

## Appendix 1: Quality Certification Standards

The basic principle that most quality programs are based upon is that organizations that follow accepted practices and procedures are more likely to create reliable products in a consistent manner suitable to the customer's needs [29].

### The ISO 9000 series:

The ISO standards were developed with the intent of creating a set of common standards for quality management and quality assurance. The ISO 9000 does not guarantee quality products. The ISO series that are most applicable to software development are:

ISO 9001 - "Quality Systems - Model for quality assurance in design/development, production, installation and servicing"

ISO 9000-3 - "Guideline for application of ISO 9001 to the development, supply and maintenance of software.

The main clauses of the ISO 9000-3 are shown in the table below:

Clause Number	ISO 9001 Title
4	Quality system requirements
4.1	Management responsibility
4.2	Quality system
4.3	Internal quality system audits
4.4	Corrective Action
5	Quality system – Life-cycle activities
5.1	General
5.2	Contract review
5.3	Purchaser's requirement specification
5.4	Development planning
5.5	Quality planning
5.6	Design and implementation
5.7	Testing and validation
5.8	Acceptance testing
5.9	Replication, delivery and installation
5.10	Maintenance
6	Quality system – Support activities
6.1	Configuration and management
6.2	Document control
6.3	Quality records
6.4	Measurement
6.5	Rules, practices and conventions
6.6	Tools and techniques
6.7	Purchasing
6.8	Included software product
6.9	Training

## CMM: The Capability Maturity Model for Software.

Initially developed by the Software Engineering Institute (SEI), the CMM is organized into five maturity levels. Predictability, effectiveness, and control of an organization's software processes are believed to improve as the organization moves up these five levels.

**Initial:** The software process is characterized as ad hoc, and occasionally even chaotic.

**Repeatable:** Basic project management processes to track cost, schedule, and functionality in place.

**Defined:** The software process for both management and engineering activities is documented, standardized and integrated into a standard software process for the organization. All projects use an approved, tailored version of the organization's standard software process for developing and maintaining software.

**Managed:** Detailed measures of the software process and product quality are collected. Both the software process and products are quantitatively understood and controlled.

**Optimizing:** Continuous process improvement, enabled by quantitative feedback from the process and from piloting innovative ideas and technologies.

Each level has a set of key process areas (KPA's). They are shown in the table below:

CMM Level	Key Process Areas (18)	Essence
<b>2</b> Repeatable level	-Requirements management -Software project planning -Software project tracking and oversight, -Software subcontract management -Software quality assurance -Software configuration management	Policies for managing a software project and procedures to implement those policies are established
<b>3</b> Defined level	-Organization process focus -Organization process definition -Training program -Integrated software management -Software product engineering -Inter-group coordination -Peer reviews	A standard process (processes) for maintaining software is documented and used across the organization
<b>4</b> Managed level	-Quantitative process management -Software quality management	The organization sets quantitative quality goals for both software products and processes
<b>5</b> Optimizing level	-Defect prevention -Technology change management -Process change management	Entire organization is focussed on continuous process improvement

### Comparing the CMM and ISO 9001:

Trade publications suggest that an ISO certified company is about SEI-CMM level 3. A detailed comparison is available as a technical report published by the SEI [30]. The salient difference is that the CMM is more tuned to software development, quantitative in its approach and is intent based as far as an organization's metrics/ measurement program is concerned [19].

## Appendix 2: Software metrics

Halstead's[13] measure of volume of a program is based on the number of operators and operands.

In a program, we define the following measurable quantities:

$n_1$  is the number of distinct operators,

$n_2$  is the number of distinct operands,

$f_{1,j}$  is the number of occurrences of the  $j$ th most frequent operator and

$f_{2,j}$  is the number of occurrences of the  $j$ th most frequent operand.

Then the vocabulary  $n$  of the program is defined as

$$n = n_1 + n_2.$$

The total occurrences of the operators ( $N_1$ ) and operands ( $N_2$ ) are defined as:

$$N_1 = \sum f_{1,j} \text{ and } N_2 = \sum f_{2,j}.$$

The total length of the program ( $N$ ) is defined as:

$$N = N_1 + N_2$$

From the length and the vocabulary, the volume  $V$  of the program is defined as:

$$V = \log_2 n$$

This definition of the volume of the program represents the minimum number of bits necessary to represent the program. This volume could be used as a size metric for the program.

### Appendix 3: The Fuller-Battese method for panel data

Fuller-Battese Method (Variance Components Model)

$$\mathbf{y} = \mathbf{X}\boldsymbol{\beta} + \mathbf{u}$$

$$\mathbf{u} = \boldsymbol{\alpha}_i + \mathbf{v}_t + \boldsymbol{\varepsilon}_{it}$$

where

$$\mathbf{y} = (y_{11}, y_{12}, \dots, y_{1T}, \dots, y_{N1}, \dots, y_{NT})'$$

$$\mathbf{X} = (\mathbf{x}_{11}, \mathbf{x}_{12}, \dots, \mathbf{x}_{1T}, \dots, \mathbf{x}_{N1}, \dots, \mathbf{x}_{NT})'$$

$\mathbf{x}_{it}$  are  $p \times 1$  vectors of independent variables

$\boldsymbol{\beta}$  is a  $p \times 1$  parameter vector

$$\mathbf{u} = (u_{11}, u_{12}, \dots, u_{1T}, \dots, u_{N1}, \dots, u_{NT})'$$

The covariance matrix for the vector of random errors  $\mathbf{u}$  can be expressed

$$\mathbf{V} = E(\mathbf{u}\mathbf{u}') = \sigma_{\varepsilon}^2 \mathbf{I}_{NT} + \sigma_v^2 \mathbf{A} + \sigma_e^2 \mathbf{B}$$

$$\mathbf{A} = \mathbf{I}_N \otimes \mathbf{J}_T$$

$$\mathbf{B} = \mathbf{J}_N \otimes \mathbf{I}_T$$

$\mathbf{I}_{NT}$ ,  $\mathbf{I}_N$ ,  $\mathbf{I}_T$  are identity matrices of order  $NT$ ,  $N$ ,  $T$ ;  $\mathbf{J}_N$  and  $\mathbf{J}_T$  are  $N \times N$  and  $T \times T$  matrices with all elements as 1; and  $\otimes$  represents the Kronecker product. The following square matrices are defined as:

$$\mathbf{M}_{..} = \mathbf{J}_{NT}/NT$$

$$\mathbf{M}_{1.} = \mathbf{A}/T - \mathbf{M}_{..}$$

$$\mathbf{M}_{.2} = \mathbf{B}/T - \mathbf{M}_{..}$$

$$\mathbf{M}_{12} = \mathbf{I}_{NT} - \mathbf{A}/T - \mathbf{B}/N + \mathbf{M}_{..}$$

Where  $\mathbf{J}_{NT}$  is a  $NT \times NT$  matrix with all elements equal to 1.

The estimators for variance components are obtained by the fitting-of-constants method with the provision that any negative variance component is set to 0 for parameter estimation purposes.

First, the least-squares residual vectors are defined as:

$$\hat{\boldsymbol{\varepsilon}} = \mathbf{C}_1(\mathbf{I}_{NT} - \mathbf{X}[\mathbf{X}'\mathbf{C}_1\mathbf{X}]^{-1}\mathbf{X}'\mathbf{C}_1)\mathbf{y}$$

$$\hat{\mathbf{v}} = \mathbf{C}_2(\mathbf{I}_{NT} - \mathbf{X}[\mathbf{X}'\mathbf{C}_2\mathbf{X}]^{-1}\mathbf{X}'\mathbf{C}_2)\mathbf{y}$$

$$\hat{\boldsymbol{\alpha}} = \mathbf{C}_3(\mathbf{I}_{NT} - \mathbf{X}[\mathbf{X}'\mathbf{C}_3\mathbf{X}]^{-1}\mathbf{X}'\mathbf{C}_3)\mathbf{y}$$

Where  $\mathbf{A}^{-}$  denotes the generalized inverse of  $\mathbf{A}$ ,  $\mathbf{C}_1 = \mathbf{M}_{12}$ ,  $\mathbf{C}_2 = \mathbf{M}_{12} + \mathbf{M}_{1.}$  and  $\mathbf{C}_3 = \mathbf{M}_{12} + \mathbf{M}_{.2}$ .

The generalized least-squares estimation steps are:

1. Obtain the constants using the following estimators for variance components

$$\hat{\alpha}_1 = 1 - [\hat{\sigma}_\varepsilon^2 / (\hat{\sigma}_\varepsilon^2 + T\hat{\sigma}_v^2)]^{\frac{1}{2}}$$

$$\hat{\alpha}_2 = 1 - [\hat{\sigma}_\varepsilon^2 / (\hat{\sigma}_\varepsilon^2 + N\hat{\sigma}_e^2)]^{\frac{1}{2}}$$

$$\hat{\alpha}_3 = \hat{\alpha}_1 + \hat{\alpha}_2 - 1 + [\hat{\sigma}_\varepsilon^2 / (\hat{\sigma}_\varepsilon^2 + T\hat{\sigma}_v^2 + N\hat{\sigma}_e^2)]^{\frac{1}{2}}$$

2. Transform the variables using constants  $\alpha_1$ ,  $\alpha_2$  and  $\alpha_3$  as follows:

$$y_{it}^* = y_{it} - \hat{\alpha}_1 y_{i.} - \hat{\alpha}_2 y_{.t} + \hat{\alpha}_3 y_{..}$$

$$\mathbf{x}_{it}^* = \mathbf{x}_{it} - \hat{\alpha}_1 \mathbf{x}_{i.} - \hat{\alpha}_2 \mathbf{x}_{.t} + \hat{\alpha}_3 \mathbf{x}_{..}$$

Where  $y_{..}$ ,  $y_{i.}$  and  $y_{.t}$  are defined the same way as  $x_{..}$ ,  $x_{i.}$  and  $x_{.t}$ .

3. Regress  $y_{it}^*$  on  $\mathbf{x}_{it}^*$  using OLS.

The estimated generalized least-squares (EGLS) estimator  $\hat{\beta}_F$  and its standard error can be obtained from the OLS estimator in step 3.

$$\hat{\beta}_F = (\mathbf{X}'\hat{\mathbf{V}}^{-1}\mathbf{X})^{-1}\mathbf{X}'\hat{\mathbf{V}}^{-1}\mathbf{y}$$

where

$$\hat{\mathbf{V}}^{-1} = \frac{\mathbf{M}_{12}}{\hat{\sigma}_\varepsilon^2} + \frac{\mathbf{M}_{1.}}{\hat{\sigma}_\varepsilon^2 + T\hat{\sigma}_v^2} + \frac{\mathbf{M}_{.2}}{\hat{\sigma}_\varepsilon^2 + N\hat{\sigma}_e^2} + \frac{\mathbf{M}_{..}}{\hat{\sigma}_\varepsilon^2 + T\hat{\sigma}_v^2 + N\hat{\sigma}_e^2}$$

#### Appendix 4: Description of control variables

<b>Variable</b>	<b>Definition</b>	<b>Number of firms in category</b>
<i>Captive</i>	Firms that provide services for parent companies only	16
<i>Telecom</i>	Companies that provide services to the telecom sector	34
<i>Commsoft</i>	Companies working in communications software (networking)	29
<i>Year2000</i>	Companies providing year-2000 and Euro conversion services	36
<i>Netbased</i>	Companies working on web based technologies and E-commerce	46
<i>ERPS</i>	Companies providing ERP services like the implementation of SAP, BAAN and PeopleSoft	27
<i>Qyr94</i>	Companies certified in 1994 or before	17
<i>Qyr95</i>	Companies certified in 1995	9
<i>Qyr96</i>	Companies certified in 1996	11
<i>Qcateg1</i>	Companies that have been certified for one year	
<i>Qcateg2</i>	Companies that have been certified for 2 years	