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DEFINING THE FUTURE

Statistical Control of System and Software Design Activities

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Topics

- **Organizational overview**
- **The challenge of SPC early in the life cycle**
- **Practical difficulties & how we addressed them**
  - Process selection
  - Data rates
  - Statistical innumeracy
- **Ongoing issues**

- **Math details (for reference only)**

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Corporate Overview

- **Comprehensive business portfolio to address the defense and government markets**
  - Systems integration
  - Military aircraft
  - Unmanned aerial vehicles
  - C4ISR
  - Defense electronics
  - Information technology and networks
  - Naval shipbuilding
  - Space and missile defense
- **2005 sales of $30.7 billion**
- **125,000 people; 50 states; 25 international countries**
- **Headquartered in Los Angeles, CA**

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Northrop Grumman Integrated Systems

Electronic Systems
Jim Pitts
President

Information Technology
Jim O'Neill
President

Integrated Systems
Scott Seymour
President

Newport News
Michael Petters
President

Ship Systems
Phil Teel
President

Mission Systems
Jerry Agee
President

Space Technology
Alexis Livanos
President

Tech Services
James Cameron
President

Western Region
Gary Ervin

AEW & EW Systems
Duke Dufresne

AGS & BM Systems
Alan Doshier
Leroy Barnidge
Deputy

Premier Aerospace and Defense Systems Integration Enterprise

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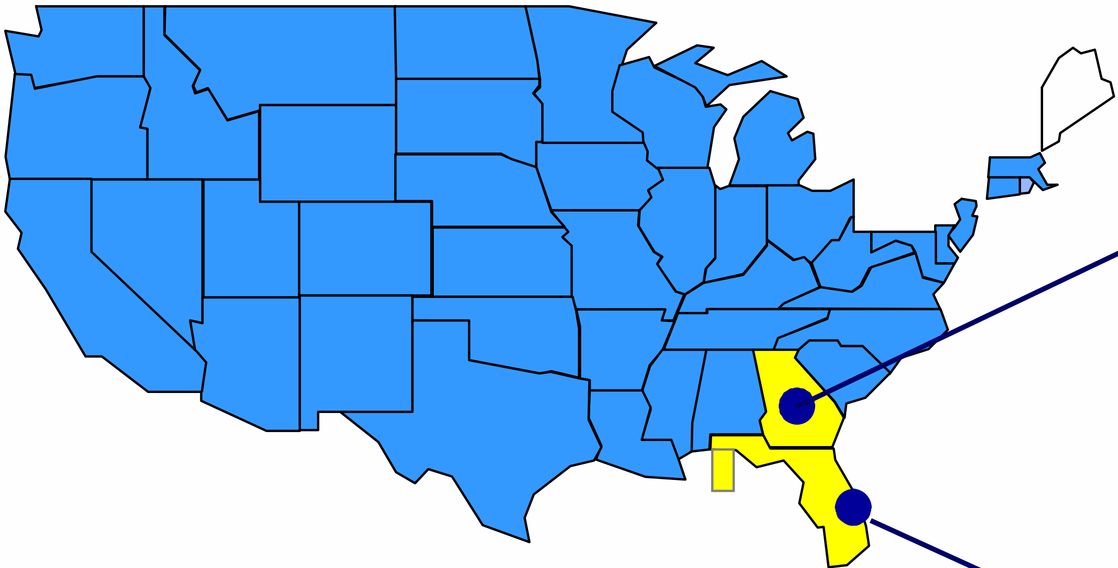
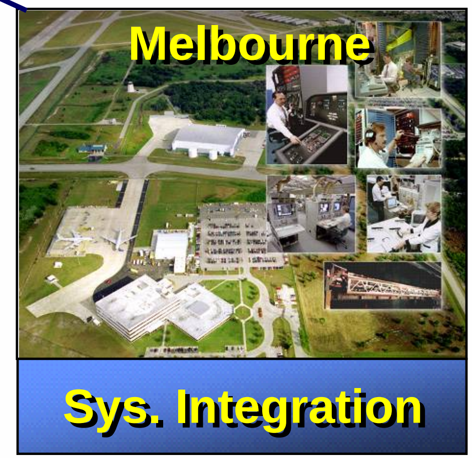
AGS&BMS Major Sites





Level 5 CMMI-SE/SW/IPPD/SS	6/06
Level 5 CMMI-SE/SW	4/05
ISO 9001:2000/TickIT	9/04

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Where We Were

- **First demonstration of CMMI℠ Level 4 and 5 capabilities focused on code inspections and peer review of test plans, procedures and reports**
  - High data rates inherent in these “back end” processes helped us to understand and overcome statistical difficulties
  - We gained practical lessons learned on the obstacles that had to be overcome
  - Senior author developed innovative log-cost model presented at 2005 CMMI℠ Technology Conference and User Group
- **Positive business benefit (& successful CMMI℠ Level 5 appraisal) resulted in strong senior management support to expand**

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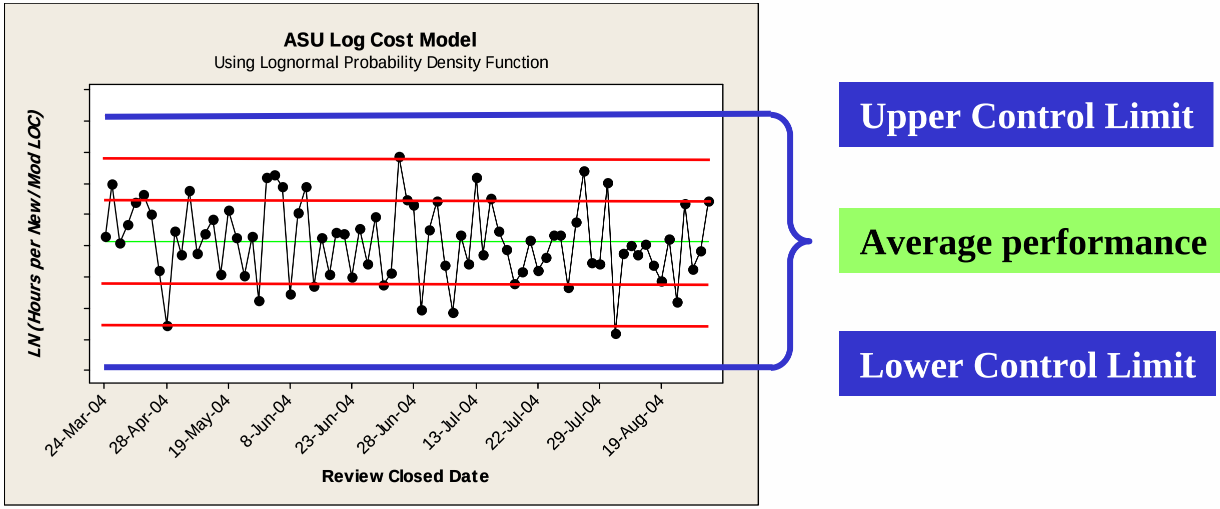
SPC Determines the Voice of the Process

Quantitative Project Management



A stable process operates within the control limits 99.7% of the time

Analysis of

- **Special cause variation** focuses on recognizing & preventing deviations from this pattern
- **Common cause variation** focuses on improving the average and tightening the control limits
  - Offering opportunities for systematic process improvement that NGC & industry benchmarks indicate will yield an ROI averaging between 4:1 & 6:1

Challenge

- **Desire to introduce successful SPC techniques for quantitative project management in the "front end" system and software design phases**
- **When coding starts**
  - Product development is one-half over
  - Opportunities to recognize and correct special & common cause variation in the design process are gone

DoD studies indicate first-year decisions determine up to 70% of total life cycle cost. Early, effective statistical control offers great practical benefit

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Practical Difficulties at Level 4

- **Getting started**
  - Selecting good candidates for statistical management
- **Little historical data & inherently low data rates**
  - Process model for successful statistical control
- **Statistical innumeracy**
  - Discipline needs to own the right skill set
- **Cautionary note: this assumes you have also taken care of the basics (CMMI^{SM} Level 3)**
  - Budget and charter
    - Project impacts
  - Metrics infrastructure across engineering
    - Metric definitions
    - Data collection mechanisms
    - Consistency of processes across projects

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Getting Started

Process Selection for Statistical Management

- **Statistical control is imposed on sub-processes at an elemental level in the process architecture**
- **Processes are selected based on their**
  - Business significance – "sufficient conditions"
  - Statistical suitability – "necessary conditions"
- **Business checklist**
  - Is the candidate sub-process a component of a project's defined "key" process?
    - Is it significant to success of a business plan goal?
    - Is it a significant contributor to an important estimating metric in the discipline?
  - Is there an identified business need for predictable performance as projects execute the subprocess?
    - Cost, schedule or quality

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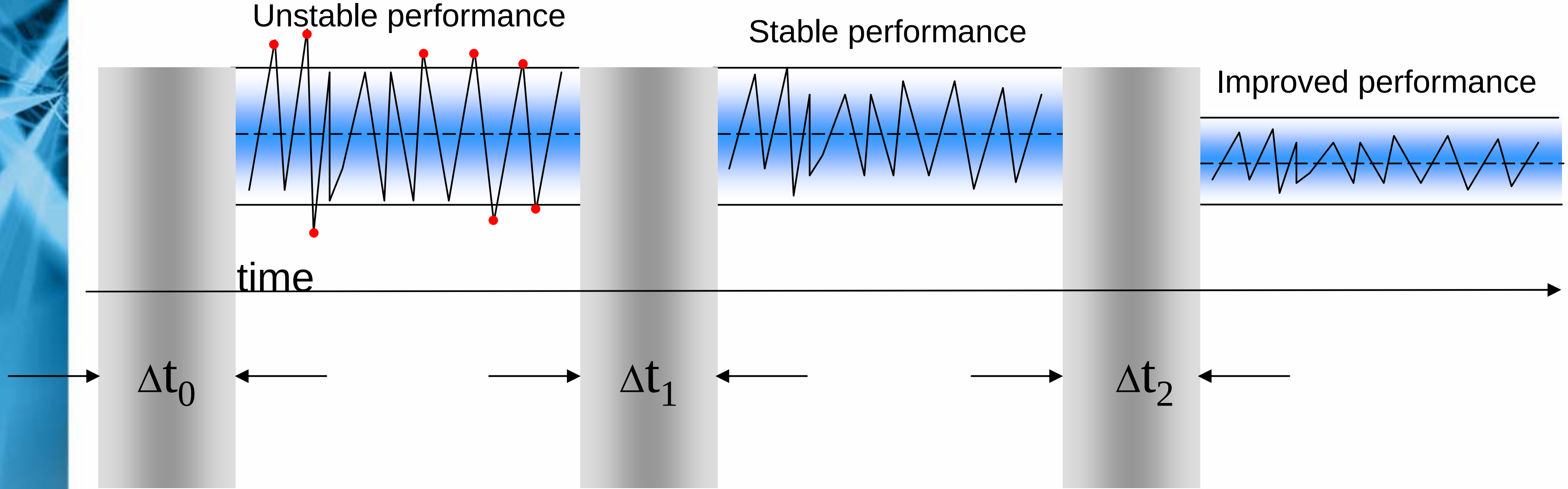
Statistical Checklist

PRINCIPAL FACTORS INVOLVED IN SUB-PROCESS SELECTION FOR STATISTICAL PROCESS CONTROL		
PRIMARY QUESTION	SUPPORTING QUESTION	DEMONSTRATED INDICATOR
Are data collected?	Does the data collection system require update or redeployment?	Data collection system ready for deployment
What is the data rate? That is, how often will the process be repeated on the project?	Will the process be repeated frequently enough to develop control limits if such limits do not exist from baseline historical performance?	At least 20-30 data points exist or will be produced
Are there historical performance data?	Stable performance: Will the process be performed in roughly the same manner as on previous projects?	A documented procedure or training materials are used by those performing the process
Has a control metric been identified?	Has statistical analysis of past project performance identified measures that are indicative of overall process performance?	Control metric can be computed from the collected data
Does a baseline exist for the control metric?	What are the average and statistical variation of previous performance?	Performance excursions outside the control limits can be identified & attributed to their root causes
Do specification limits exist for process performance? (Optional)	Do limits exist beyond which process performance is deemed unacceptable?	Specification limits are documented

The High Maturity Data Dilemma



Δt_0 :

- Process selection
- Analysis of suitability for SPC

Δt_1 & Δt_2 :

- Identify improvement proposals
- Evaluate & prioritize proposals
- Select improvement
- Pilot improvement
- Deploy improvement

We can minimize $\Delta t_{0,}$ Δt_1 & Δt_1 by careful management, but the length of the data runs will depend on the periodicity of the process itself

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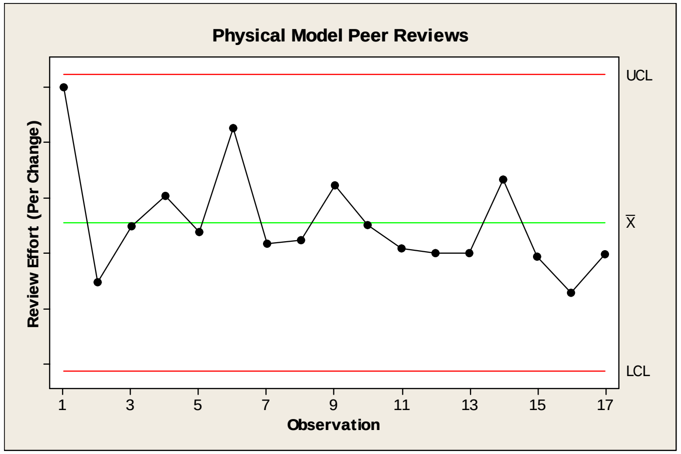
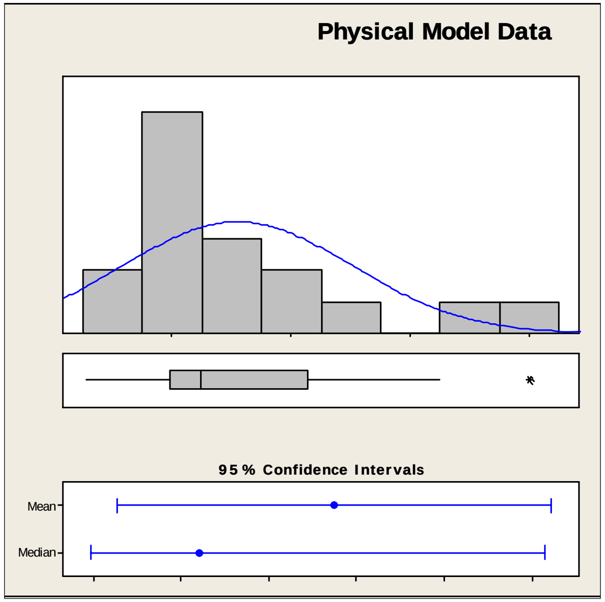
Reality at the Front End of the Life Cycle

- **9 candidate systems & software design processes identified for statistical management**
  - Small sample issues present
  - Control charts may look OK
  - Further analyses show data skews
  - How do we find the best model?



Anderson-Darling Test for Normality $p < 0.025$



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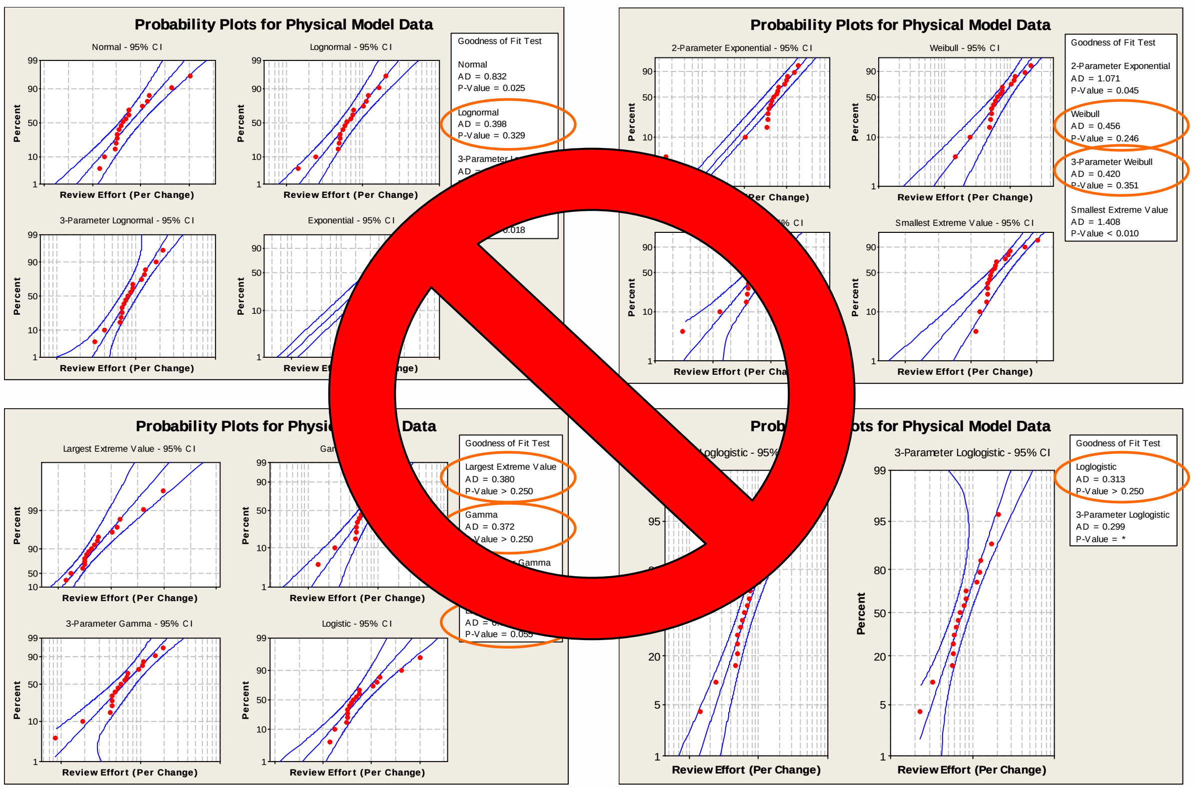
Finding the Right Model Is Not a Random Hunt!

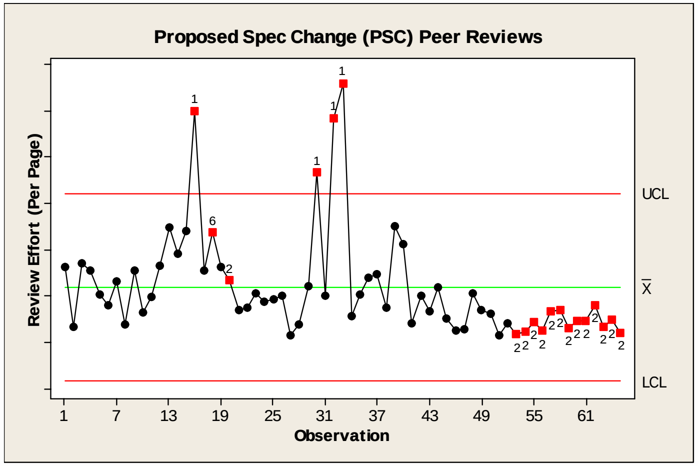
- **Minitab's Individual Distribution Identification tool**
  - 14 simultaneous goodness-of-fit tests



- **7 models "pass" – what next?**
- **What happens when you collect one or two more data points?**
- **In this case, one of the models is actually correct!**
  - But you'll never be able to prove it like this

More Data

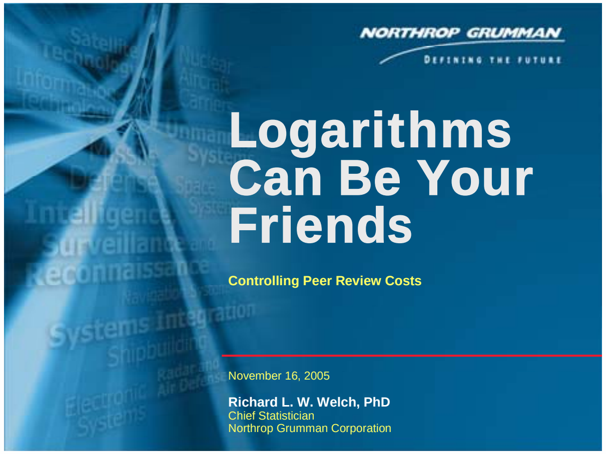
- **Larger samples don't solve everything**
  - How can you show this process is stable and in-control?
  - And if we can't control the effort, how can we compare defects in a meaningful way?



Anderson-Darling Test $p < 0.005$

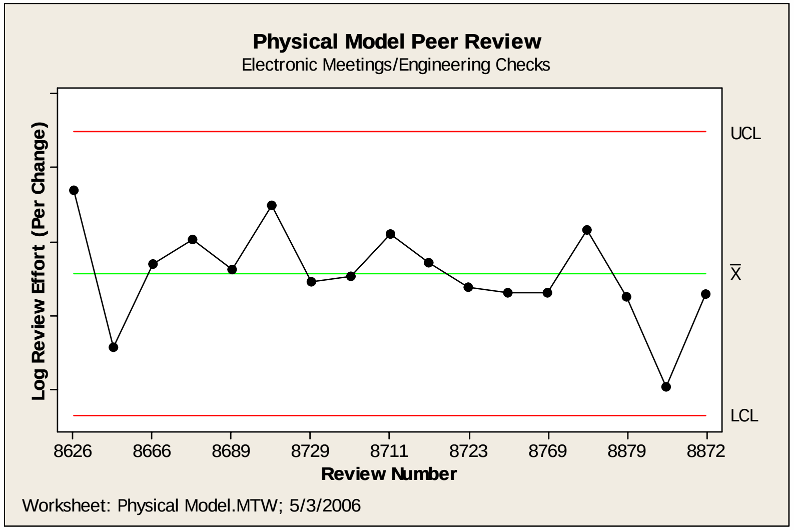
Stabilizing the Data

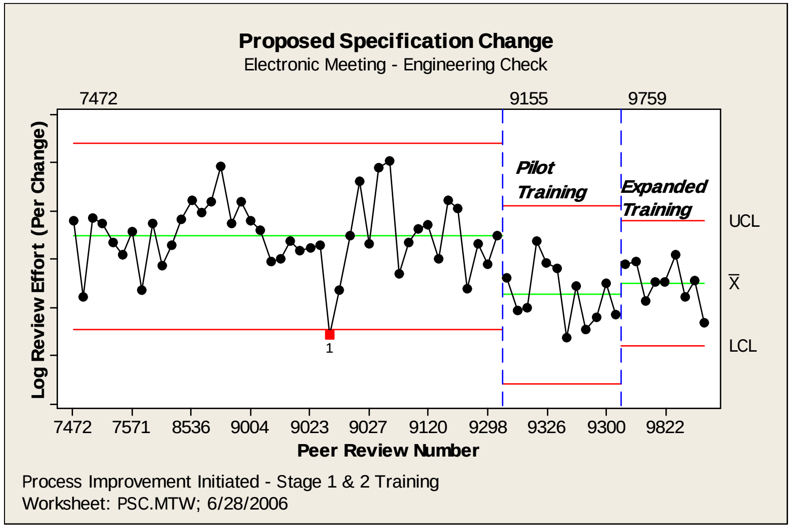
- **Senior author’s presentation at last year’s CMMI℠ Technology Conference demonstrated the applicability of a log-cost model to control software code inspections**



  - Peer review effort behaves like commodity prices in the short term
  - The math is applicable to any per unit “price” of a repeatable engineering effort
  - Using natural log transforms data to normal distribution

Log Transformed Series
Physical Model and PSC Examples





Anderson-Darling Test $p < 0.329$

Anderson-Darling Test $p < 0.919$

- **Can you eyeball the difference with slide 13?**

- **Did you realize slide 15 had**
  - 2 buried improvement cycles?
  - Only 1 special cause point - which wasn't flagged?

The Two Models Compared

Raw Data

- **11% false alarm rate (Chebyshev's inequality)**
  - *Penalizes due diligence in peer reviews*
- **No meaningful lower control limit**
  - *Does not flag superficial reviews*
- **Arithmetic mean distorts the central tendency**
  - *Apparent costs can exceed budget*

Log-Cost Transformation

- **False alarms minimized**
- **Meaningful lower control limit**
- **Geometric mean preserves the budget**
  - *OK, you still have to find the antilog*
- **Dramatically improves the evidence of stability and control**

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Overcoming Statistical Innumeracy

Success Factors

- **Minitab**
- **"Dark green belt" training**
  - Curriculum tailored to focus on applied statistical techniques and Minitab familiarity
  - Deming principle applied in the class room
    - In God we trust, *all others bring data*
  - Lean and process management training covered in other courses
- **Green belt community of practice**
- **Chief statistician**

Key success factor: management recognition & support for the investment

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Statistically Managed Processes

Systems & Software Baselines

- **System Engineering**
  - System design & system architecture peer reviews of
    - System threads
    - System model (structure diagrams)
    - Physical model
    - UML diagrams
  - System & software requirements peer reviews of
    - Proposed specification changes (PSCs)
- **Software Engineering**
  - Software design peer reviews of
    - Software threads
    - Physical model
    - Component/task descriptions
    - Data model
  - Software code inspections
  - Software build process
  - Software build returns
  - Software test returns

Most are applicable to early life cycle phases

Note: baselines highlighted in blue use the log-cost model.

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Statistically Managed Processes

Other Engineering Baselines

- **Test & Engineering**
  - Peer reviews of test plans, procedures & reports
  - System Integration Lab (SIL) scheduling
- **Avionics**
  - Discrepancy Inspection Report (DIR) processing
  - Avionics Drawing Sign-off
  - Field Service Engineering Request (FSER) processing
  - Management of seller issues
- **Vehicle Engineering**
  - Electro-mechanical drawing errors
  - Vehicle subsystems (i.e., crew & equipment) drawing errors
- **Logistics**
  - AF Tech Order (AFTO) processing of the
    - Total contractor schedule
    - LSA group schedule
  - Integrated electronic technical manual (IETM) delivered quality

Statistically managed baselines span all life cycle phases & engineering disciplines

Note: baselines highlighted in blue use the log-cost model.

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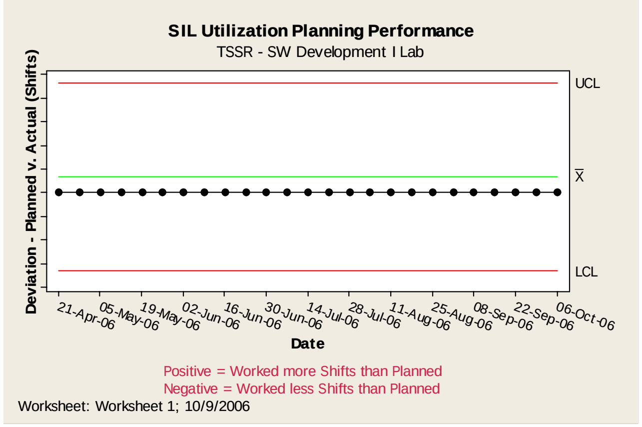
Ongoing Steps

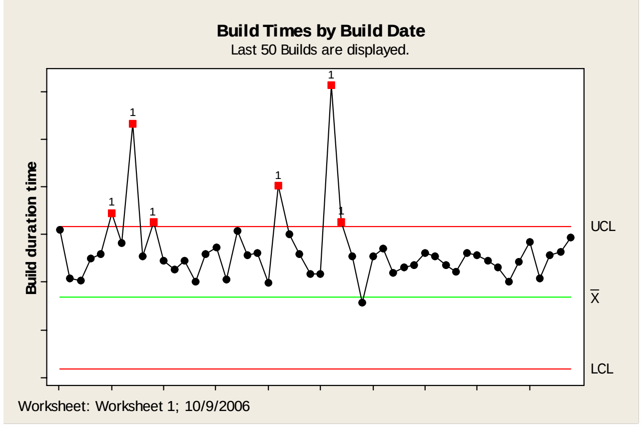
As a consequence of the successful expansion across all engineering disciplines and all life cycle phases, we have recognized the need to grow the infrastructure of trained, experienced statistical practitioners at the mid-level

- **Sector standards for certifying Green Belts, Black Belts & Master Black Belts**
  - Training
  - Project portfolio
- **Developing Black Belts cadre**
- **Future Master Black Belt cadre**

Pitfalls

- **Dealing with what was taught, but not learned in Green Belt class**
  - Monthly data won't work
    - It takes 20-30 months to accumulate 20-30 points
  - After-the-fact hypothesis testing is not a designed experiment
  - A time series is not a random variable
  - "Between the lines" doesn't mean in-control





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QUESTIONS

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Reference Slides

From Last Year’s Presentation

Math Details

- **Consider a stochastic process . . ., X_{-2}, X_{-1}, X_0, X_1, X_2, . . . that represents an asset price recorded over time, like a daily sequence of prices for shares of a stock or other commodity**
- **We assume at time t that the realization x_t of X_t is known, but the realization x_{t+1} of X_{t+1} is unknown**
- **The single-period log-return, $ln(X_{t+1}/x_t)$, is random and assumed to be normally distributed, at the given time t**
- **Under these assumptions, X_{t+1}/x_t is a lognormally distributed random variable, and therefore, so is X_{t+1}**

Math Details extracted from:
http://www.riskglossary.com/articles/lognormal_distribution.htm

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Salient Properties of the Model

- **When log-returns are normally distributed, the corresponding prices are lognormally distributed**
  - This model “is one of the most ubiquitous models in finance”
- **The distribution of log-returns and share prices have been validated empirically by many market studies accessible on the web**
- **For short time periods in a stable market, the mean return is 0**

Quotation from:
http://www.riskglossary.com/articles/lognormal_distribution.htm

Lognormal Density Function

$$f(x) = \begin{cases} \dfrac{\exp\left(-\dfrac{1}{2}\left(\dfrac{\ln(x)-\mu}{\sigma}\right)^2\right)}{x\sigma\sqrt{2\pi}} & x > 0 \\ 0 & x \le 0 \end{cases}$$

$$X \sim \Lambda[\mu, \sigma^2] \qquad Y = \ln(X) \sim N[\mu, \sigma^2]$$

$$E(X) = \exp(\mu + \sigma^2 / 2)$$

$$Var(X) = \left(\exp(\sigma^2) - 1\right)\exp(2\mu + \sigma^2)$$

Math details can be found in any standard mathematical statistics reference, see for example, http://en.wikipedia.org/wiki/Lognormal_distribution.