University of Southern California
Center for Software Engineering

CASE Impact Analysis on Software Development Effort Via Bayesian Modeling Approach

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Outline

- Motivation
- COCOMO II & TOOL Productivity Impact
- COCOMO II Modeling Methodology
- Rating Scales and Research Model
- Bayesian Analysis (Delphi, Sample, & Posterior)
- Cross Validation – Data Splitting & Bootstrap
- Contributions
- Future Works

Motivation

- **Very Simple Tool Rating Scale in COCOMOII Model**
- **Strong Statistical Significance of TOOL Effect on Effort & Schedule**
- **No Consideration of Correlations and Overlaps with Other Parameters**
- **No Consideration of tool integration, maturity, and user support**

COCOMO II
Early Design & Post Architecture Model

$$PM_{NS} = A \times Size^{E} \times \prod_{i=1}^{n} EM_i$$

$$\text{where } E = B + 0.01 \times \sum_{j=1}^{5} SF_j$$

$$TDEV_{NS} = C \times (PM_{NS})^{F}$$

$$\text{where } F = D + 0.2 \times 0.01 \times \sum_{j=1}^{5} SF_j$$

$$= D + 0.2 \times (E - B)$$

A = 2.94 **B = 0.91**

C = 3.67 **D = 0.28**

- Early Design Model [6 EMs]:
- Post Architecture Model [16 EMs]:
  *Exclude SCED driver

EMs: Effort multipliers to reflect characteristics of particular software under development

A : Multiplicative calibration variable

E : Captures relative (Economies/Diseconomies of scale)

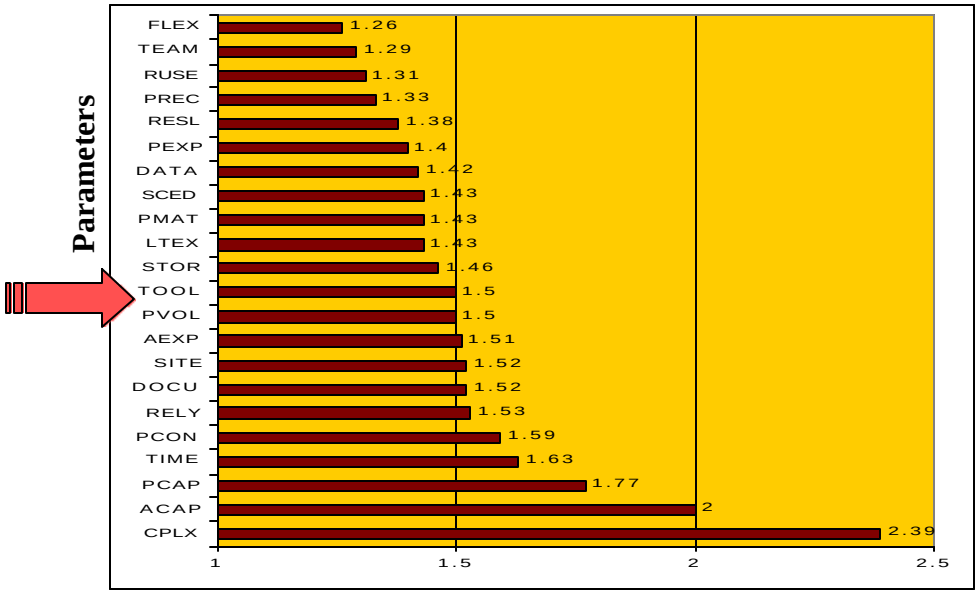
SF: Scale Factors

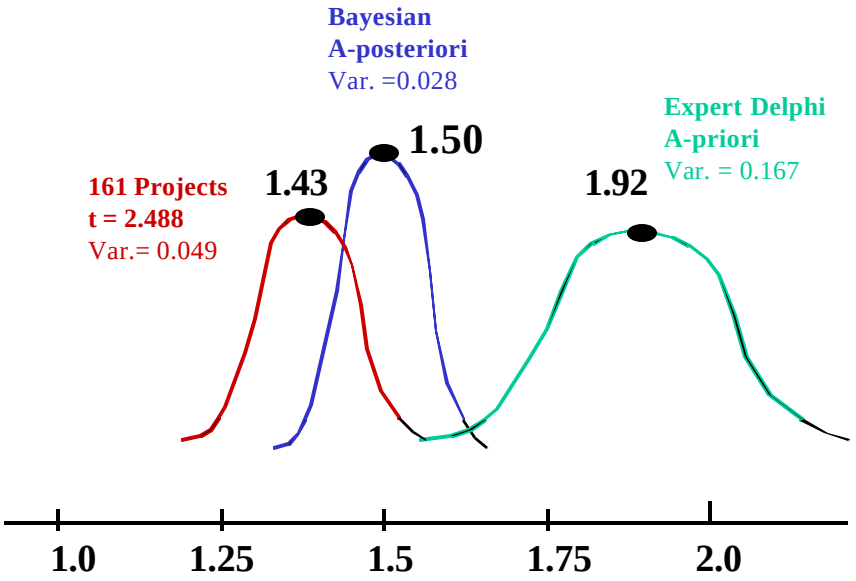
COCOMO II TOOL Rating Scale & Value

	Very Low	Low	Nominal	High	Very High
Use of Software Tools (TOOL)	Edit, code, debug	Simple front-end CASE, back-end CASE; Little Integration	Basic lifecycle tools; Moderately integrated	Strong, mature, lifecycle tools; Moderately integrated	Strong, mature, proactive lifecycle tools; Well integrated with process, methods, reuse
	1.17	1.09	1.00	0.90	0.78

- **No Comparison of the Same Kind of Tools**
- **No Clear Definition of Tools and Integration**
- **No Consideration of Tool Maturity and User Support**
- **No Considerations of Interactions with Other Factors**

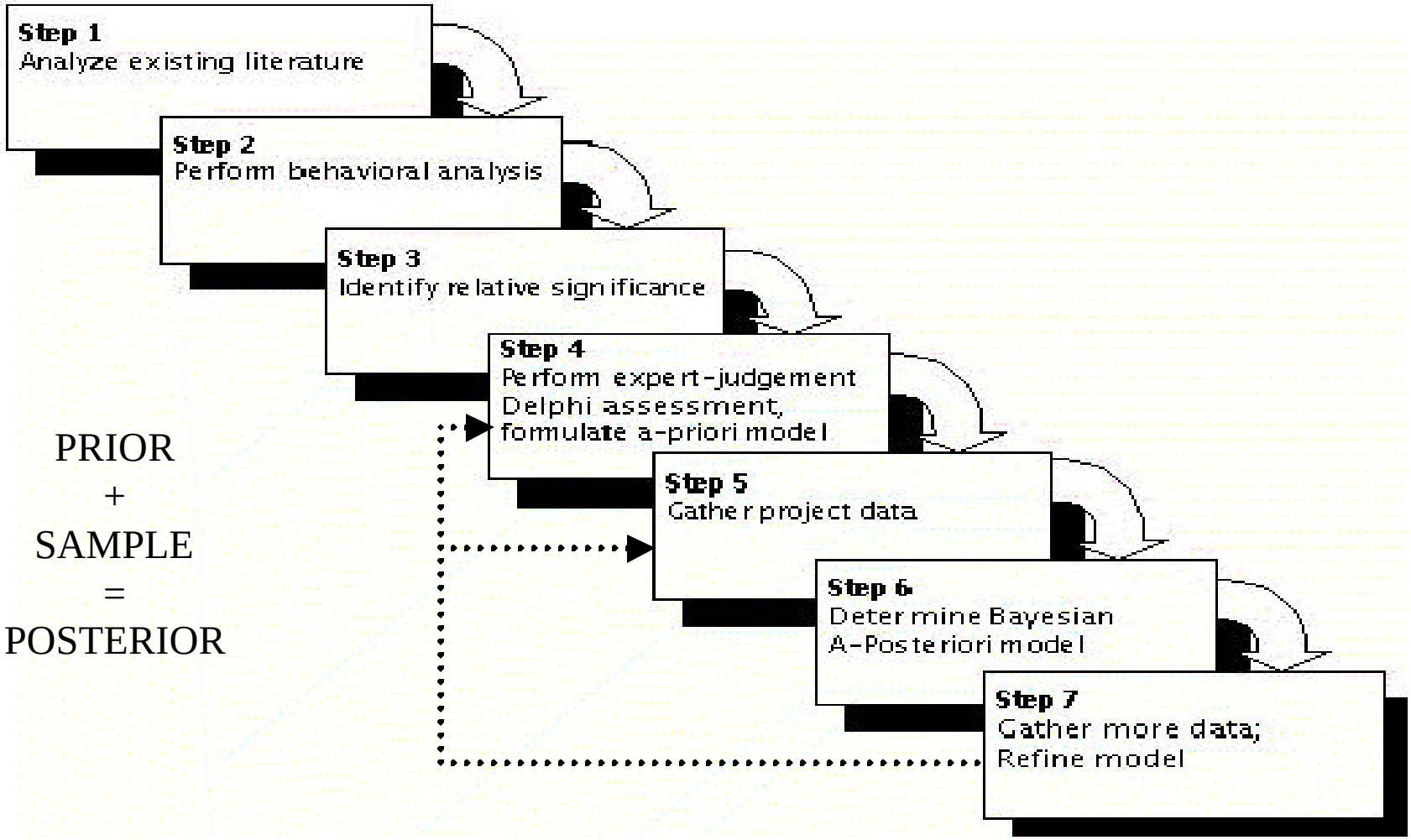
COCOMOII.2000 Productivity Ranges





- **Productivity Range (PR) = Highest Rating Value / Lowest Rating Value**
- **Statistically Significant : t = 2.488 > 1.96**

COCOMO II Modeling Methodology



Tool Impact in Software Cost Models

	SLIM	Jensen	Checkpoint	PRICE-S	Softcost	COCOMO
"Use of Software Tools"	Yes	Yes	Yes	Yes	Yes	Yes
Completeness of Activity Coverage	No	No	Yes	No	Yes	Yes
Degree of Tool Integration	No	No	Yes	No	No	Yes
Tool Maturity and User Support	No	No	No	No	No	No

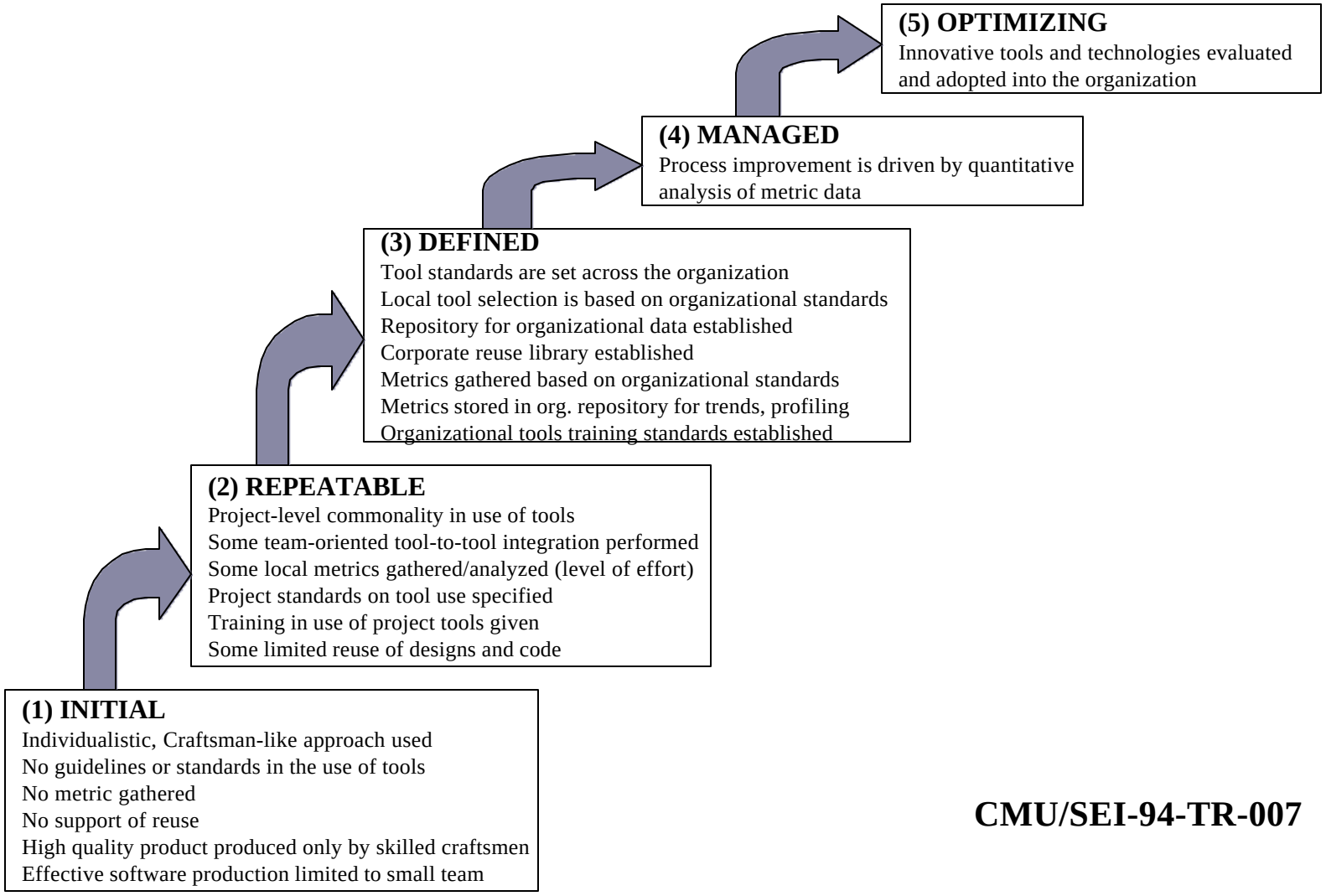
Completeness of Activity Coverage (TCOV)

Very Low	Text-Based Editor Basic 3GL Compiler Basic library Aids Basic Text-based Debugger Basic Linker
Low	Graphical Interactive Editor Simple Design Language Simple Programming Support Library Simple Metrics/Analysis Tool
Nominal	Local Syntax Checking Editor Standard Template Support Document Generator Simple Design Tools Simple Standalone Configuration Management Tool Standard Data Transformation Tool Standard Support Metrics Aids with Repository Simple Repository, Basic Test Case Analyzer
High	Local Semantics Checking Editor Automatic Document Generator Requirement Specification Aids and Analyzer Extended Design Tools Automatic Code Generator from Detailed Design Centralized Configuration Management Tool Process Management Aids Partially Associative Repository (Simple Data Model Support) Test Case Analyzer with Spec. Verification Aids Basic Reengineering & Reverse Engineering Tool
Very High	Global Semantics Checking Editor Tailorable Automatic Document Generator Requirement Specification Aids and Analyzer with Tracking Capability Extended Design Tools with Model Verifier Code Generator with Basic Round-Trip Capability Extended Static Analysis Tool Basic Associative, Active Repository (Complex Data Model Support) Heterogeneous N/W Support Distributed Configuration Management Tool Test Case Analyzer with Testing Process Manager, Oracle Support Extended Reengineering & Reverse Engineering Tools
Extra High	GroupWare systems Distributed Asynchronous Requirement Negotiation and Tradeoff tools Code Generator with Extended Round-Trip Capability Extended Associative, Active Repository Spec-based Static and Dynamic Analyzers Pro-active Project decision Assistance

- **Based on**
  - **Breadth of Activity Coverage**
    - **Specification, Analysis, Design, Programming, Test, CM, QA, Collaboration, Management, etc.**
  - **Tool's Functionality Support**
  - **SEI- CMM Tool Characteristics**

"Clear relationship b/w tool functionality and the needs of a particular KPA of CMM"

Tool-Use Characteristics at CMM Levels



CMU/SEI-94-TR-007

Degree of Tool Integration (TINT)

	Very Low	Low	Nominal	High	Very High	Extra High
Degree of Tool Integration	Individual File Formats for Tools (No Conversion Aid), No Activation Control for Other Tools, Different User Interface for each Tools, Fundamental Incompatibilities among Process Assumptions and Object Semantics	Various File Formats for Each Tools (File Conversion Aids), Message Broadcasting to Tools, Some Standardized User Interfaces among Tools, Difficult Incompatibilities among Process Assumptions and Object Semantics	Shared-Standard Data Structure, Message Broadcasting through Message Server, Standard User Interface Usage among Tools, Workable Incompatibilities among Process Assumptions and Object Semantics	Shared Repository, Point-to-Point Message Passing, Customizable User Interface Support, Largely Workable Incompatibilities among Process Assumptions and Object Semantics	Highly Associative Repository, Point-to-Point Message Passing Using reference for Parameters, Some level of Different User Interface, Largely Consistent among Process Assumption and Object Semantics	Distributed-Associative Repository, Extended Point-to-Point Message Passing for Tool Activation, Complete Set of User Interface for different level of Users, Fully Consistent among Process Assumption and Object Semantics

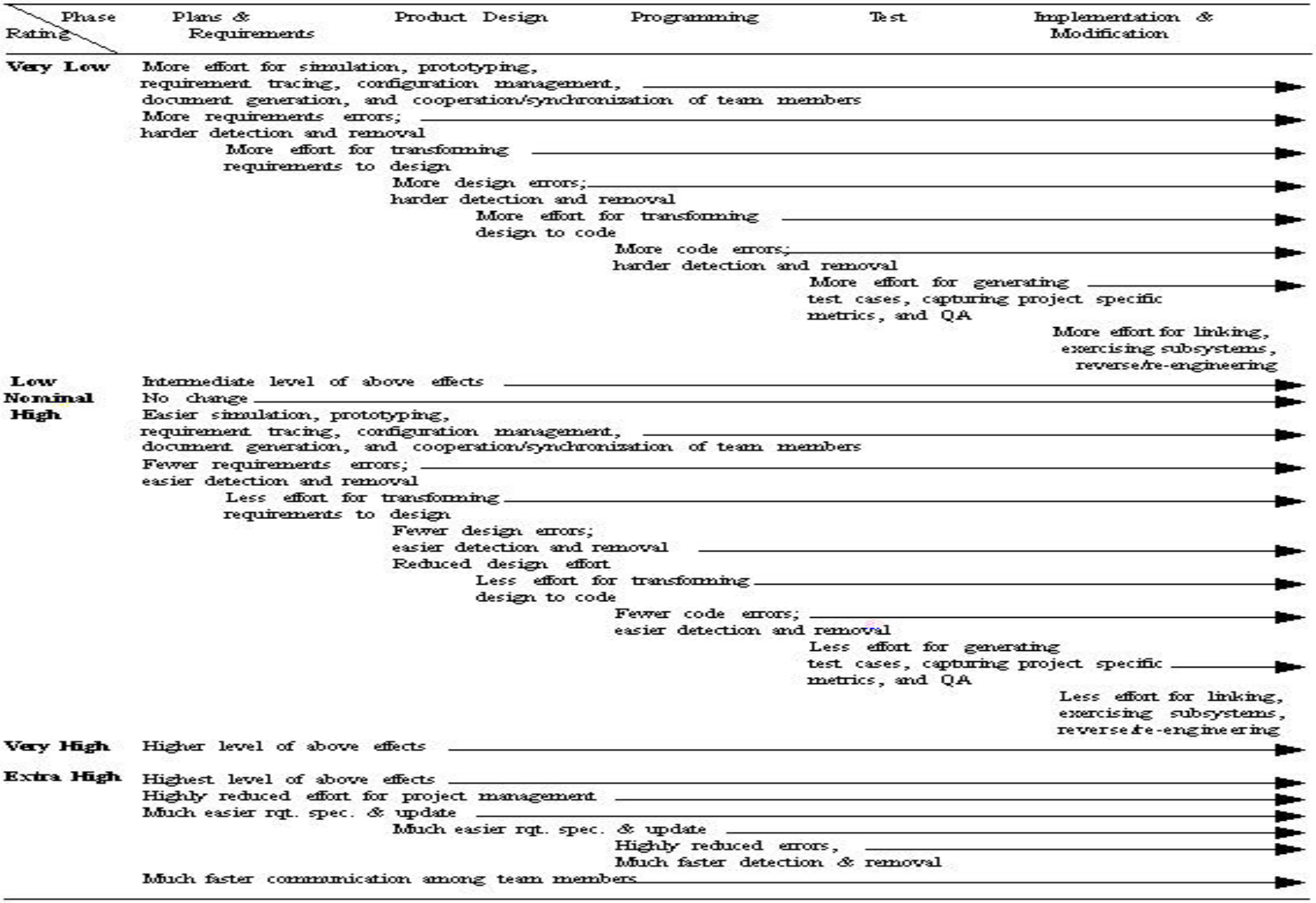
- Based on
  - **Wasserman's five level model of Integration**
    - *Platform Integration: Tools run on the same hardware/operating system platform*
    - *Data Integration: Tools operate using the shared data model*
    - *Presentation Integration: Tools offer a common user interface*
    - *Control Integration: Tools activate and control the operation of other tools*
    - *Process Integration: Tool usage guided by an explicit process model and associated process engine*

Tool Maturity and User Support (TMAT)

	Very Low	Low	Nominal	High	Very High	Extra High
Tool Maturity and User Support	Version in pre-release beta-test, Simple documentation and help	Version on market/available less than 6 month, Up-dated documentation, help available	Version on market/available between 6 months and 1 year, On-line help, tutorial available	Version on market/available between 1 and 2 years, On-line User Support Group	Version on market/available between 2 and 3 years, On-Site Technical User Support Group	Version on market/available more than 3 years

- Based on
  - Correlation between maturity and years after they are released in CASE market
  - Increasing level of vendor support services

Project Activity Difference (TCOV)



Research Model

- Extension of COCOMO II Post-Architecture Model
- 3 Productivity Dimensions instead of 1 Productivity Dimension in COCOMO II just based on Completeness of Tool Coverage
- Weighted Sum of Product of Weighting Values and 3 TOOL Rating Scales

$$Effort = A \cdot (Size)^{B} \cdot (\prod_{\substack{i=1 \\ i \neq 15}}^{17} EM_i) \cdot TOOL$$

Where

$$EM_{15} = TOOL$$

$$TOOL = b_1 \cdot TINT + b_2 \cdot TMAT + b_3 \cdot TCOV$$

$$\sum_{i=1}^{3} b_i = 1$$

Delphi Assessment – Step 4 (Prior Distribution)

- **Expert-Judged relative weighting values for the TOOL rating scales**
- **An effective way of getting group consensus (Quantitative values)**
- **Alleviates the problem of individual biases and results in an improved consensus group estimate.**

	TCOV	TINT	TMAT
Mean	0.47	0.26	0.27
Var.	0.025694	0.005485	0.016875

2 Round Delphi Process Result

Sample Regression Fit - Step 5

- Sample: 15 Project data from COCOMO II database

$$TOOL = b_1TCOV + b_2TCOV + b_3TMAT \longrightarrow y = bX + e$$

Regression fit Using *Arc*

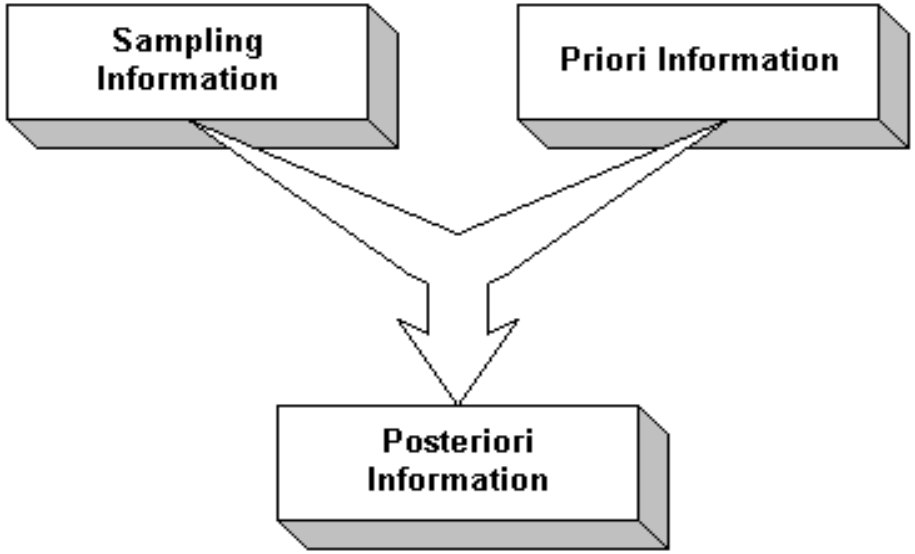
```
Data set = TOOL_15_data, Name of Fit = L1
Normal Regression
Kernel mean function = Identity
Response      = TOOL
Terms         = (TCOV TINT TMAT)
With no intercept.
Coefficient Estimates
Label      Estimate        Std. Error    t-value
TCOV       0.515982        0.0888635       5.806
TINT       0.282561        0.107657        2.625
TMAT       0.165480        0.111398        1.485

Sigma hat:                0.048214
Number of cases:               15
Degrees of freedom:            12

Summary Analysis of Variance Table
Source         df       SS             MS            F     p-value
Regression      3   20.5056         6.8352      2940.40      0.0000
Residual       12  0.027895      0.00232459
```

Bayesian Analysis - Step 6

(Combination of Delphi & Sample Info.)

$$g(q \mid Y) = \frac{f(Y \mid q)g(q)}{f(Y)}$$

$$g(q \mid Y) \approx l(q \mid Y)g(q)$$



$$\mathbf{b}^{**} = [\frac{1}{s^2}\mathbf{X}'\mathbf{X} + \mathbf{H}^*]^{-1} \times [\frac{1}{s^2}\mathbf{X}'\mathbf{X}\mathbf{b} + \mathbf{H}^*\mathbf{b}^*]$$

$$\mathrm{Var}(\mathbf{b}^{**}) = [\frac{1}{s^2}\mathbf{X}'\mathbf{X} + \mathbf{H}^*]^{-1}$$

Point Estimates of Coefficients

Distribution		b_1	b_2	b_3
PRIOR	Mean	**0.47**	**0.26**	**0.27**
	Variance	0.025694	0.005485	0.016875
SAMPLE	Mean	**0.515982**	**0.282561**	**0.165480**
	Variance	0.0078967	0.011590	0.012409
POSTRIOR	Mean	**0.495104**	**0.259691**	**0.211617**
	Variance	0.00461028	0.00335019	0.005255464

- Normalized posterior weighting values
  - Sum of the weighting values = 1
  - TOOL = 0.51 * TCOV + 0.27 * TINT + 0.22 * TMAT

Comparison of Prediction Accuracies

- Magnitude of Relative Errors

$$MRE = \left| \frac{Estimated - Actual}{Actual} \right|$$

- Improved Prediction Accuracy over 15 project data
  - From 67 % (COCOMO II.2000) to 87% actuals within 10% MRE
- Same prediction accuracy in Sample & Posterior
  - But, Variances of Coefficient Estimates in Bayesian are Smaller

	COCOMO II.2000 (1 Dimensional TOOL)	Sample (3 Dimensional TOOL)	Bayesian Posterior (3 Dimensional TOOL)
PRED (.10)	67%	87%	87%

Cross Validation by Data Splitting

- A widely used model checking method to validate a regression model
- Divides the original dataset into two parts
  - ***Construction***: Exploration and model formulation
  - ***Validation***: Model validation, formal estimation and testing
    - used in the same way as in the newly collected dataset
- Criteria Function
  - PRESS (Predicted Residual Sum of Squares)
  - Small PRESS indicates that the estimated regression model is a good model

$$PRESS = \sum \hat{e}^2_{(i)}$$

where

$$\hat{e}^2_{(i)} = y_i - X_i^T \hat{\beta}_{(i)} = \frac{\hat{e}_i}{1 - h_{ii}}$$

Cross Validation Summary

1st validation (TOOL)	Cross validation summary of cases not used to get estimates: Sum of squared deviations: **9.76793** Mean squared deviation: 0.212346 Sqrt(mean squared deviation): 0.460811 Number of observations: 46 > (/ (sum (^ (/ (send L1 :residuals) (- 1 (send L1 :leverages))) 2)) (send L1 :num-included)) **0.262203**
2nd validation (TCOV, TINT, and TMAT) **PRESS**	Cross validation summary of cases not used to get estimates: Sum of squared deviations: **9.7475** Mean squared deviation: 0.211902 Sqrt(mean squared deviation): 0.460328 Number of observations: 46 >(/ (sum (^ (/ (send L1 :residuals) (- 1 (send L1 :leverages))) 2)) (send L1 :num-included)) **0.260493**

- Different Construction datasets are used
  - 46 randomly selected project data excluded
  - 1st validation : used one dimension TOOL for both construction and validation sub-samples
  - 2nd validation: used three dimensional TCOV, TINT, and TMAT for only 15 projects out of 161 separated into both construction (11) and validation (4) sub-samples

Cross Validation - Bootstrap

- A statistical simulation methodology
  - Re-samples from the original dataset
- Used to solve two of the most important problems
  - Determination of an estimator for a particular parameter of interest
  - Evaluation of that estimator through the standard error
- Bootstrap Procedure
  - Generate a bootstrap sample of size n (where n is the original sample size) with replacement from the original distribution
  - Compute θ^*, the value of $\hat{\theta}$ obtained by using the bootstrap sample in place of the original sample
  - Repeat steps 1 and 2 , *k* times

Bootstrap Summary

- **COCOMO II log transformed regression model**

$$\log PM = \beta_0 \log A + \beta_1 B \log Size + \beta_2 SF_1 \log Size + \ldots + \beta_6 SF_5 \log Size +$$
$$\beta_7 \log Size EM_1 + \beta_8 \log Size EM_2 + \ldots + \beta_{23} \log Size EM_{17}$$

- **Bootstrap Estimates for log[TOOL]**

	Std-Error	Bias	Confidence Interval
One Dimension (TOOL)	0.392141	0.030489	(0.184884 1.67873)
Three Dimensions (TCOV, TINT, & TMAT)	0.368760	0.022662	(0.224192 1.63596)

- 1000 boots of same size (161): used in the program *Arc*
- Difference is not great. But, The results is stable and in the right direction

Contributions

- **Proposed three-dimensional TOOL rating scales to evaluate Software Tools effectively**
- **Increased the Prediction Accuracy for an initial set of data points via Bayesian Approach**
- **Demonstrated a method to calibrate the individual contributions to a multidimensional parameter**
- **Validated the research model using cross-validation methods**
  - **Data Splitting and Bootstrapping methods**

Future Works

- Refine behavioral analysis of TOOL effects
- Data Collection for interaction among TOOL rating scales
- Calibration of the next version of COCOMO II with and without TOOL rating scales
- Determine weights of individual CASE TOOL rating-scale effects on S/W development effort
- Tool Support for ROI Analysis of CASE tool adoption
- Integration of ROI Analyzer with USC-COCOMO II