



ASSOCIATION CONNECTING
ELECTRONICS INDUSTRIES®

IPC-9194

Implementation of Statistical Process Control (SPC) Applied to Printed Board Assembly Manufacture Guideline

IPC-9194

September 2004

A standard developed by IPC

3000 Lakeside Drive, Suite 309S, Bannockburn, IL 60015-1219

Tel. 847.615.7100 Fax 847.615.7101
www.ipc.org



Documents
Document Sharing Hub

The Principles of Standardization

In May 1995 the IPC's Technical Activities Executive Committee adopted Principles of Standardization as a guiding principle of IPC's standardization efforts.

Standards Should:

- Show relationship to Design for Manufacturability (DFM) and Design for the Environment (DFE)
- Minimize time to market
- Contain simple (simplified) language
- Just include spec information
- Focus on end product performance
- Include a feedback system on use and problems for future improvement

Standards Should Not:

- Inhibit innovation
- Increase time-to-market
- Keep people out
- Increase cycle time
- Tell you how to make something
- Contain anything that cannot be defended with data

Notice

IPC Standards and Publications are designed to serve the public interest through eliminating misunderstandings between manufacturers and purchasers, facilitating interchangeability and improvement of products, and assisting the purchaser in selecting and obtaining with minimum delay the proper product for his particular need. Existence of such Standards and Publications shall not in any respect preclude any member or nonmember of IPC from manufacturing or selling products not conforming to such Standards and Publication, nor shall the existence of such Standards and Publications preclude their voluntary use by those other than IPC members, whether the standard is to be used either domestically or internationally.

Recommended Standards and Publications are adopted by IPC without regard to whether their adoption may involve patents on articles, materials, or processes. By such action, IPC does not assume any liability to any patent owner, nor do they assume any obligation whatever to parties adopting the Recommended Standard or Publication. Users are also wholly responsible for protecting themselves against all claims of liabilities for patent infringement.

IPC Position Statement on Specification Revision Change

It is the position of IPC's Technical Activities Executive Committee (TAEC) that the use and implementation of IPC publications is voluntary and is part of a relationship entered into by customer and supplier. When an IPC publication is updated and a new revision is published, it is the opinion of the TAEC that the use of the new revision as part of an existing relationship is not automatic unless required by the contract. The TAEC recommends the use of the latest revision.
Adopted October 6, 1998

Why is there a charge for this document?

Your purchase of this document contributes to the ongoing development of new and updated industry standards and publications. Standards allow manufacturers, customers, and suppliers to understand one another better. Standards allow manufacturers greater efficiencies when they can set up their processes to meet industry standards, allowing them to offer their customers lower costs.

IPC spends hundreds of thousands of dollars annually to support IPC's volunteers in the standards and publications development process. There are many rounds of drafts sent out for review and the committees spend hundreds of hours in review and development. IPC's staff attends and participates in committee activities, typesets and circulates document drafts, and follows all necessary procedures to qualify for ANSI approval.

IPC's membership dues have been kept low to allow as many companies as possible to participate. Therefore, the standards and publications revenue is necessary to complement dues revenue. The price schedule offers a 50% discount to IPC members. If your company buys IPC standards and publications, why not take advantage of this and the many other benefits of IPC membership as well? For more information on membership in IPC, please visit www.ipc.org or call 847/597-2872.

Thank you for your continued support.



ASSOCIATION CONNECTING
ELECTRONICS INDUSTRIES®

IPC-9194

Implementation of Statistical Process Control (SPC) Applied to Printed Board Assembly Manufacture Guideline

Developed by the Statistical Process Control Subcommittee (7-22) of
the Process Control Management Committee (7-20) of IPC

Users of this publication are encouraged to participate in the
development of future revisions.

Contact:

IPC
3000 Lakeside Drive, Suite 309S
Bannockburn, Illinois
60015-1219
Tel 847 615.7100
Fax 847 615.7105

 **Documents**
Document Sharing Hub

This Page Intentionally Left Blank

Acknowledgment

Any document involving a complex technology draws material from a vast number of sources. While the principal members of the Statistical Process Control Subcommittee (7-22) of the Process Control Management Committee (7-20) are shown below, it is not possible to include all of those who assisted in the evolution of this standard. To each of them, the members of the IPC extend their gratitude.

Process Control Management Committee

Chair
Patricia Goldman

Statistical Process Control Subcommittee

Co-Chairs
Praveen Gupta
Quality Technology Company

and
Nicholas R. Watts
Intel Corporation

Technical Liaisons of the IPC Board of Directors

Peter Bigelow
IMI Inc

Sammy Yi
Flextronics International

Statistical Process Control Subcommittee

Peter Adams, Ramaer Printed Circuits
B.V.
John F. Glaccum, Ethicon
Endo-Surgery
Constantino J. Gonzalez, ACME
Training & Consulting

Les Hymes, The Complete
Connection
Renee Jung, NSWC Crane
Guy Ramsey, American
Competitiveness Institute
Michael Sivigny, Eagle-Eyed One

Darren Stinson, Ideal Aerosmith Inc.
Richard Williams, Pulse Electronics
Heinz Wohlrabe, Ph.D., Dresden
University of Technology
Michael J. Zurn, Phoenix
International Corp.



Documents

Document Sharing Hub

iii

Table of Contents

1 SCOPE	1	6.4.3 Data Collection	11
1.1 Purpose	1	6.5 Data Analysis	12
1.2 Interpretation	1	6.6 Documented Work Instructions	12
2 NORMATIVE REFERENCES	1	6.7 Interpretation and Process Controls	12
2.1 IPC	1	6.8 SPC Reporting - Process Levels and Trends	12
2.2 International Organization for Standardization	1	6.9 Internal SPC Audits	12
2.3 Automotive Industry Action Group	1	6.10 Management Review	12
3 TERMS AND DEFINITIONS	1	6.11 Improving Process Capability	12
4 SPC OBJECTIVES	1	6.11.1 SPC Projects and Teams	12
4.1 General and Specific Objectives	1	6.11.2 Process Improvement and Optimization	13
4.2 Financial Objectives	2	6.12 Customer Information System	13
5 CONDITIONS FOR SPC	2	A1: IPC-9191 to IPC-9194 Correlation Matrix	15
5.1 Management Support	2	A2: IPC-9194 to IPC-9191 Correlation Matrix	19
5.1.1 Organizational Structure	3		
5.1.2 Implementation Plan	3		
5.1.2.1 Elements	3		
5.1.2.2 Action Plan	3		
5.2 Understanding of SPC Tools and Methods	3		
5.2.1 Executive Overview	4		
5.2.2 Basic Statistics and SPC Tools	5		
5.2.3 Advanced Problem Solving Tools	5		
5.3 Integration with Quality System	5		
6 ELEMENTS OF STATISTICAL PROCESS CONTROL SYSTEM	5		
6.1 Process Documentation	5		
6.1.1 Process Mapping	5		
6.1.2 Establishing Process Targets and Limits and Performance Baseline	5		
6.1.3 Process Prioritization Matrix	5		
6.1.4 Parameter Identification	5		
6.2 Measurement System Evaluation	8		
6.3 Process Characterization	9		
6.3.1 Process Characterization Method	9		
6.3.2 Determining Parameter Capability	10		
6.4 Practicing SPC	10		
6.4.1 Employee Training and Involvement	10		
6.4.2 Control Plan	11		

Figures

Figure 4-1	Example of a Cost of Quality Report Format (Estimated Annual Sales \$200M)	2
Figure 5-1	Steps to Statistical Process Control	3
Figure 6-1	Electronics Manufacturing Process Flowchart	6
Figure 6-2	Example of a Fishbone Diagram for Solder Shorts due to Solder Printing Process	8
Figure 6-3	Gage R&R Analysis Output of Optical Inspection System for Solder Paste Height	9
Figure 6-4	PBA SMT Solder Printing Process Control Plan	11
Figure 6-5	DOE Strategy Example (Number of Factors <6)	13

Tables

Table 5-1	Elements of an SPC Implementation Plan (Not Inclusive)	4
Table 5-2	Printed Board Assembler Training Plan	5
Table 6-1	Printed Board Assembly Process Prioritization Matrix (Values shown are benchmarks)	7
Table 6-2	Parameter Identification Matrix for Solder Paste Deposition	8
Table 6-3	Acceptance Levels	9
Table 6-4	Gage R&R Analysis (ANOVA)	9
Table 6-5	Process Characterization Guidelines	10

Implementation of Statistical Process Control (SPC) Applied to Printed Board Assembly Manufacture Guideline

1 SCOPE

The IPC-9194 should be used in conjunction with IPC-9191. The IPC-9191 provides general guidelines for implementing SPC in electronics industry.

This standard is intended to aid in interpretation of the requirements in IPC-9191 specifically for Printed Board Assembly (PBA) manufacture. This standard promotes process thinking and control of process inputs, in-process parameters and process outputs, including product parameters. The standard organizes various aspects of process control in the Plan, Do, Check and Act (PDCA) cycle.

1.1 Purpose Purpose of the IPC-9194 is to establish practical guidelines for implementation of SPC in the electronics manufacturing operations for continually improving processes and reducing waste.

The standard includes establishing conditions for SPC, implementation of SPC and sustaining SPC. The Implementation phase includes the following elements:

1. Preparation
2. Set up and Process Characterization
3. Practicing SPC
4. Monitoring Effectiveness of SPC
5. Improving Process Capability

Successful implementation of SPC is contingent on effectiveness of the quality management system that includes controlled documentation, calibration, corrective action and management review elements.

1.2 Interpretation “Should” and “may” are used whenever it is necessary to express nonmandatory provisions.

“Will” is used to express a declaration of purpose.

“Applicable” reflects mutual agreements between customer and organizations.

“Documentation” is factual or substantial support for statement made.

“References” are intended to clarify and to add information not to be used as auditable criteria. Any reference is noted by the author’s last name, followed by the year of publication in parenthesis.

“Examples” provide additional information only and are not to be interpreted as requirements. These examples are shown in the outlined sections.

“Where appropriate” indicates the organization is expected to provide rationale for appropriateness.

2 NORMATIVE REFERENCES

2.1 IPC¹

IPC-T-50 Terms and Definitions for Interconnecting and Packaging Electronic Circuits

IPC-9191 General Guidelines for Implementation of Statistical Process Control

IPC-9199 Statistical Process Control (SPC) Quality Rating

2.2 International Organization for Standardization²

ISO 9001:2000 Quality Management System Requirements

ISO 10012 Calibration System Requirements

ISO 10017 Guidance on Statistical Techniques for ISO 9001:2000

ISO 11462-1 Guidelines for Implementation of Statistical Process Control (SPC) - Part 1: Elements of SPC

2.3 Automotive Industry Action Group³

AIAG-APQP-2 Advanced Product Quality Planning and Control Plan

AIAG-MSA-3 Measurement Systems Analysis

3 TERMS AND DEFINITIONS

Terms and definitions **shall** be in conformance with IPC-T-50 and as defined in IPC-9191.

4 SPC OBJECTIVES

4.1 General and Specific Objectives General objectives of Statistical Process Control (SPC) are: Increasing knowledge about the process; steering a process to behave in the desired way; reducing variation of final-product parameters, or in other ways improving performance of a process.

1. www.ipc.org

2. www.iso.org

3. www.aiag.org

Objectives of implementing SPC in electronics manufacturing operations include maintaining process capability, reducing process variability, reducing product inspection and testing, and achieving superior process efficiencies and throughput.

Each organization should clearly establish specific objectives for implementing SPC. The objectives should be linked to business objectives such as waste, customer satisfaction or profitability. The SPC objectives should be translated into organizational objectives with clear responsibility and measurements.

See IPC-9191 for further elaboration of SPC objectives.

4.2 Financial Objectives The SPC objectives should be defined based on cost and benefit analysis, including cost of quality.

Example: Cost of Quality:

A typical cost of quality program monitors the four areas of cost. The breakdown of cost is as follows in Figure 4-1.

5 CONDITIONS FOR SPC

5.1 Management Support Executive management should drive SPC throughout operations.

Description	Estimates	
	Total Cost	As % of Sales
External Failure Costs		
1 - Material Review	0.5 M	0.25%
2 - Corrective Action	0.5 M	0.25%
3 - Rework/Freight	1.5 M	0.75%
4 - Customer Service	1 M	0.5%
5 - Loss of Contract	0.5 M	0.25%
Subtotal	\$4 M	2.0%
Appraisal Costs		
1 - Tests	0.75 M	0.375%
2 - Organization Inspection	0.35 M	0.175%
3 - In-Process Inspections	0.40 M	0.2%
4 - Final Inspection	1.25 M	0.625%
5 - Maintenance/Calibration	0.25 M	0.125%
Subtotal	\$3.0 M	1.50%
Internal Failure Costs		
1 - Design	-	-
2 - Organization	1.5 M	0.75%
3 - Material Review	1 M	0.5%
4 - Corrective Action	0.5 M	0.25%
5 - Scrap	4 M	2.0%
6 - Rework	3 M	1.5%
Subtotal	\$10 M	5.0%
Prevention Costs		
1 - Design	-	-
2 - Purchasing	0.125 M	0.625%
3 - Planning	0.0625 M	0.03125%
4 - Administration	0.125 M	0.0625%
5 - Training	0.1875 M	0.09375%
Subtotal	\$0.5 M	0.25%

	Total Cost	As % of Sales
External Failure Cost Subtotal	\$ 4.0 M	2.0%
Internal Failure Cost Subtotal	\$10.0 M	5.0%
Appraisal Cost Subtotal	\$ 3.0 M	1.5%
Prevention Cost Subtotal	\$ 0.5 M	0.25%
Total Cost of Quality	\$17.5 M	8.75%

IPC-9194-4-1

Figure 4-1 Example of a Cost of Quality Report Format (Estimated Annual Sales \$200M)

Executive management of a PBA should commit to implementing SPC through its intent, action, decision making, and resources allocation. The management should actively review effectiveness of its SPC system in terms of customer satisfaction, process improvement and waste reduction (\$).

5.1.1 Organizational Structure The SPC organizational support structure should be in coordination with other initiatives in the organization. Typically, an executive level quality management representative, or a designated SPC Champion can become responsible for initiating, training, facilitating, implementation and maintaining statistical process controls in an organization.

Depending upon the size of an organization, a full time or part time SPC Champion, or equivalent can be designated to lead the SPC effort throughout the organization. For effective implementation of statistical process controls, the following should be clearly defined and documented:

1. An organization chart establishing the independence of the quality organization from production operation.
2. Manufacturing has the primary responsibility for quality. The adversary relationship between quality and production is discouraged, however, the quality organization is the final authority on process/product quality.
3. Quality organization is responsible for maintaining and updating the process control system.

5.1.2 Implementation Plan

5.1.2.1 Elements IPC-9191 outlines the SPC system elements that should be adopted by an organization establishing an SPC system. SPC is a process that continually leads towards optimization. The elements outlined in IPC-9191 are used to drive improvement in the overall quality system.

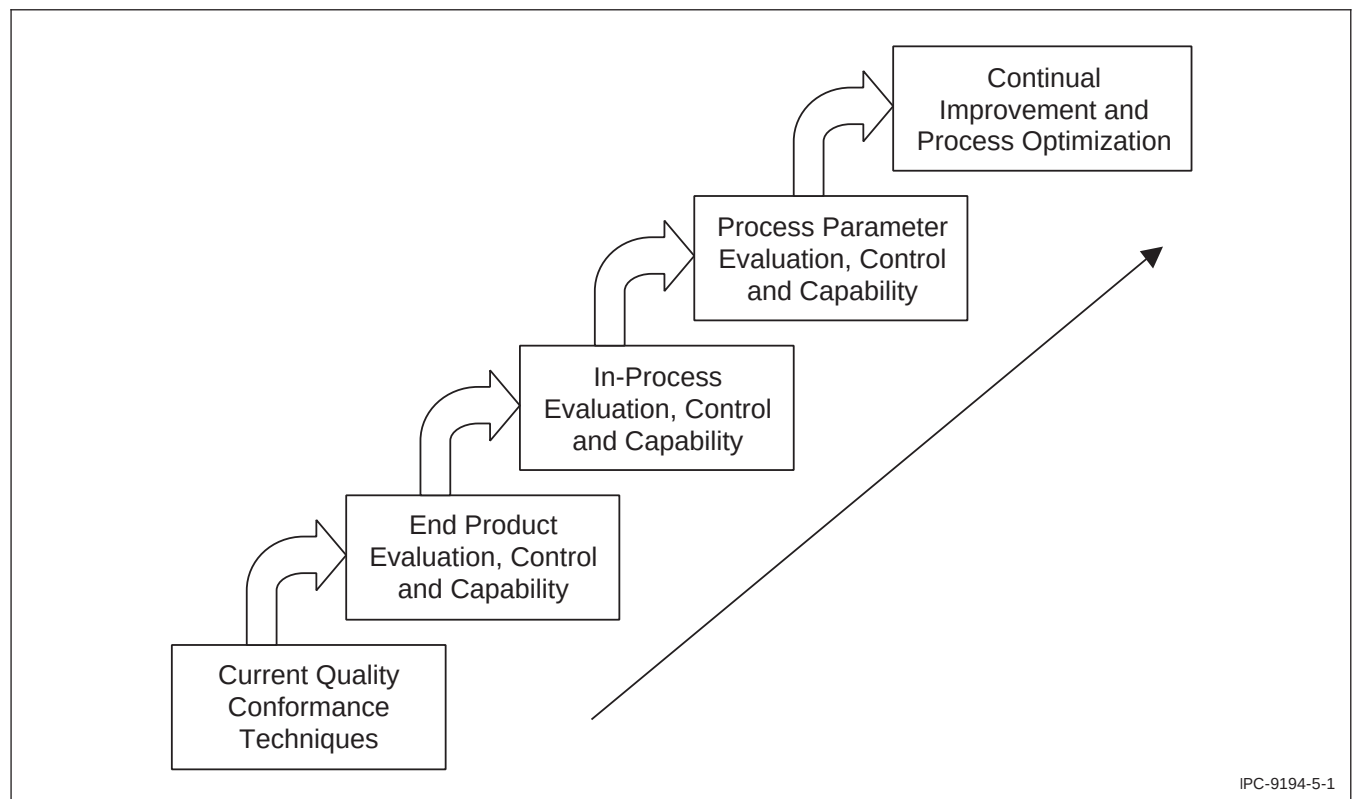
Figure 5-1 shows the stages of quality management from detection to optimization using the SPC tools.

5.1.2.2 Action Plan An SPC action plan is required for a systematic implementation of SPC. Elements of an action plan, shown in Table 5-1, can be used as guidelines for developing an organization specific action plan for SPC.

Considering the above aspects of planning, the SPC Implementation Action Plan should include the similar items in the following format:

Item #	Action Item	Responsibility	Committed Completion Date	Critical Resource Required	Status/Comments
1					
2					

5.2 Understanding of SPC Tools and Methods It is critical that PBA company executives understand value of implementing SPC and basic understanding various SPC techniques. Most importantly their role in making best use



IPC-9194-5-1

Figure 5-1 Steps to Statistical Process Control

Table 5-1 Elements of an SPC Implementation Plan (Not Inclusive)

General Principles	
Financial Consideration	A cost of quality model will be used to identify key projects for application of statistical methods using the elements of IPC-9191. The cost of quality model will capture costs in the categories of prevention, appraisal, and internal and external failure.
Management Support	Sufficient management support will be provided to support the use of statistical methods in reducing overall quality costs. Improvement projects will be evaluated on an ROI basis to evaluate the effectiveness of the SPC programs. The Accounting department will serve as the governing body over ROI evaluations. Management bonus and performance will be based on success of the statistical methods application projects.
Quality System	Organization will maintain ISO 9001 or equivalent quality system and its effectiveness in meeting intended business objectives.
Strategic Planning	This SPC strategic plan will be reviewed and revised at least annually to maintain its relevance. The plan should be communicated to and understood by all employees for their role, responsibilities and consequences.
SPC System Development	Projects identified for application of statistical methods will establish a baseline, and improve to achieve optimization as shown in Figure 4-1, i.e., statistical control of End Product to Process Parameters.
PBA Strategic Project List	Project selection should be based on the prioritization based on cost, benefits and return on investment, i.e., economic sense.
Understanding of SPC Tools and Methods	A plan to provide SPC training should be developed, funded, and implemented as needed. The plan should address training needs of all employees.
Implementation Elements	
Documentation	An effective documentation system should be in place to ensure quality of product through effective work instructions or operating procedures, traceability of material, parts or sub-assembly as required, and data collection for an effective root cause analysis.
Process Management	Key processes should be managed for their inputs, in-process and outputs, instead of just producing products. The Deming's Plan, Do, Check and Act thinking should be implemented as much as possible.
Audit and Review	Audit of SPC activities should become part of the quality system audits and the effectiveness of SPC audits should be reviewed in the management review meetings.
Parameter Management	
Identification	Critical input, in-process and end-product parameters should be identified and prioritized for each key process. Parameters should be ranked based on variation or process capability index Cp.
Measurement Systems	Repeatability and Reproducibility (R&R) studies should be performed periodically to monitor capability of measurement devices.
Capability Assessment	Weekly or regular review per Cp and Cpk index should be monitored for critical process parameters throughout operations. Minimum acceptable Cp, Cpk are 1.33 and 1.0, and preferred Cp and Cpk are 2 and 1.5, respectively.
Cause and Effect Analysis	A clearly defined methodology should be implemented to identify root cause for excessive variation in the process or to improve process capability.
Control Plan	A Parameter Control plan should be documented in the process procedure or work instructions, or in a company-wide control plan according to some established guidelines.
Continuous Improvement	A company-wide methodology (such as 8-D, Six Sigma, or equivalent) for continual improvement should be established in philosophy, intent and action.
Supplier Performance	Organization should encourage suppliers of critical supplies to implement IPC-9191 or equivalent system to improve Cp and Cpk, and reduce inspection levels.
Customer Feedback	Printed Board Assembler (PBA) should monitor customer returns and complaints related to various processes and evaluate impact of SPC on the frequency of customer concerns.
Process Reliability	PBA should complete Failure Mode and Effect Analysis (FMEA) on key processes and improve the process reliability.

of statistical controls should be understood through planning and training. To develop such an understanding, the PBA company should implement a SPC training plan for all employees, starting with executives. Each course contains a written syllabus and specific objectives. Qualified (internal or external) personal should teach all courses.

Examples of training offered to various employees are shown in Table 5-2 with the content of each level of training course as shown below the table.

5.2.1 Executive Overview Philosophy of SPC, Descriptive statistics, Statistical thinking through understanding of

Table 5-2 Printed Board Assembler Training Plan

Audience	Training Course	Cycle
Upper Management	Executive Overview of SPC methodology, Statistics and SPC Tools	Every Year
Administration/Management/Sales/Procurement	Proficiency in Basic Statistics and SPC Tools using a software	Every other year
Design, Manufacturing and Production Engineering	Proficiency in use of Statistics and Advanced Problem Solving Tools using a software	Every other year
Auditors/Operators	Proficiency in Applicable SPC tools	Every Year
New Employees	Overview of SPC methodology, Statistics and SPC Tools	Within 90 days

random and assignable variation, Capability indices (Cp and Cpk), Metrology, Improvement techniques (Design of Experiments), Six Sigma, and Cost of Quality.

5.2.2 Basic Statistics and SPC Tools Philosophy of SPC, Data collection, Data display, Data analysis and Process control techniques. Tools may include Check Sheets, Histogram, Pareto chart, Multi-vary analysis, Descriptive statistics, Control charts, Cp, Cpk, DPU and DPMO, and Gage Repeatability and Reproducibility.

5.2.3 Advanced Problem Solving Tools Analysis of Variance (ANOVA), Design of Experiments (DOE), Taguchi Methods, DMAIC or equivalent improvement methodology, and Optimization methods, such as Response Surface Methodology (RSM).

5.3 Integration with Quality System PBA should implement an ISO 9001 or equivalent quality management system that includes the following procedures:

- Process parameter identification.
- Capability assessment and reporting.
- Failure modes and effects analysis.
- Root-cause analysis.
- Gage R&R.

Additionally, the agenda for the management review meeting should include the effectiveness of the SPC implementation.

6 ELEMENTS OF STATISTICAL PROCESS CONTROL SYSTEM

6.1 Process Documentation

6.1.1 Process Mapping The PBA organization should develop a flowchart identifying all manufacturing and related operations. Using the flowcharts, one should identify critical processes based on the value-added to the product. An example of a flowchart is shown in Figure 6-1.

6.1.2 Establishing Process Targets and Limits and Performance Baseline At each process step, the organization should define process targets and limits for each critical

parameter, and establish process variability, defect level and the cycle time. The cycle time includes time to process a subassembly from receiving to shipping of the subassembly.

Note: Initially, most companies have yield information instead of defect rate. The DPU can be estimated using the formula $DPU = -\ln(\text{yield})$. Commercially available spreadsheet or statistical software or scientific calculators have these functions programmed for ease of calculation.

To initiate the process improvement one can estimate the initial defect rate as Low, Medium or High for prioritizing the improvement effort pending completion of the process control data collection system.

6.1.3 Process Prioritization Matrix The organization should establish a prioritization matrix based on process performance in terms of Cp, Cpk DPU or DPM (see Table 6-1). [Please use any reference book for details of Cp and Cpk measurements.]

6.1.4 Parameter Identification The PBA should identify input, in-process and end-product parameters for critical processes based on the above matrix. An example of Parameter Identification for the Solder Paste Deposition process is shown in Table 6-2.

The control of process parameters to ensure the integrity of product parameters is the key focus of any SPC plan. The fundamental establishment of stable and capable processes is a baseline requirement for meeting in-process product and finished product criteria. The relation and effects of process parameters or independent variables can only be established through cause/effect analysis.

The solder paste deposition process is sensitive to many factors (material, equipment, operator, and process) It also is a major contributor to the creation of all surface mount solder joints in the final product. The solder paste deposition process was chosen by the PBA company as one of the initial processes to analyze and increase first pass yield at in-circuit test.

