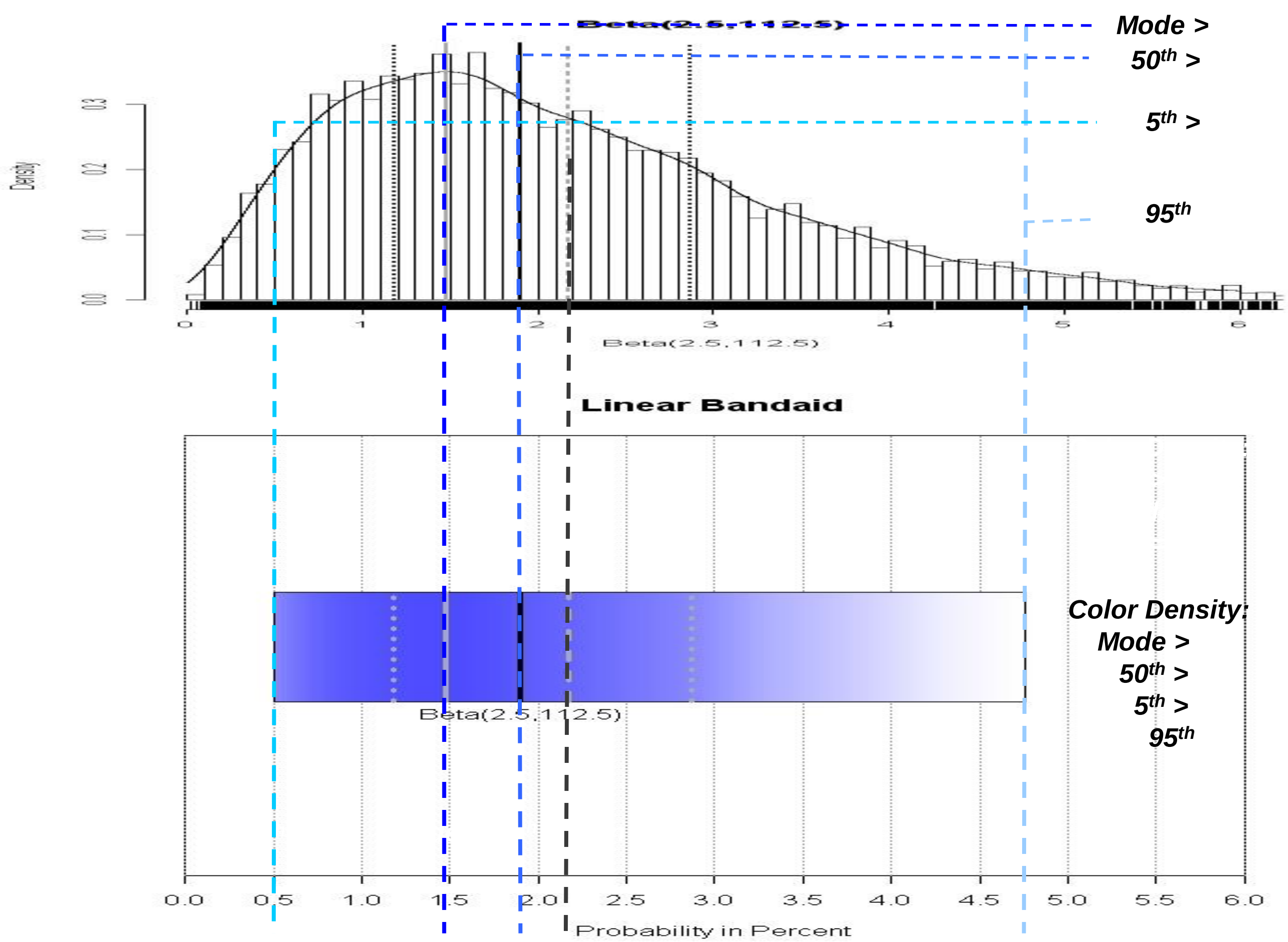
O_2 Sensor Test Data



Drift Corrected O_2 Sensor Data



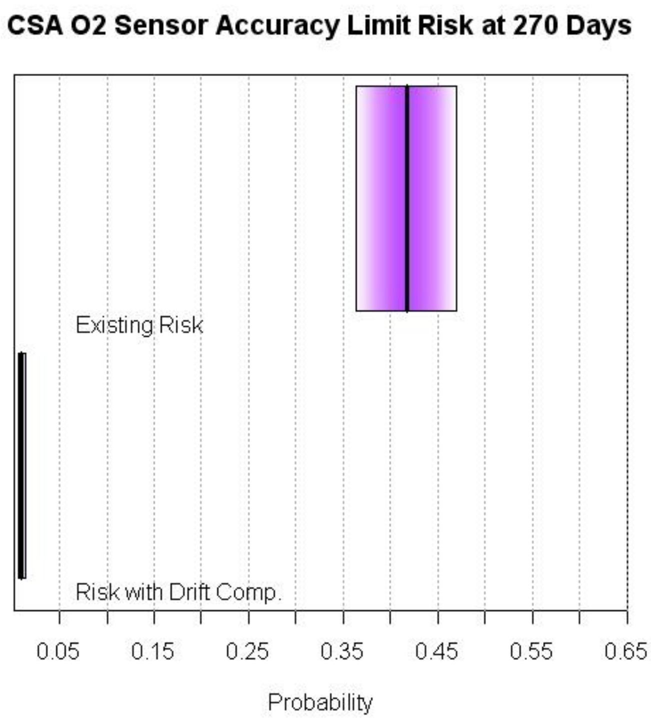
Aside: Risk Density Strips



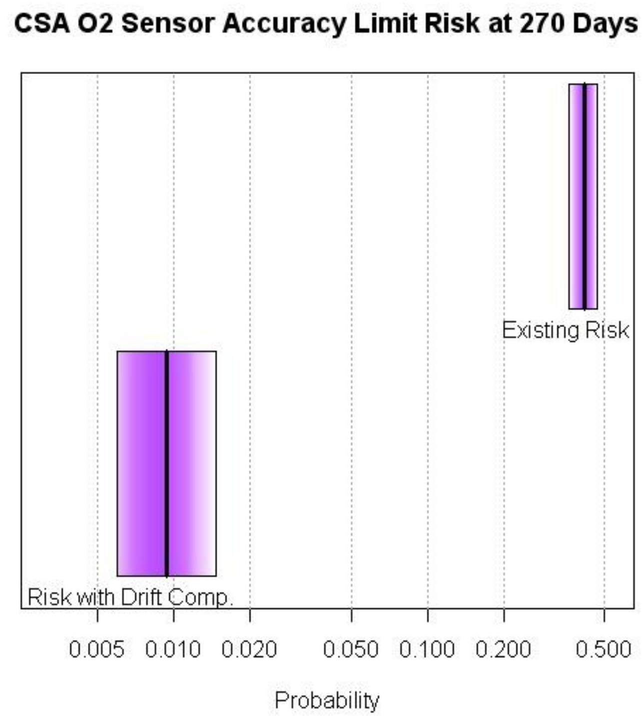
- Great way to display *Risk* distributions
- Great for comparing *Risks*
- Left side at 5%
- Right side at 95%
- Color density proportional to probability density
- Bar at Mode or Median helps

Risk Density Strip codes available free on www.attwaterconsulting.com

O_2 Sensor Risk: Before and After Drift Correction



Linear Scale



Logarithmic Scale

O_2 Sensor Risk Summary

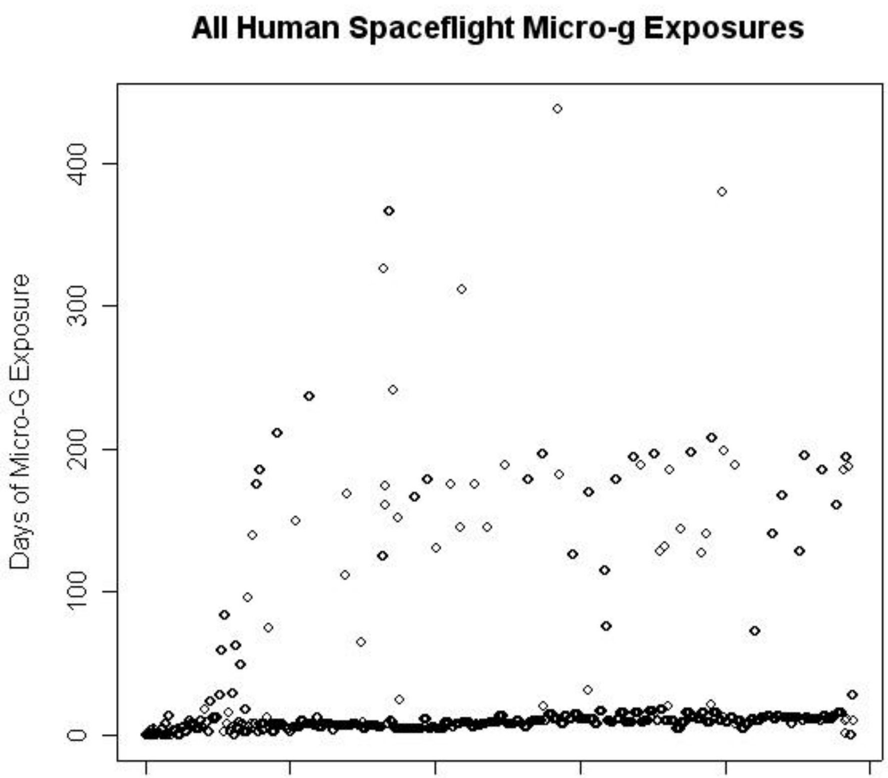
- **Without drift compensation, *Risk* of exceeding accuracy limits at 270 days is 36-46% (with *90% assurance*)**
- **With drift compensation, *95% Sure Risk* of exceeding accuracy limits at 270 days is < 1.5%**
- **Additional O_2 level compensation could reduce *Risk* further**
- ***No Assumptions Needed***

Could Not be Solved Without
Markov Chain Monte Carlo Methods!

Example: Astronaut Bone Fracture Risk

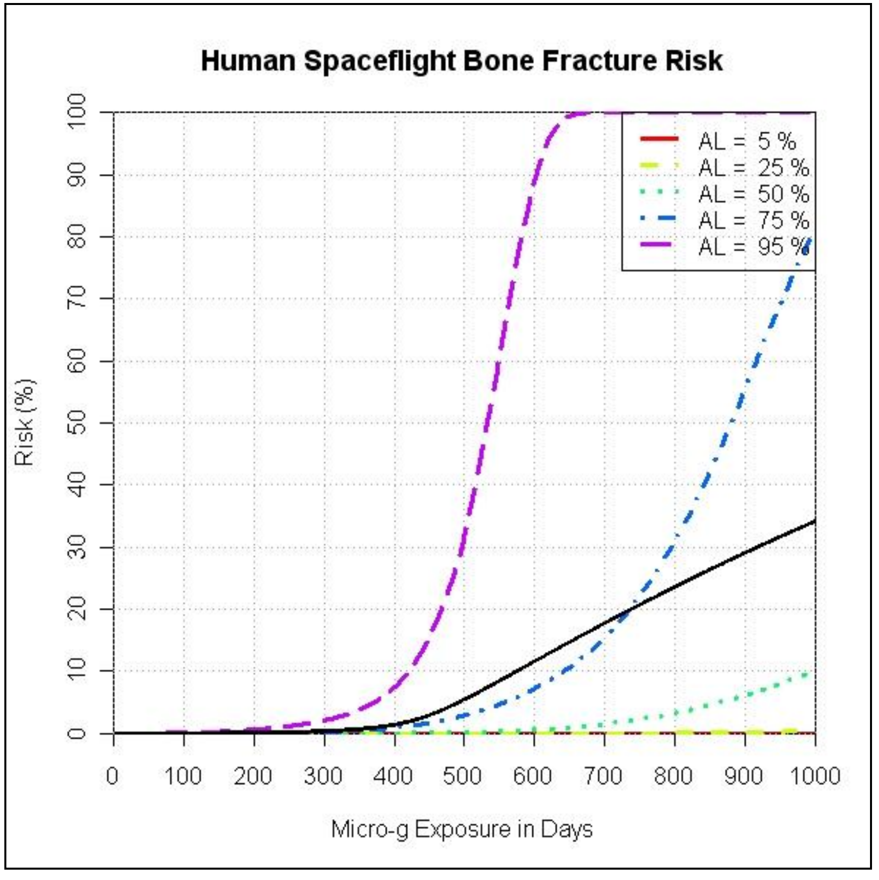
- **On-orbit astronaut bone fractures could have severe consequences.**
  - **To the Astronaut**
  - **To the Mission**
- **Very low probability event – No astronaut has ever broken a bone during a μG mission in history.**
- **Example *Risk* Questions**
  - **What is the *Risk* of bone fracture for long Mars missions?**
  - **How much will the *Risk* increase if International Space Station missions extend from 180 to 365 days?**

The Available Information (the data)



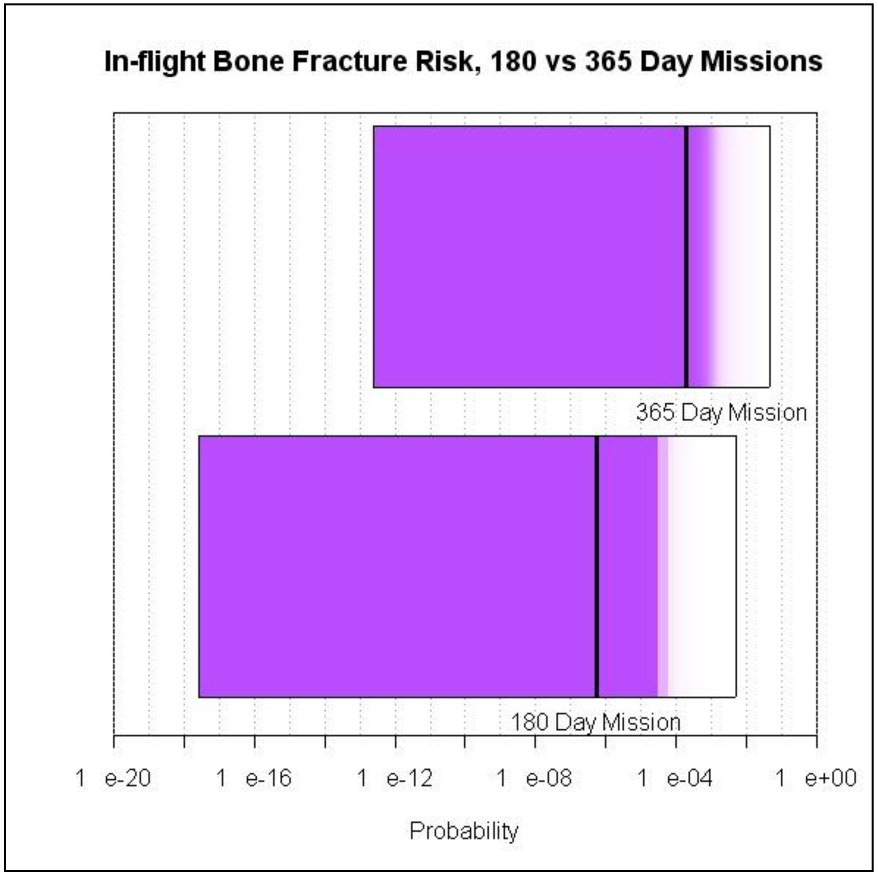
- **977 astronaut μG missions of varying lengths (as of May 2005)**
- **No events observed**
  - **No bones broken**
  - **Did observe 977 μG missions without a broken bone**

Risk Results Parameterized for μG Mission Duration



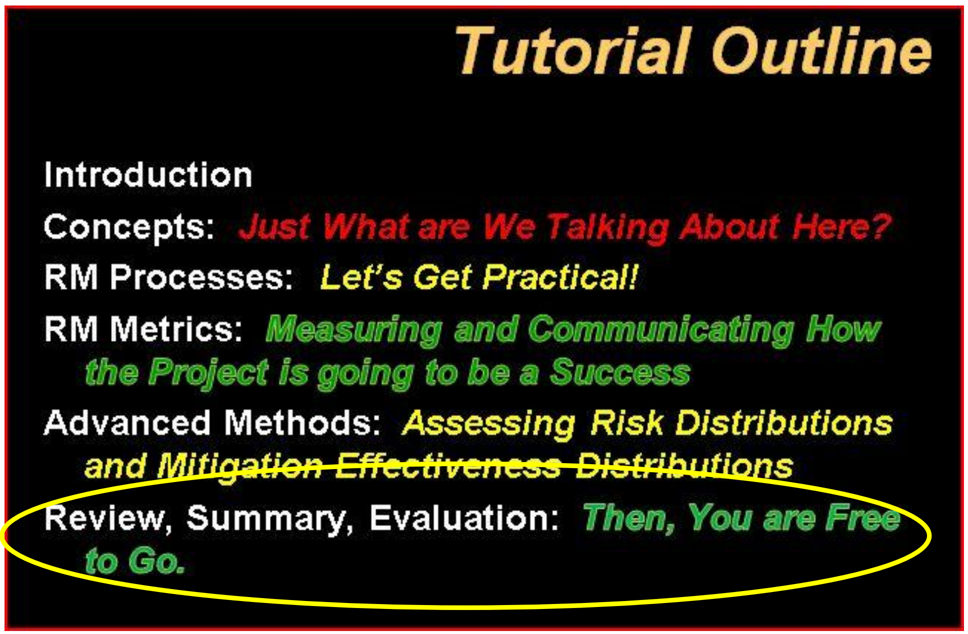
- **Plotted various assurance levels**
- **As a function of μG mission duration**
- **For Mars missions of 270 days – we can be 95% certain that *Risk* of fracture during the mission is < 3%, based on the information available**
- **Quantified result consistent with *Intuition!***

The ISS Mission Extension Question



- *Risk* Density Strip legend
  - Left side at 5th quantile
  - Right side at 95th quantile
  - Color density proportional to probability density
  - Black bar at median (50th quantile)
- Can you feel better about making such a decision?

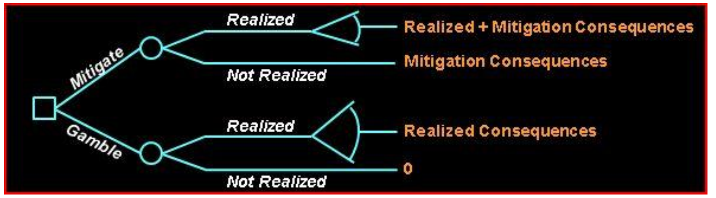
Evaluation, Review and Summary



- **Evaluation Forms**
- **Review and Summary**
- **Contact Information**

Review and Summary 1

- ***Risk*** **Management is pretty complex**
  - **Only looking at *risks* NOT identified before project start and NOT addressed in management plans**
  - **RM strategies depend on contract type, among many other factors**
- **Every *Risk:* "The" Decision**



- **It gets personal**
  - **Decision Maker Values**
  - **Should not let *Risk* analyst values affect results**
- ***Risks*** **and *Risk* Management and Values are never Stationary**

Review and Summary 2

- **Seven RM Processes**
  - ***Risk* ID is part of everybody's normal job**
  - ***Risk* Analysis, Assessment, and Mitigation consume 95% of RM resources**
- **Closed, Open, and Active *Risks* < *12 Active!***
- ***Risk* metrics: evidence we are saving the project!**
- **Qualitative vs. Quantitative**
  - **If assumptions are used, or any other guesses, it is Qualitative *Risk* Assessment**
  - **Quantitative *Risk* Assessment does not involve anybody's personal values or *risk* tolerances**

Review and Summary 3

- **MCMC and Objective Uncertainty Models allow us to do proper Quantitative *Risk* and Mitigation Effectiveness Assessments**
  - **Easy to Make “The” Decision**
  - **Actually, very easy to produce Quantitative *Risk* and Mitigation Effectiveness Assessments using MCMC**
- ***Risk Management Saves Technical Projects from Failure!***

Contact Information

- **Numerous published papers, references, and free codes at www.attwaterconsulting.com**
- **Always looking for new, exciting, and challenging problems to solve so I can write more papers**
- **Contact Me!**
  - **e-mail: mark.powell@attwaterconsulting.com**
  - **Telephone: +1 208 521 2941**
- ***Link with me*: http://www.linkedin.com/in/attwatermarkpowell**

Additional Useful Material not Presented

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**
  - **Vehicle and Crew are *More Important* than Experiments**
  - **If *Assurance Level* (for $P(coll) > 10^{-4}$) > 10%, Then Maneuver**
- ***Strategy 2:* Minimize Experiment Disturbance/Replanning**
  - **Experiment and Replanning Costs *More Important* than Vehicle and Crew**
  - **Don't Maneuver *Unless Assurance Level* (for $P(coll) > 10^{-4}$) > 90%**

Common Risk Pitfalls

RM Pitfalls

- ***Pitfall:*** **Managing Disadvantageous (Risks) and Advantageous (Opportunities) Separately**
- ***Solution:*** **Manage Both *Together*; If Some Manager wants it Separate, Report Separately, but Manage Together**
- ***Pitfall:*** **Calling Risk Management *Quantitative* when Really *Qualitative***
- ***Solution:*** **Be *Honest* – Managers will Lose Faith Otherwise; Don't Use Misleading Terms like Semi-Quantitative**
- ***Pitfall:*** **Ignoring the Advantageous Side of a Risk Consequence**
- ***Solution:*** **Include the Potential Advantageous Consequences**

More RM Pitfalls

- ***Pitfall:*** **Managing "Programmatic" Risks Separately**
- ***Solution:*** **Manage All Risks with the Same System; Have Systems Engineering Perform all Risk Management**
- ***Pitfall:*** **Failing to Establish Risk Margins for Schedule and Budget**
- ***Solution:*** **Re-schedule and Re-budget to Establish Risk Margins**

Even More RM Pitfalls

- ***Pitfall:*** **Using Risk Margins for Something besides Risk Analysis, Risk Assessment, and Risk Mitigation**
- ***Solution:*** **Manage with Some Discipline; Never Use or Release Margin unless the Risks become OBE**
- ***Pitfall:*** **Using Point Estimates of Risk**
- ***Solution:*** **Plot Risk Distributions, not Means or Variances**
  - **All Risk Assessments, even Qualitative, Produce a Risk Distribution**
  - **Quantiles Work Well**

Yet, Even More RM Pitfalls

- ***Pitfall:*** **Probability Value Numerical Distortions**
  - **Relative vs. Absolute**
  - **1.3e-5 is 30% More than 1e-5**
  - **1e-6 is 1,000 times More than 1e-9**
- ***Solution:*** **Be very Careful with Probability (or Risk) Comparisons**
  - **Most of us Only Handle Probabilities in the Deciles Well**
  - **Most of Our Project Risks should have Low Probabilities**
- ***Pitfall:*** **Treating Consequences with Different Units the Same**
- ***Solution:*** **Attempt Multi-Attribute Utility Approaches**

Qualitative Risk Assessment Pitfalls

- *Pitfall:* **Forgetting or Ignoring or Not Revealing Assumptions**
- *Solution:* **Be Forthright about All Assumptions**
  - **Managers always Question Assumptions**
  - **Parameterize Risk Assessment based on Distributions of Assumptions**
  - **The Independence Assumption *Always* Adds Conservatism**
- *Pitfall:* **Forgetting that Engineers are Notoriously Conservative when Providing Assessments**
- *Solution:* **Don't Take the First Qualitative Assessment**
  - **Drill Down to Understand *The Why***
  - **Parameterize The Engineer's Qualitative Assessment**
  - **Or, Use *Quantitative* Risk Assessment**

Risk Roll-up Pitfalls

- ***Pitfall:*** **Using Risk Assessment Point Estimates in Roll-ups**
- ***Solution:*** **Roll-up Risk Distributions**
  - $\mu_A \neq (\mu_B^2 + \mu_C^2)^{1/2}$
  - **Monte Carlo Techniques Have to Be Used**
  - **Be Careful with Assumed (Qualitative) Risk Distributions**
- ***Pitfall:*** **Forgetting Multi-Attribute Utilities in Roll-ups**
- ***Solution:*** **Scale Differing Unit Consequences According to Decision Maker Values using Multi-Attribute Utilities**

Decision Maker Pitfalls

- **The Entire Point of Risk Management is to *Enable Good Decisions***
- **Risk Management Can be Performed to Minimize Decision Maker Pitfalls**
- **The List of these Pitfalls for Risk Management**
  - ***Focusing* on *Extreme* Consequences**
  - **Excessive *Optimism***
  - **Use of *Fudge* Factors to Account for *Risk***
  - ***Decision Paralysis* from too *few* Data**
  - **Reliance on *First Impressions***
  - **Fear of Change**

More Decision Maker Pitfalls

- **Letting *Sunk Costs* Influence your Decision**
- **Seeing only *Confirming Evidence***
- ***Framing* the Problem for the Answer wanted**
- ***Overvaluing* Prediction Capabilities**
- ***Neglecting* Relevant Information**
- **Seeing *Patterns* in *Randomness***
- **Assigning *Reasons* for *Coincidences* or Observing *Rare Events***