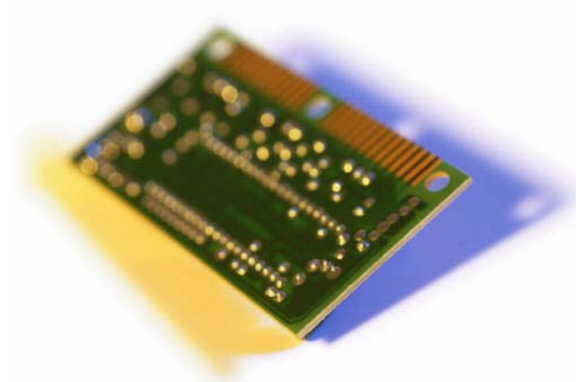

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Process Performance Models for Hardware Engineers

CMMI Technology Conference

November 15-18

Tom Fosness

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Northrop Grumman Corp., Electronic Systems Sector

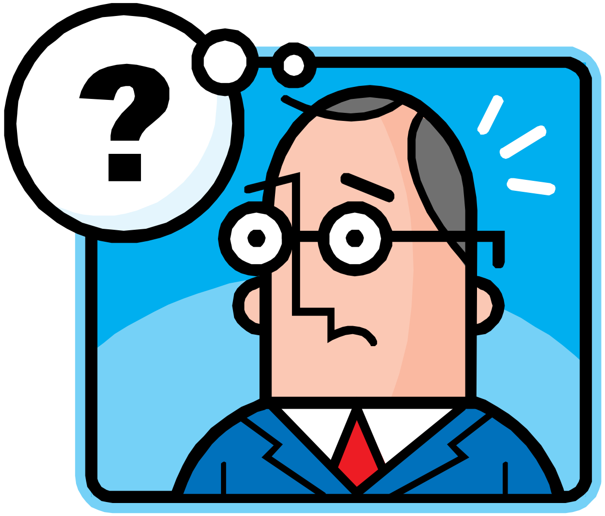
Rolling Meadows

First a Brief Story...

Work Product Inspection
Error Density Analysis

High Maturity???

Error Prediction and Removal
Process-Performance Model



Equivalent Effort
Source Lines of Code

Drawing Normalization

- Kind of drawing
- Number of Sheets
- Lines of Notes
- Drawing Originator
- Drawing Complexity

K	**S**	**L**	**O**	**C**
i	h	i	r	o
n	e	n	i	m
d	e	e	g	p
	t	s	i	l
	s		n	e
		o	a	x
		f	t	i
			o	t
		n	r	y
		o		
		t		
		e		
		s		

The Goals of this Presentation

- Goals
  - Give hardware engineers an idea of where to start when devising PPMs
  - Provide some guidance on developing PPMs
  - Teach tactics and techniques that hardware engineers can put directly to use

- Agenda
  - General guidance on PPMs
  - Look at common hardware development processes and identify some aspects that lend themselves to modeling
  - Identify what we want to predict and what measures and baselines are needed to establish a model
  - Look at some modeling techniques and some examples of hardware PPMs used at Northrop Grumman Electronic Systems, Rolling Meadows
  - Talk about the value and potential benefits of these models

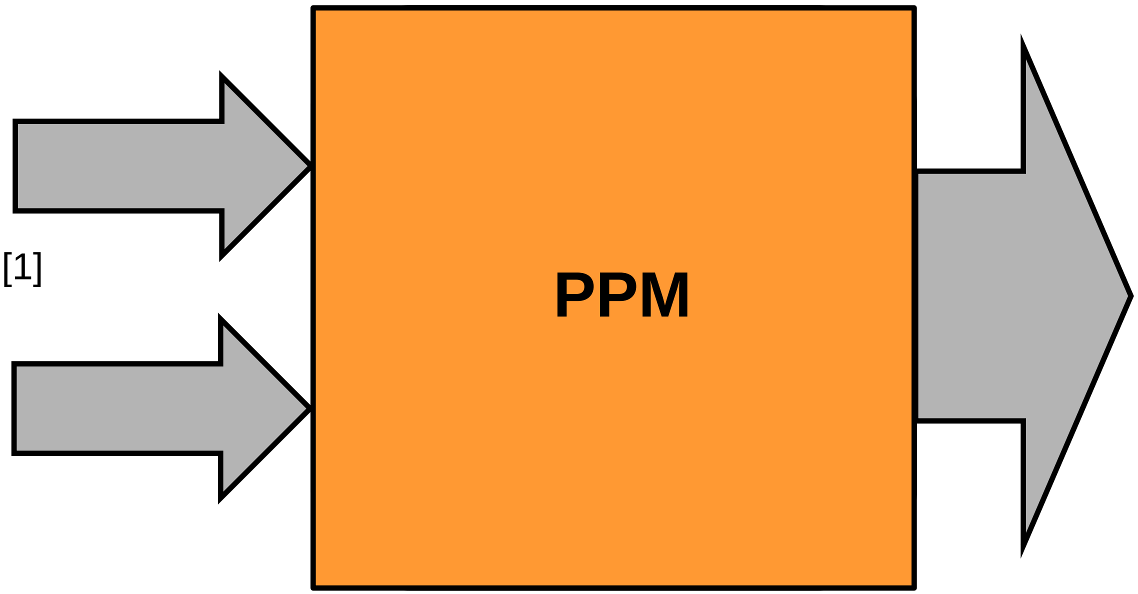
Process-Performance Models (PPM)

PPM

Process-Performance Models (PPM)

“Process and Product Measurements” [1]

Process Selections



“Models are defined to provide [] the ability to predict critical process and product characteristics.” [1]

Process-Performance Models (PPM)

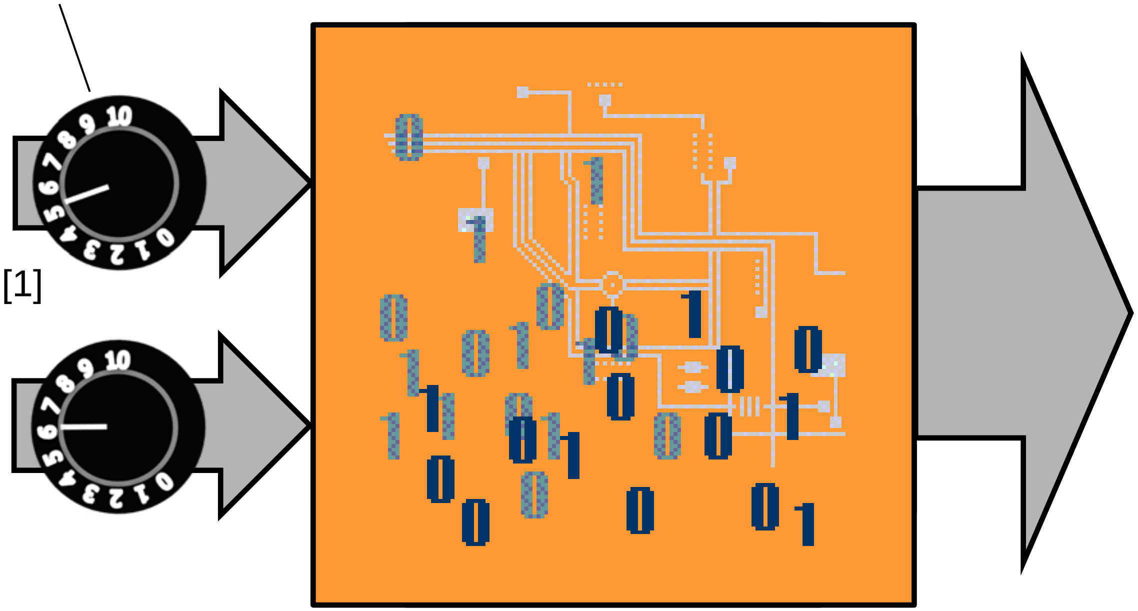
Controllable Inputs

Must be statistical or probabilistic in nature. [4]

Predict future outcomes and support “what-if” analyses. [4]

“Process and Product Measurements” [1]

Process Selections



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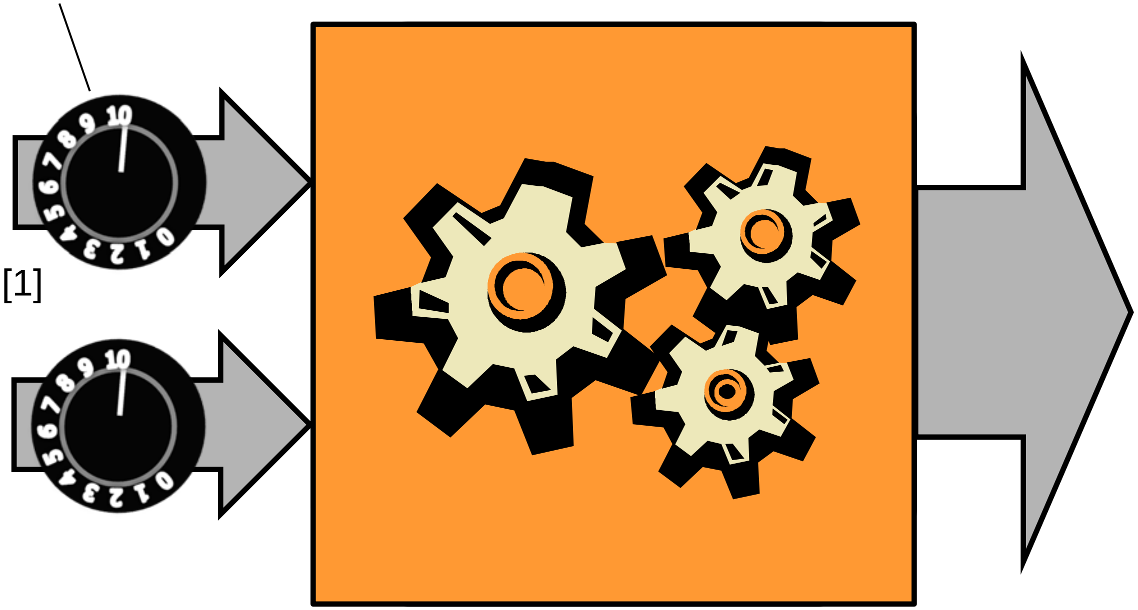

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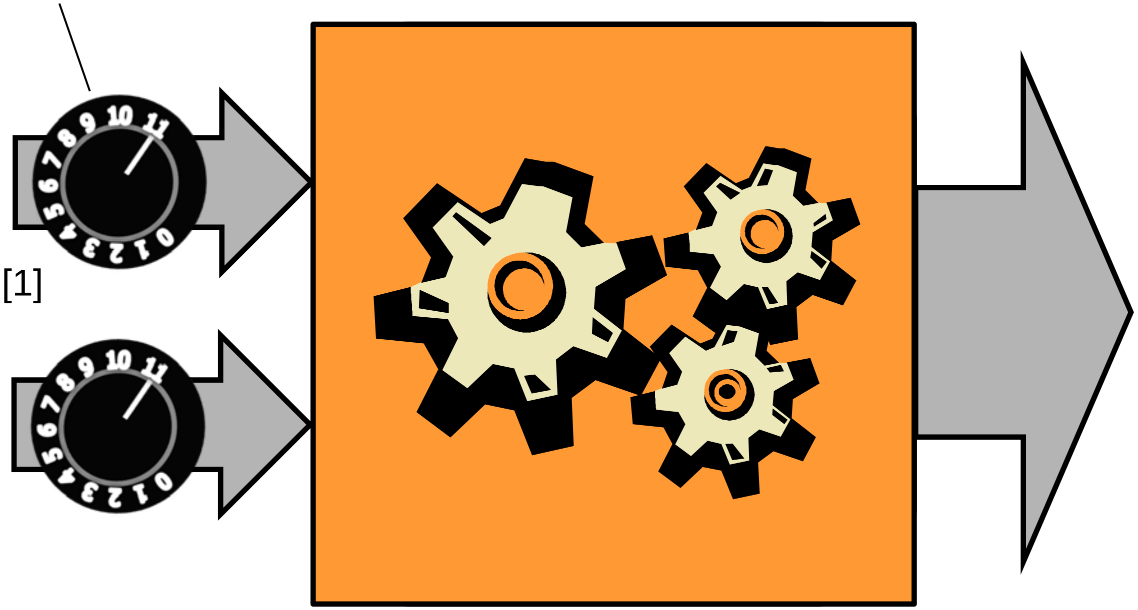
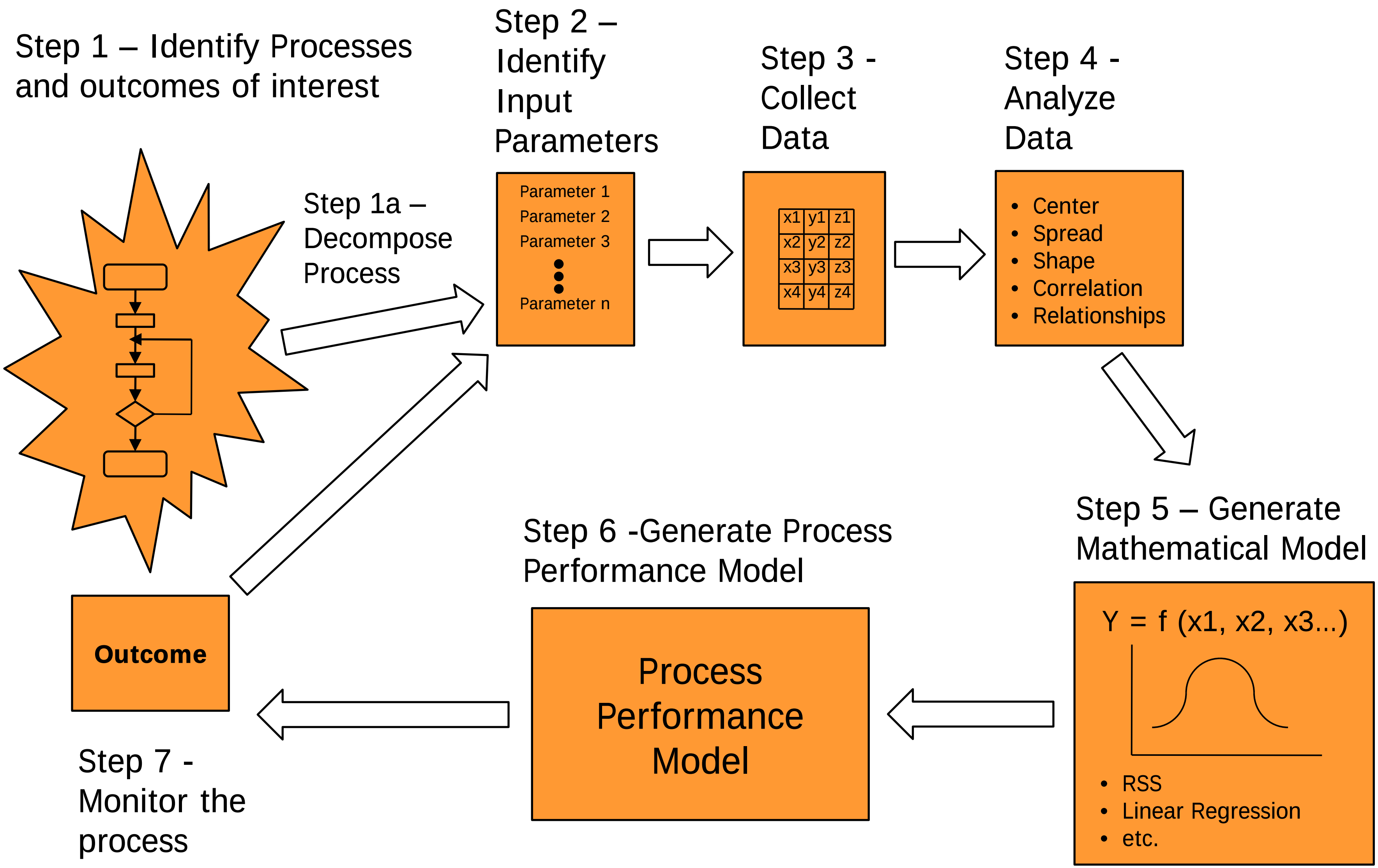


“Models are defined to provide [] the ability to predict critical process and product characteristics.” [1]

PPM Uses:

- Predict Process or Product Characteristics
- Evaluate the impact of process composition
- Evaluate the impact of processes measurements on performance relative to objectives

Process Performance Model Development



What do Hardware Engineers Do?

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Requirements Development

- Customer Requirements
- Product Requirements
- Analyze and Validate

REQM

Requirements Review

Technical Solution

- Select Component Solutions
- Develop the Design
- Implement the Design

Critical Design Review

Product Integration

- Prepare for Integration
- Ensure Interface Compatibility
- Assemble and Deliver

Test Readiness Review

Verification

- Prepare for Verification
- Perform Peer Reviews
- Verify Selected Work Products

VAL

[1]

What do Hardware Engineers Do? (Translation)

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Requirements Development

- Customer Requirements
- Derived Requirements
- Conceptual Design

REQM

◇ Requirements Review

Technical Solution

- Evaluate Design Alternatives
- Model, Analyze, Document
- Procure Hardware

◇ Critical Design Review

Product Integration

- Assy Dwgs And Instructions
- Assembly Tolerance Analysis
- First-Build Support

◇ Test Readiness Review

Verification

- Test Plan and Procedure
- Internal Design Reviews
- Verification / Qual. Testing

VAL

Repetitive Tasks

What do Hardware Engineers Care About?

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Hardware Requirements

- Size & Weight (Form)
- Interfaces (Fit)
- Performance (Function)
- Endurance (Environment & Mission Survivability)
- Reliability

Quality Objectives

Meet or Exceed Requirements
Minimize Size and Weight
Maximize Performance
Maximize Endurance
Maximize Reliability
Maximize Customer Satisfaction

Guiding Design Principles

- Design for Manufacture
- Design for Assembly
- Design for (Lifecycle) Cost
- Design for Quality
- Process-Driven Design (Consistent & Efficient)
- Customer Focused Design

Process-Performance Objectives

Minimize Manufacturing Cost
Minimize Assembly Cost
Minimize Lifecycle Cost
Minimize Escaped Defects
Minimize Process Cycle Times
Maximize Customer Satisfaction

Identifying Processes and Measures that Impact Key Characteristics

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	Quality Characteristics					Process-Performance Characteristics				
Process Area	**Size & Weight**	**Product Perf.**	**Product Endurance**	**Product Reliability**	**Customer Satisfaction**	**Manuf. Cost**	**Assembly Cost**	**Lifecycle Cost**	**Escaped Defects**	**Cycle Times**
Requirements Development										
Technical Solutions										
Product Integration										
Verification										
Modeling										
Analysis										
Doc / Drafting										
WPI										
CM										
Drawing Revs										
Reviews										
AI Resolution										
Procurement										
Testing										
Product										

Example Questions

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- Requirements Development
  - How will the vibration requirement affect the product development time and cost?
  - How does the quantity of requirements affect the development time and cost?
  - How does requirements maturity affect task on-time completions?

- Technical Solutions
  - How does analysis conservatism impact cost, schedule, quality? Test success?
  - How does design time impact integration, test, manufacture, and assembly time?
  - How do process selections to create prototypes and perform preliminary testing affect development cost?

- Product Integration
  - How does standard part usage, design reuse, and other part selections affect procurement time?
  - How does the tolerance stack method affect assembly quality?
  - How does component testing affect assembly time?

- Verification
  - How does the level of testing affect product reliability?
  - How does verification method (similarity, analysis, test) affect development cost?

Example Questions

- Product
  - How does product complexity affect schedule, cost, and quality?
  - How do Technical Performance Measures predict success/risk for the program?
  - How does design decisions influence the manufacturing process?
  - How does part count affect assembly time?

Decomposing the Process and Identifying Input Parameters

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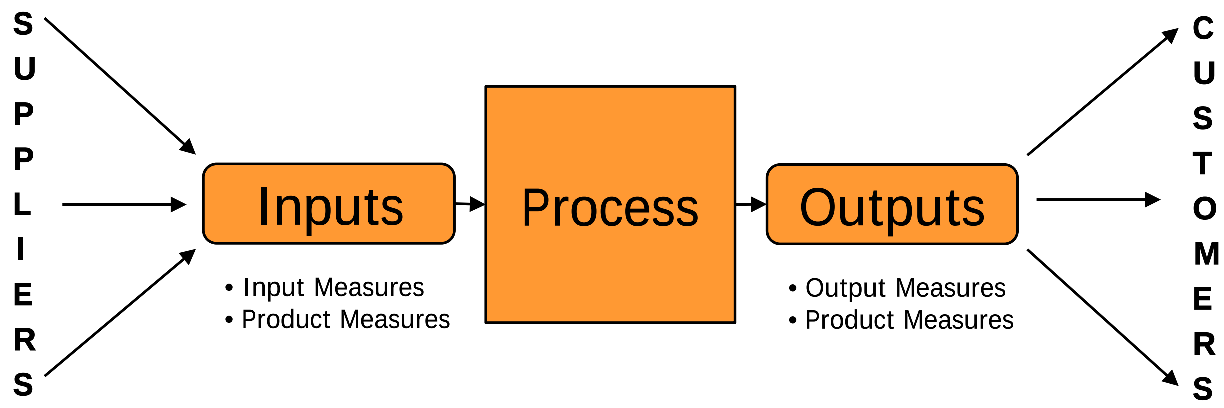
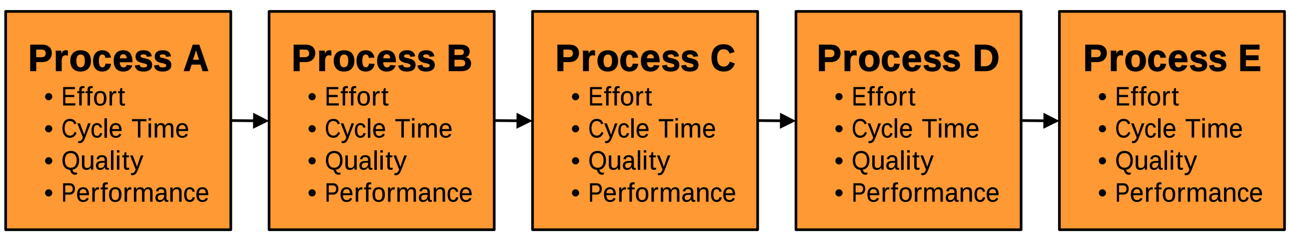
S I P O C



Further Decomposition



- Decompose until sub-process is measureable
- For each sub-process try to identify each of the following measures:
  - Effort Measure (labor hours)
  - Cycle Time Measure (schedule)
  - Quality Measure (errors / defects)
  - Performance Measure (yield / efficiency)

Analysis Time Process Example

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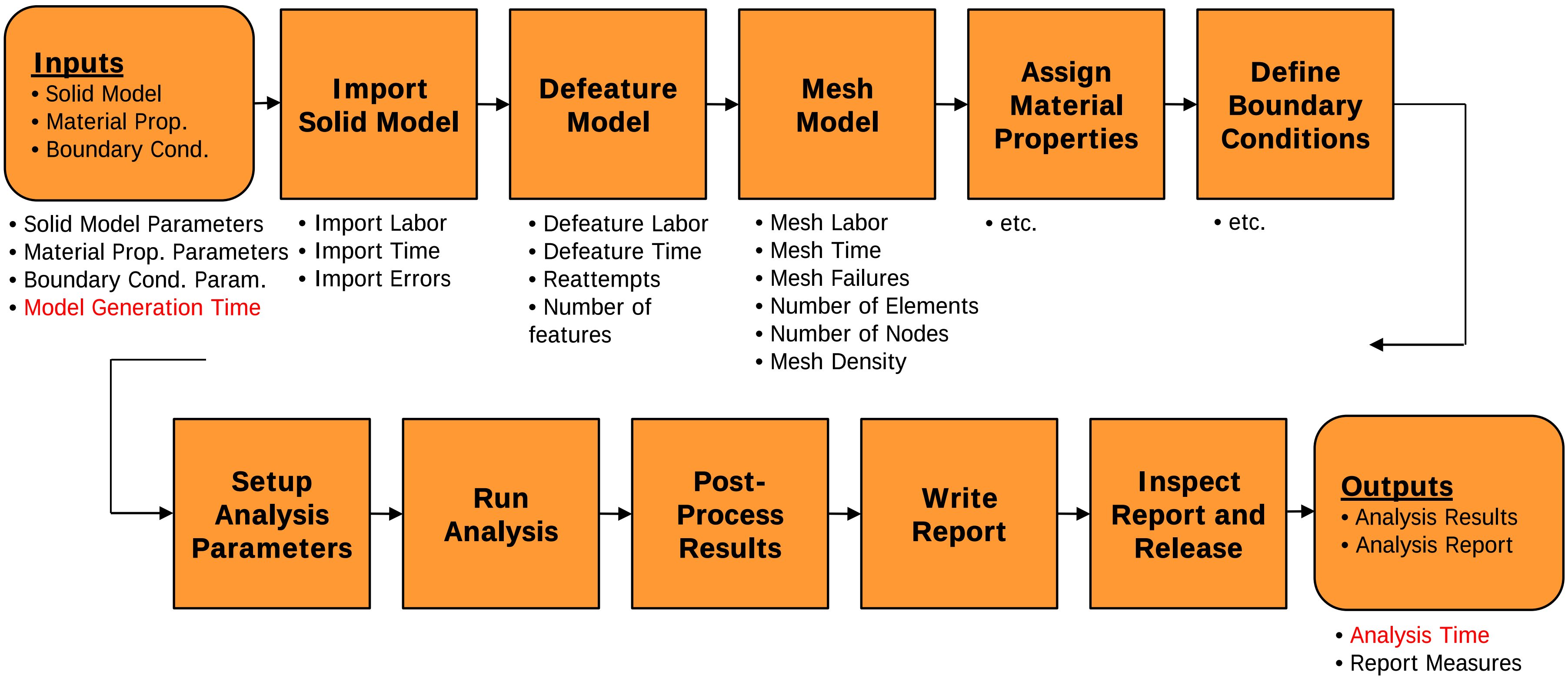


- For each subprocess identify measures that may contribute to the characteristic of interest
- Model may be dependent upon how one process or subprocess affects another

How will one process affect another?

\ Effect Cause \	Requirements Development	Technical Solutions	Product Integration	Verification
Requirements Development	• How does the quantity of requirements affect the requirements development time?	• How will reqmts. affect analysis time? • How does requirements maturity impact HW design time?	• How will requirements affect assembly time?	• How does the quantity of requirements affect test cost and schedule?
Technical Solutions		• How does the drawing generation time and quantity of errors found affect procurement time?	• How does the drawing generation time and quantity of errors found affect integration time?	• How does analysis time affect testing success? • How does prototyping affect testing success?
Product Integrations			• How does standard part usage, design reuse, and other part selections affect assembly time?	• How does integration time impact system testing time and number of failures?
Verification			• How does component testing affect integration time?	• How do design review scores impact testing time?

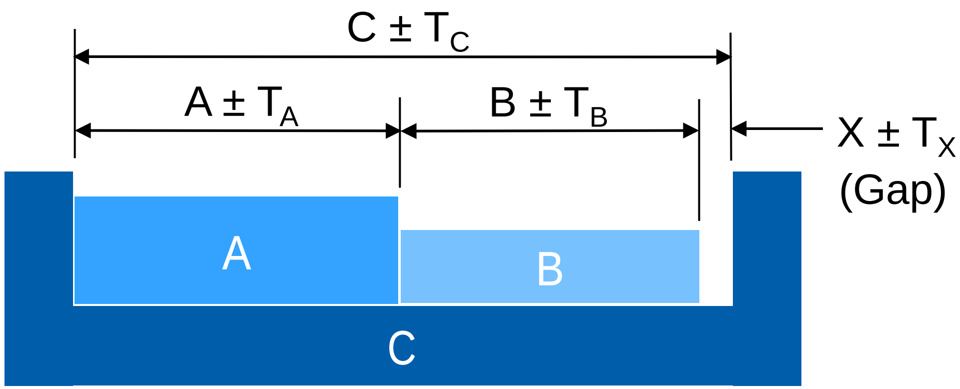
Drawing Release Schedule (DRS) PPM

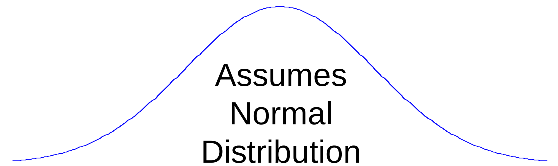
- Engineering drawings are a major work product for hardware engineering
- Once the design has been reviewed and deemed ready for procurement drawings are generated, inspected, and released to CM, in series
- Hardware procurement is dependent upon the timely release of drawings
- Engineering, Project Management, and Operations are interested to know when drawings will be released and to manage the Drawing Release Schedule

The DRS PPM forecasts when drawings will be completed and indicates when the schedule is off track

Statistical Tolerance Stack Analysis

- Lets begin with something familiar to mechanical engineers...





$$\overline{X} = \overline{C} - \overline{A} - \overline{B}$$

$$\sigma_X = \sqrt{\sigma_A{}^2 + \sigma_B{}^2 + \sigma_C{}^2}$$

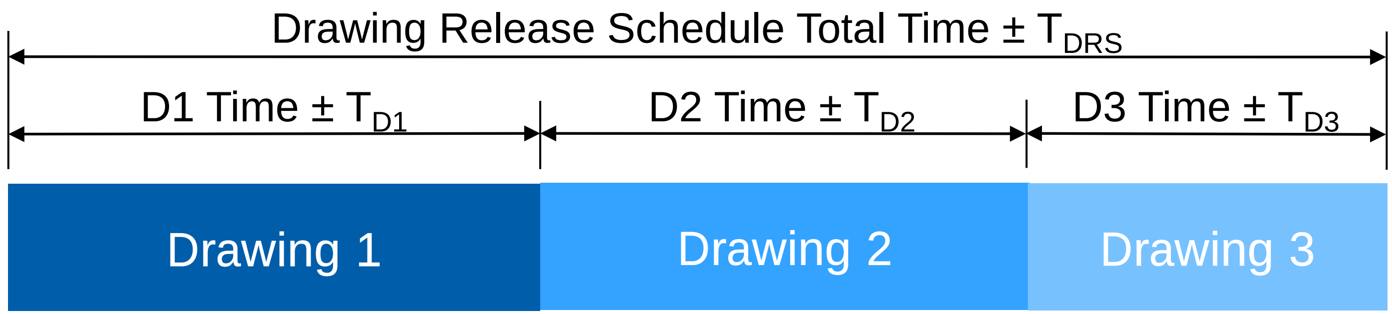
$$T_X = \sqrt{T_A{}^2 + T_B{}^2 + T_C{}^2}$$

- Statistical Tolerance Stacking allows the designer to evaluate the effect part tolerances will have on critical interfaces of a higher level assembly. (Product attributes are used to predict product attributes.)

- How can a similar approach be used to predict process performance?

Stack-Up PPMs

- Method works well for time durations or labor hours summing in series



Drawing 1 + Drawing 2 + Drawing 3 = Drawing Release Schedule

Process A + Process B + Process C = Composed Process

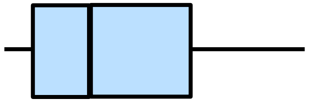
Iteration 1 + Iteration 2 + Iteration 3 = Analysis Time

Test A + Test B + Test C = Total Test Time

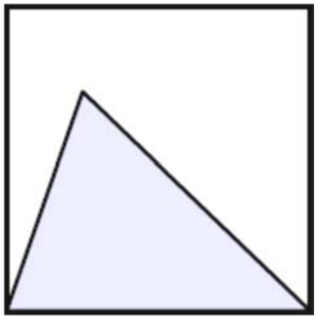
CCA Design + PWB Layout + CCA Procurement Time

What if the data is not Normal? (and it probably is not)

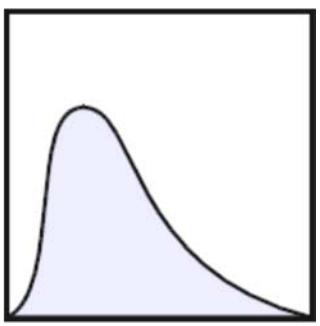
Fractiles



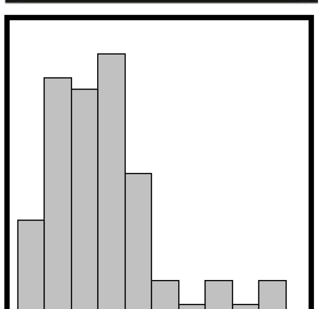
Triangular Distribution



Beta Distribution

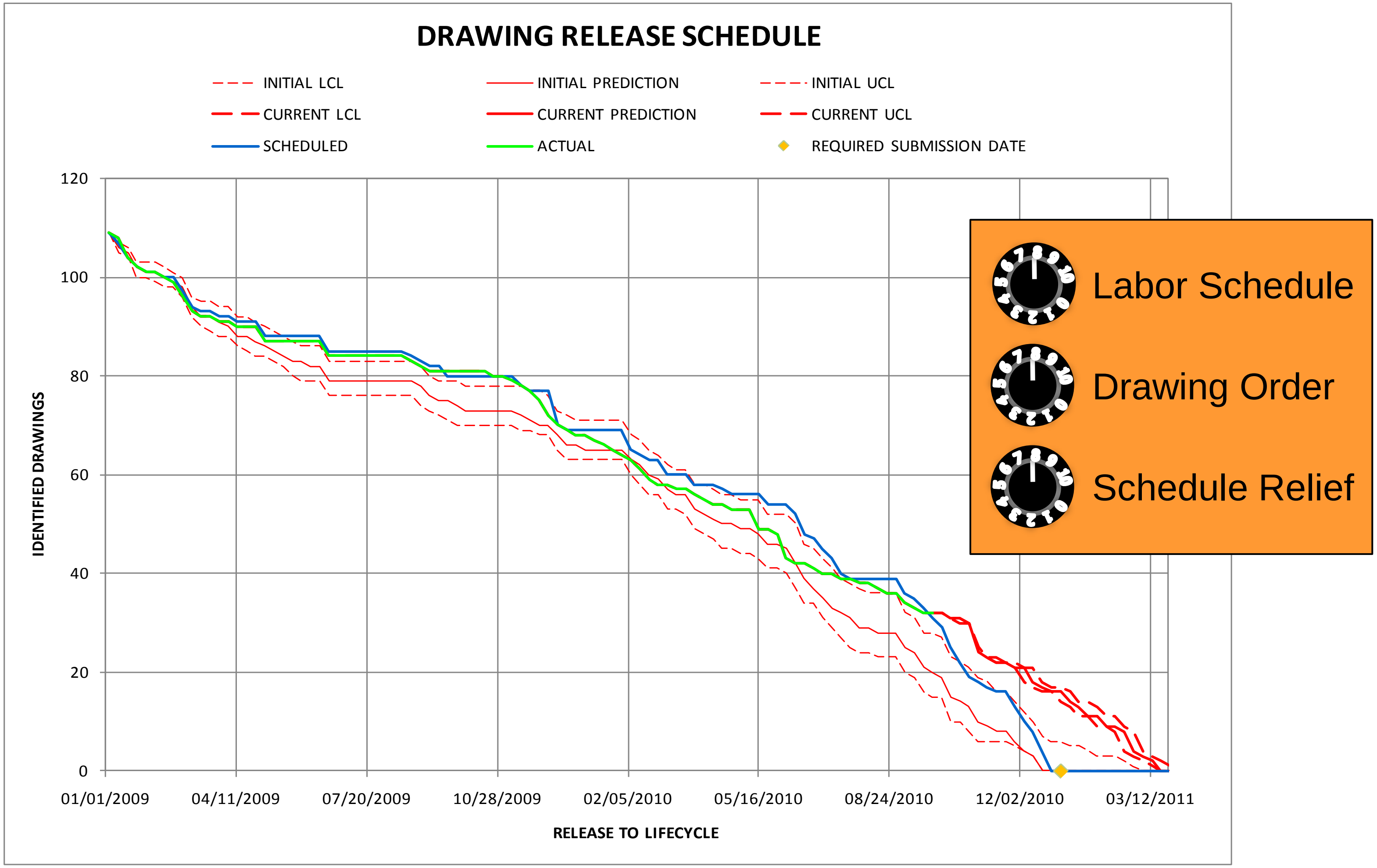


Histogram w/ Best Fit



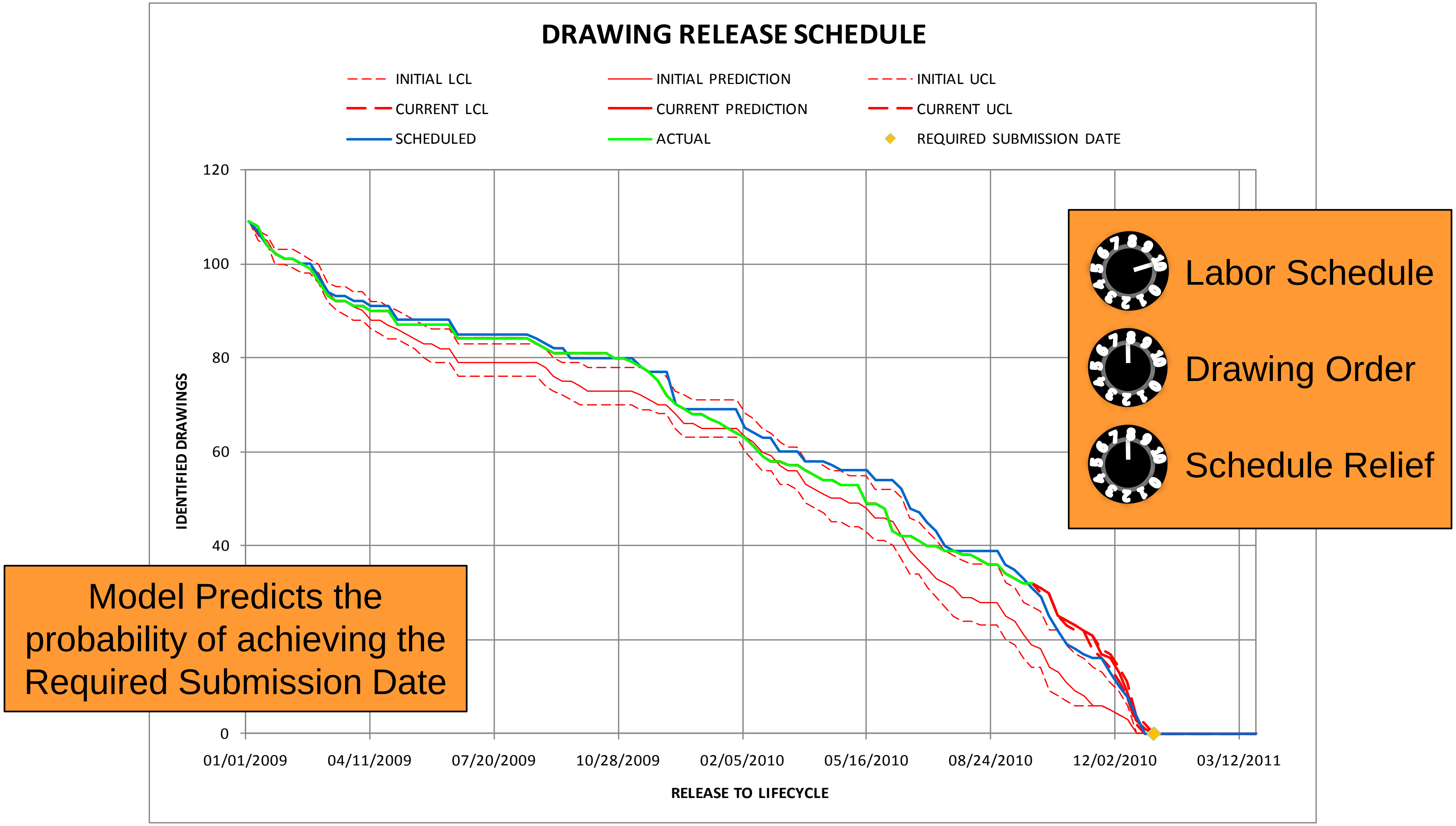
- For a sufficiently large number of independent random variables that are identically distributed but not normal, the Central Limit Theorem states that the resulting summation is approximately normally distributed, allowing the RSS approach to remain valid. [6]
- Triangular or Beta distributions are commonly used for predicting time-based events. It is more likely that an event will exceed a predicted finish date than finish early (PERT - Program Evaluation Review Technique). [3]
- In the absence of historical data, a subject expert may predict the best-case, worst-case, and most likely case. [4]
- Better yet, Process Performance Baselines (PPBs) characterized using the mean and standard deviation and vetted for special causes can be fitted with a beta distribution, if appropriate.
- Alternatively, PPBs characterized using the median and fractiles can be fitted with a beta distribution based upon five or seven point estimates. This approach can be advantageous because fractiles are not significantly impacted by outliers. [5]
- Best of all, use Monte Carlo Simulation to predict a more exact output distribution from PPBs with a variety of input distributions.

Drawing Release Schedule (DRS) PPM



Model predicts DRS based upon statistical stack-up of drawing generation, review, and release cycle times.

Drawing Release Schedule (DRS) PPM



A violation of statistical limits invokes corrective action, typically an increase in devoted labor hours.

Printed Wiring Board (PWB) Layout Labor Forecasting PPM

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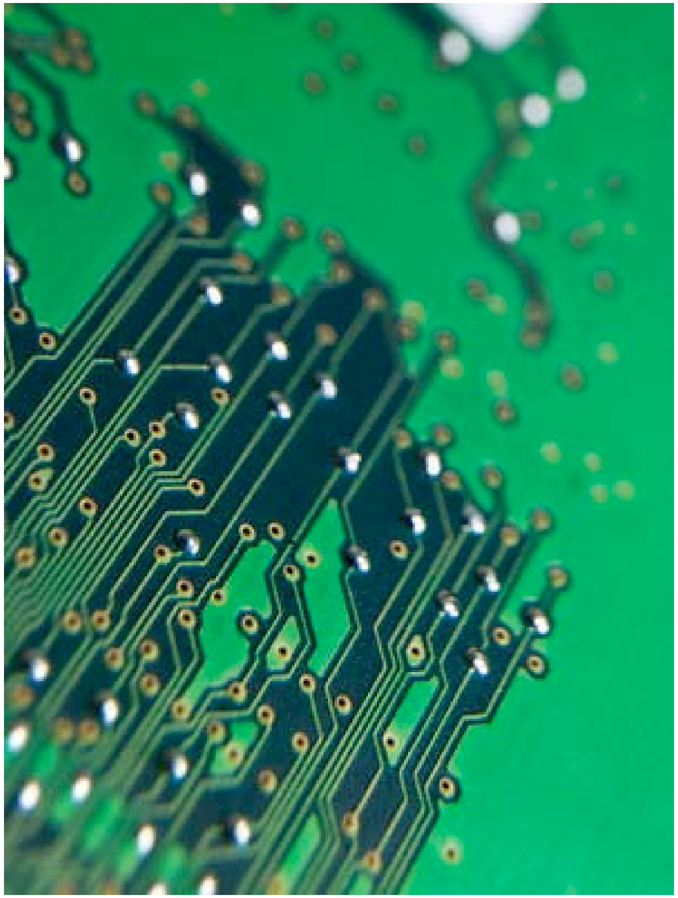
- The Design Layout Technology (DLT) group lays out where components will be placed on a Printed Wiring Board (PWB) and the layers, vias, and traces that will connect them
- Historically, the workload in this area has been difficult to manage (very up and down)
- DLT was interested in being able to predict their upcoming workload accurately based upon board complexities in order to adjust controllable factors and meet these demands.



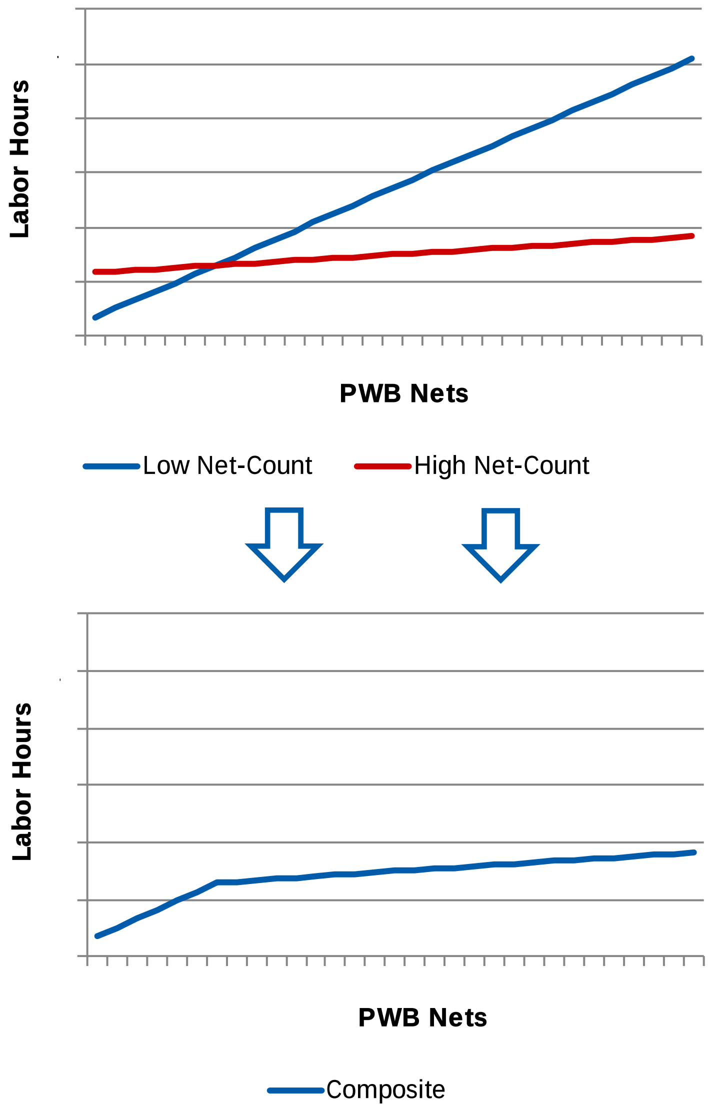
The PWB Layout PPM forecasts the workload for the DLT group and allows for the management of labor

Generating a Linear Regression Model

- Complexity Factors
  - Component Count
  - Number of Nets
  - Number of Pins
  - Number of Vias
  - Number of Connections
  - Number of Vias per Connection
  - Number of PWB Layers
  - Number of Padstacks

- Strong correlation discovered between Labor Hours and PWB Net count

- Two-stage linear regression model established



PWB Layout Labor Forecasting PPM

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PWB Design Labor Prediction/Estimator Tool			95% Prediction Interval			Actuals		Proposed Handling of PWB Design					Manpower Scheduling					
CCA Board Number	Number of Nets w/Rats	Month Scheduled To Start PWB Design	Lower PWB Design Labor Prediction Limit (Hours)	Average PWB Design Labor Prediction (Hours)	Upper PWB Design Labor Prediction Limit (Hours)	Actual PWB Design Labor (Hours)	Average Predicted Man Months	No Special Handling Start Design	Authorize Overtime	Temporarily Hire Contractor	Reschedule Start Of PWB Design	Comments	Sep-09	Oct-09	Nov-09	Dec-09	Jan-10	Feb-10
								Yes	No	No	No	DLT and PMO concur on labor resolution, board not in critical path, no special handling required	1.29					
								Yes	No	No	No	DLT and PMO concur on labor resolution, board not in critical path, no special handling required	1.60					
								No	Yes	No	No	DLT and PMOconcur on labor resolution, board is in critical path, special handling required		4	3.45			
								No	Yes	Yes	No	DLT and PMO concur on labor resolution, board is in critical path, special handling required			4.00	3.83		
								Yes	No	No	No	DLT and PMO concur on labor resolution, board not in critical path, no special handling required			0.75	0.76		
								No	Yes	No	No	Prior direction provided to DLT for handling			1.50	1.18		
								No	Yes	No	No	Prior direction provided to DLT for handling				1.50	1.33	
								No	Yes	Yes	No	Prior direction provided to DLT for handling				1.00	1.27	
								No	Yes	No	No	DLT and PMO concur on labor resolution				1.25	1.25	
												Total Number Of Man-Months	**2.89**	**4**	**9.7**	**9.52**	**3.85**	**0**

DLT Labor Prediction PPM provides:

- Ability for Project and DLT organization to control scheduling and costs for design of PWBs
- Ability to predict DLT labor requirements, as well as prediction interval
- Model allows for feedback of actual labor requirements for monitoring and control

What do Hardware Engineers Care to Avoid?

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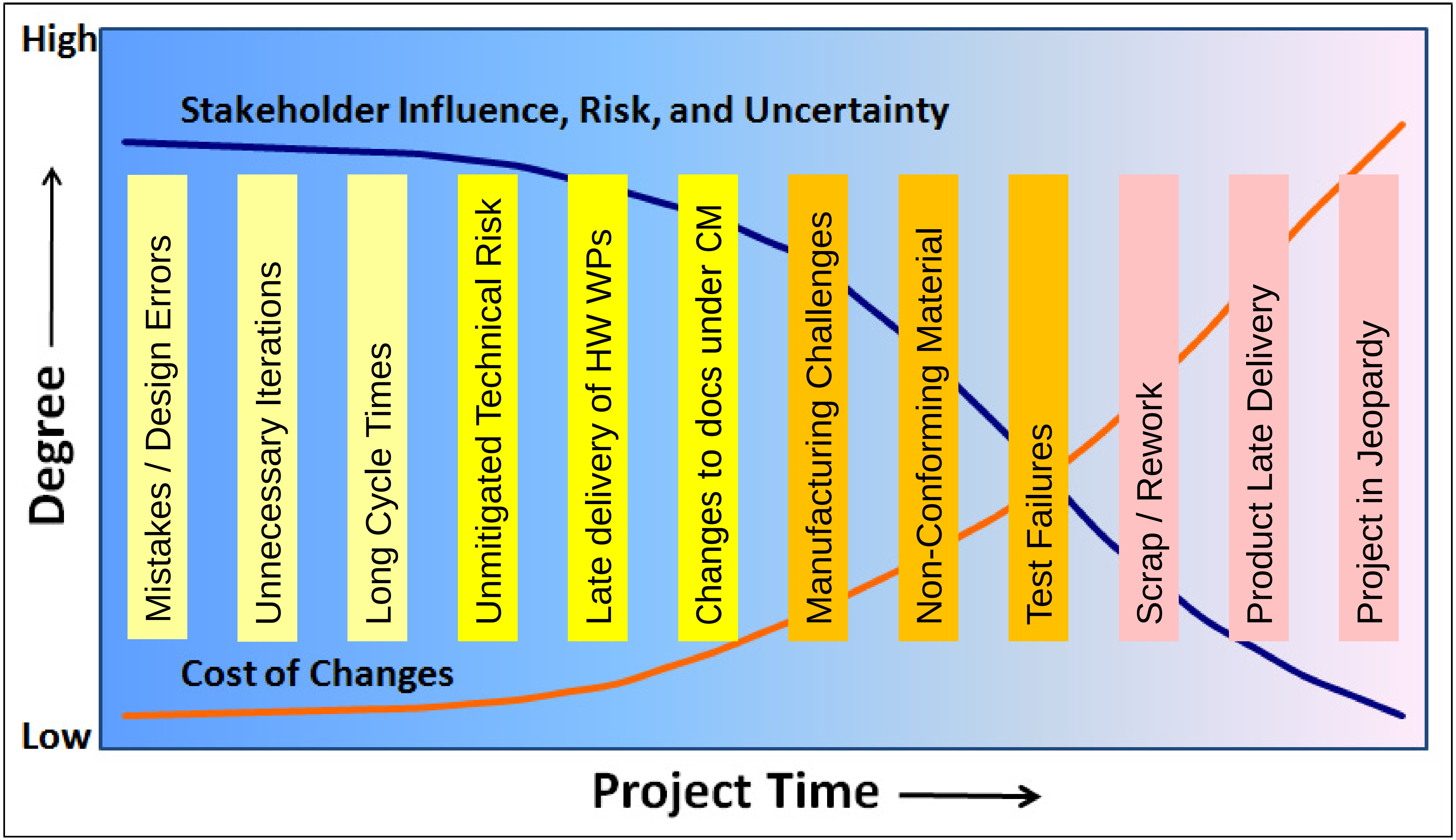
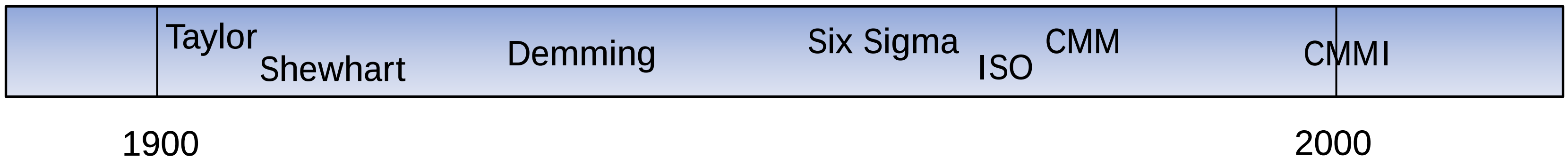


http://leadinganswers.typepad.com/.a/6a00d834527c1469e20105368793e2970b-500wi

Design for Manufacture and Assembly

- Often we think about manufacturing and assembly as production processes, but they are development processes as well
  - “Use effective methods to implement the product components” [1] (TS SP3.1, Subpractice 1)
  - “Assemble product components” [1] (PI SP3.2)
- Best practice advises that a component be designed with the manufacturing and assembly processes in mind
- It is the responsibility of the hardware engineer to consider manufacturing and assembly costs throughout the development process (the earlier the better!)
- Take advantage of process baselines from manufacturing focused process improvement initiatives, such as Six Sigma, Lean, and Total Quality Management, to devise Process Performance Models that offer insight into the development process.



Considerations for a DFM PPM

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- How do the manufacturing processes selected during the design phase affect the manufacturing cost?

Joining
- Welding
- Brazing
- Soldering
- Adhesive Bonding
- Press Fit
- Snap Fit
- Mechanical
- Fastener
- Other

Machining
- Turning
- Forming
- Drilling
- Milling
- Sawing & Filing
- Grinding
- Buffing & Polishing
- ECM, EDM, Laser
- Other

Casting
- Sand
- Shell Mold
- Plaster Mold
- Ceramic Mold
- Investment
- Permanent Mold
- Die Casting
- Centrifugal
- Other

Bulk Deformation
- Rolling
- Drawing
- Extrusion
- Forging
- Other

Powder Metallurgy

Sheet Metalworking
- Shearing
- Bending
- Spinning
- Stretch Forming
- Deep Drawing
- Sheet Forming
- Press Forming
- Other

Polymer Processing
- Compression Molding
- Transfer Molding
- Injection Molding
- Rotational Molding
- Extrusion Molding
- Blow Molding
- Thermoforming
- Other

- How do product and process parameters affect manufacturing process cost?

Machining Cost Drivers
- Volume of Material Removed
- Material Properties
- Tolerances
- Surface Roughness
- Number of Operations
- Number of Setups and/or Machines
- Part Size
- Number of Non-Standard Features
- Tool Clearance
- Access to Surface to be Machined
- Length of Tool Path

Plastic Injection Molding Cost Drivers
- Parting Line
- Number of Under-cuts
- Nominal Wall Thickness
- Draft
- Surface Finish
- Tolerances

[2] Stoll

A PPM predicting manufacturing process cost would depend upon process selections and product and process parameters

Considerations for a DFA PPM

- How do product and process parameters affect assembly process cost?

$$Assembly\ Cost = \sum_{i=1}^{m}(C_H + C_I + C_S + C_A + C_V)_i + \sum_{j=1}^{n}(C_{SO} + C_V)_j$$

$m =$ total number of parts or subassemblies

$n =$ total number of separate operations

$C_H =$ handling cost

$C_I =$ insertion cost

$C_S =$ securing cost

$C_A =$ adjustment cost

$C_V =$ verification cost

$C_{SO} =$ separate operation cost

Assembly Cost Drivers
- Number of Parts
- Number of Fasteners
- Part Commonality
- Standard Part Usage
- Assembly Sequence
- Part Handling
- Part Insertion
- Part Securing
- Adjustments
- Verification
- Number of separate operations
- Tolerances

[2] Stoll

A PPM predicting assembly process cost would depend upon product and process cost driving parameters

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[1] Chrissis, Mary Beth, Mike Konrad, and Sandy Shrum. *CMMI Second Edition – Guidelines for Process Integration and Product Improvement,* Addison-Wesley, Boston, 2007.

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[4] Software Engineering Institute, *Understanding CMMI High Maturity Practices*, Carnegie Mellon University, 2007.

[5] Zhang, Yue*. A simple and logical alternative for making PERT time estimates,* IIE Transactions, 1996.

[6] Siegel, Andrew F. Practical Business Statistics. McGraw-Hill Irwin, Boston, 2000.

[7] http://en.wikipedia.org/wiki/Central_limit_theorem, Oct. 11, 2010.

Questions?

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Abstract – 35 minute presentation

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- Looking for something a little more…hard-hitting? Well, this presentation is not for softies and it is guaranteed to hit close to home with hardware engineers. Learn tactics and techniques that hardware engineers can put directly to use.
- We will begin with a look at common hardware development processes and identify some aspects that lend themselves to modeling.
- Next, we will identify what we want to predict and what measures and baselines are needed to establish a model.
- We will look at some modeling techniques and some examples of hardware PPMs used at the Northrop Grumman Electronic Systems Rolling Meadows Campus, a CMMI Level 5 organization.
- Finally we will talk about the value and potential benefits of these models. Join us for a rock-solid approach to hardware process performance models.