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ELECTRONICS INDUSTRIES

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General Guidelines for Implementation of Statistical Process Control (SPC)

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General Guidelines for Implementation of Statistical Process Control (SPC)

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

APPROVED NOVEMBER 11, 1999 BY



AMERICAN NATIONAL STANDARDS INSTITUTE

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

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INTRODUCTION

Worldwide competition in the electronics industry has prompted many companies to reevaluate business strategies. To increase the profit margin and market share, companies are streamlining their internal operations to minimize the cost of operation, reduce scrap and rework, and in general, improve quality and customer satisfaction. However, these goals cannot be realized if the manufacturing processes and the support service operations are not in control. A process not in control is unpredictable in nature; therefore, process yield, product quality, cost and schedule cannot be determined with any degree of certainty. Such processes cannot be managed effectively. A systematic way to identify the process unpredictability is to use statistical methods throughout the life cycle of the product and process(es). Improvements to processes are only realized when corrective actions are taken to reduce or eliminate causes of process instability.

The objective of statistical process control is to continually identify variation of the end product, through control and reduction of variation upstream in the process. Statistical Process Control (SPC) is a legitimate method to be used by management throughout the company to achieve quality improvement, reduction in costs, and increased customer satisfaction. Experience has shown that implementation planned, directed, and applied in a methodical way on a project-by-project basis has a higher probability of success.

SPC consists of statistical methods and procedures used to document and assure compliance with requirements and to analyze root cause problems and provide approaches to improvement. Quality has traditionally been accepted as “conformance to requirements.” Thus SPC is integral to making a process conform to customer requirements.

Depending on the progress made in implementing SPC on a particular product, an individual organization may prove compliance to specification with:

1. Quality conformance evaluations
2. End-product control
3. In-process control
4. Process parameter control

An individual organization may choose to use a combination of the four assurance techniques listed above to prove compliance. For example, a product with 15 characteristics may meet specification by quality conformance evaluations on two characteristics, in-process product evaluations on five characteristics, and process parameter control for five characteristics. The remaining three characteristics meet specification by a combination of in-process control and quality conformance evaluations. Evidence of compliance to the specification at the level of SPC implementation claimed is auditable by the customer or an appointed third party.

Requirements are dynamic in nature and based on what is accepted in the world wide market. Requirements must be agreed upon by organization and customer. Requirements may be stated as a reduction of variation around a target value, as opposed to just meeting the specifications, drawing, etc.

FOREWORD

IPC-9191 is a harmonization of IPC-PC-90 and the International Organization for Standardization (ISO) SPC Guideline 11462-1. ISO 11462-1 has been adopted as the foundation for IPC-9191 and is printed in italicized type. Interpretations and supplemental SPC system requirements, as well as implementation guidelines have been harmonized and printed in normal type. Companies may adopt this document; the IPC retains full control over the content except for ISO 11462-1, of which copyright remains with the ISO.

This document is intended to provide information to support the application of process control and related statistical techniques specified in international and industry standards. The ISO 11462-1 sections were prepared by working group 8 of ISO/ITC 69 SC 4.

Appendix A, Appendix B, Appendix C, and Appendix D of this guideline are for information only.

Introduction

The guideline specified is aimed primarily at increasing production efficiency and reducing cost, by reducing variation in all processes, from design through to servicing.

This Standard extends the definition of process control to integrate the traditional definitions of statistical process control, algorithmic process control, and model-based control methods. They are different approaches with the same purpose of reducing variation in products and in processes.

This Standard also extends the definition and usage of the term parameter to apply to a process parameter or a product parameter; and to recognize that a product parameter can be either an in-process product parameter or a final-product parameter. Under specified conditions of measurement, a product parameter can be equivalent to a product characteristic.

Some considerations given in the formulations of this Standard are noted:

- (a) *Elements of Part 1 of this Standard guide an organization in how to implement an SPC system. Specific tools and techniques that experience has shown useful in applying these elements within processes are catalogued in Part 2 of this standard, in process of establishment.*
- (b) *To clarify for practitioners, in both parts - Elements of SPC (Part 1) and Tools and Techniques for Operation of These Elements (Part 2) - "should" indicates:*
 - 1. *Among several possibilities, one or more are recommended as being particularly suitable and effective, without mentioning or excluding others;*
 - 2. *A certain course of action is preferred but not necessarily required for the economic control of production from a process. In both parts, choice of language does not indicate requirements strictly to be followed in order to conform to a standard and from which no deviation is permitted.*

Note: See Appendix D for a detailed explanation of the importance of the distinctions between the three types of parameters and their relationship with characteristics.

At the time of publication of IPC-9191, ISO 11462-1 parts 1 and 2 are in their final stages of draft. The IPC SPC Subcommittee will monitor the progress made toward finalization of those documents and incorporate changes as required.

Acknowledgment

Any Standard 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.

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General Guidelines for Implementation of Statistical Process Control (SPC)

1 SCOPE

This guideline describes the general provisions for implementation of SPC and is intended for use by individuals in electronics and other industries involved in the planning, implementation, and evaluation of an SPC system. This guideline outlines SPC philosophy, implementation strategies, tools, and techniques. These may be applied in different sequences depending on the specific company, operation, or variable under consideration. These tools are also used for relating process control and capability to final product requirements.

This document represents the second revision to the IPC Statistical Process Control (SPC) Standard. This revision reflects the principals of SPC represented by the International Organization for Standardization (ISO) Statistical Methods Technical Committee.

NOTE: Text from ISO 11462-1 is included in this document in italics with permission of ISO/TC 69 and has been approved by ANSI.

1.1 Subject of this Standard *Statistical process control (SPC) concerns the use of statistical techniques and/or statistical or stochastic control algorithms to achieve one or more objectives:*

1. *To increase knowledge about the process;*
2. *To steer a process to behave in the desired way;*
3. *To reduce variation of final-product parameters, or in other ways improve performance of a process.*

These guidelines give elements for implementing an SPC system to achieve the above objectives. The common economic objective of statistical process control is to increase good process outputs produced for a given amount of resource inputs.

Note 1. *SPC operates most efficiently by controlling variation of a process parameter or an in-process product parameter that is correlated with a final-product parameter; and/or by increasing the process's robustness against this variation. A supplier's final-product parameter may be a process parameter to the next downstream supplier's process.*

Note 2. *Although SPC is concerned with manufactured goods, it is also applicable to processes producing services or transactions (for example, those involving data, communications, software, or movement of material).*

1.2 Aspects Covered *This International Standard provides elements to guide an organization in planning, devel-*

oping, executing, and/or evaluating a Statistical Process Control system. By implementing those elements deemed applicable and appropriate by customer and supplier, an organization may satisfy a requirement to adopt a comprehensive and effective SPC system. By also deploying a quality system for assuring that products and services meet customer requirements (such as the system defined by ISO 9001), an organization can install the infrastructure to help hold the gains from its SPC system.

1.3 Field of Application

1.3.1 General *This International Standard specifies SPC system guidelines for use when a supplier's capability to reduce variation in processes associated with design or production needs to be proved, or when a supplier is beginning SPC implementation to achieve such capability.*

It is intended that elements in this Standard will be selected based on their applicability and appropriateness to a specific process. Elements' selection, the order in which an organization implements the elements, and the depth of elements' adoption and application by an organization all depend on factors including: customer needs, market being served, nature of product or service, technology, and the nature and speed of production and transaction processes.

It is emphasized that the SPC system guidelines specified in this standard are complementary (not alternative) to technical (product) specified requirements and to quality system requirements. These guidelines specify what elements SPC systems are recommended to encompass. It is not the purpose of these SPC system guidelines to enforce uniformity of Statistical Process Control systems. These guidelines are generic, independent of any specific process, industry, or economic sector. These guidelines are intended to be adopted in their present form by organizations implementing SPC, but on occasions may need to be tailored by adding or deleting certain SPC system elements for specific circumstances. The phrases, "Where appropriate" and "Where applicable" are used to highlight those elements whose particular application is expected to be more process-dependent or more market-sensitive.

These guidelines are not intended for contractual, regulatory, or certification use.

1.3.2 Production Characteristics Covered *This International Standard is applicable in circumstances when:*

- (a) *Variation or deviation from either product requirements or performance to a target value*

(b) *Confidence in product conformance can be attained by adequate demonstration of a supplier's capabilities in design, development, production, installation, and/or servicing.*

Production characteristics that benefit from SPC implementation include, but are not limited to:

- (a) *Design and development, production, installation, and/or servicing.*
- (b) *Customized or mass production.*
- (c) *Short runs or long runs.*
- (d) *Small, medium, or large scale production.*
- (e) *Discrete, batch, or continuous processes.*
- (f) *Transactions, as in services, information or communications.*
- (g) *Manual or automated technologies for production, assembly, test, or communications.*
- (h) *First pass or loops for rework, repair, reprocessing, or purging.*

References in this Standard to a "product" include service, hardware, processed material, software, or a combination thereof, such as an information or communications transaction.

This guideline also serves to:

- Provide a framework for strategic planning of SPC implementation.
- Outline the general implementation issues that are recommended for an SPC system (see Section 4 and Section 5).

Figure 1-1 establishes a planning framework to use as a guide in applying the elements of SPC for IPC-9191.

Guidelines specific to certain products and/or processes will be specified through the applicable product specifications. Examples of SPC application for specific industries (base materials, printed circuit fabrication, and printed circuit assembly) are shown in IPC-9192, IPC-9193, and IPC-9194. Guidelines for auditing an SPC System are given in IPC-9199. A paragraph cross-reference to IPC-9191's structure is provided in each of these application documents to show relationship to specific sections of IPC-9191.

1.3.3 Techniques for Control and Models of Processes
SPC elements extend to techniques applied on-line within the operation of the process; and off-line either outside the operation of the process, or on the outputs at the end of the process. They are limited neither to traditional control charting techniques, nor to specific models of process data involving specific distributions or specific patterns of correlation. The SPC elements are applicable regardless of the tactics used to control processes; for example: automatic controllers for continuous and batch processes, automated editors for data inputs, control algorithms for timing or

spacing of resource inputs, manual maintenance procedures for low volume outputs, and analytical procedures such as control charts. A supplier may use statistical, algorithmic, or model-based methods, or a combination, depending on process data availability, model availability, business needs, and the relative frequency of random, unknown, and assignable causes of variation

1.4 Interpretation

"Should" and "may" are used whenever it is necessary to express non-mandatory 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 statements made.

"References" are intended to clarify and 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 outlined sections.

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

2 NORMATIVE REFERENCE(S)

The following International Standards contain provisions which, through reference in this text, constitute provisions of this International Standard. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For updated references, the latest edition of the normative document referred to applies. Members of ISO and IEC maintain registers of currently valid International Standards.

ISO 3534-1:1993, *Statistics - Vocabulary and Symbols - Part 1: Probability and General Statistical Terms*

ISO 3534-2:1993, *Statistics - Vocabulary and Symbols - Part 2: Statistical Quality Control*

ISO 3534-3:1985, *Statistics - Vocabulary and Symbols - Part 3: Design of Experiments*

ISO 7870:1993, *Control Charts - General Guide and Introduction*

ISO 7873:1993, *Control Charts for Arithmetic Average with Warning Limits*



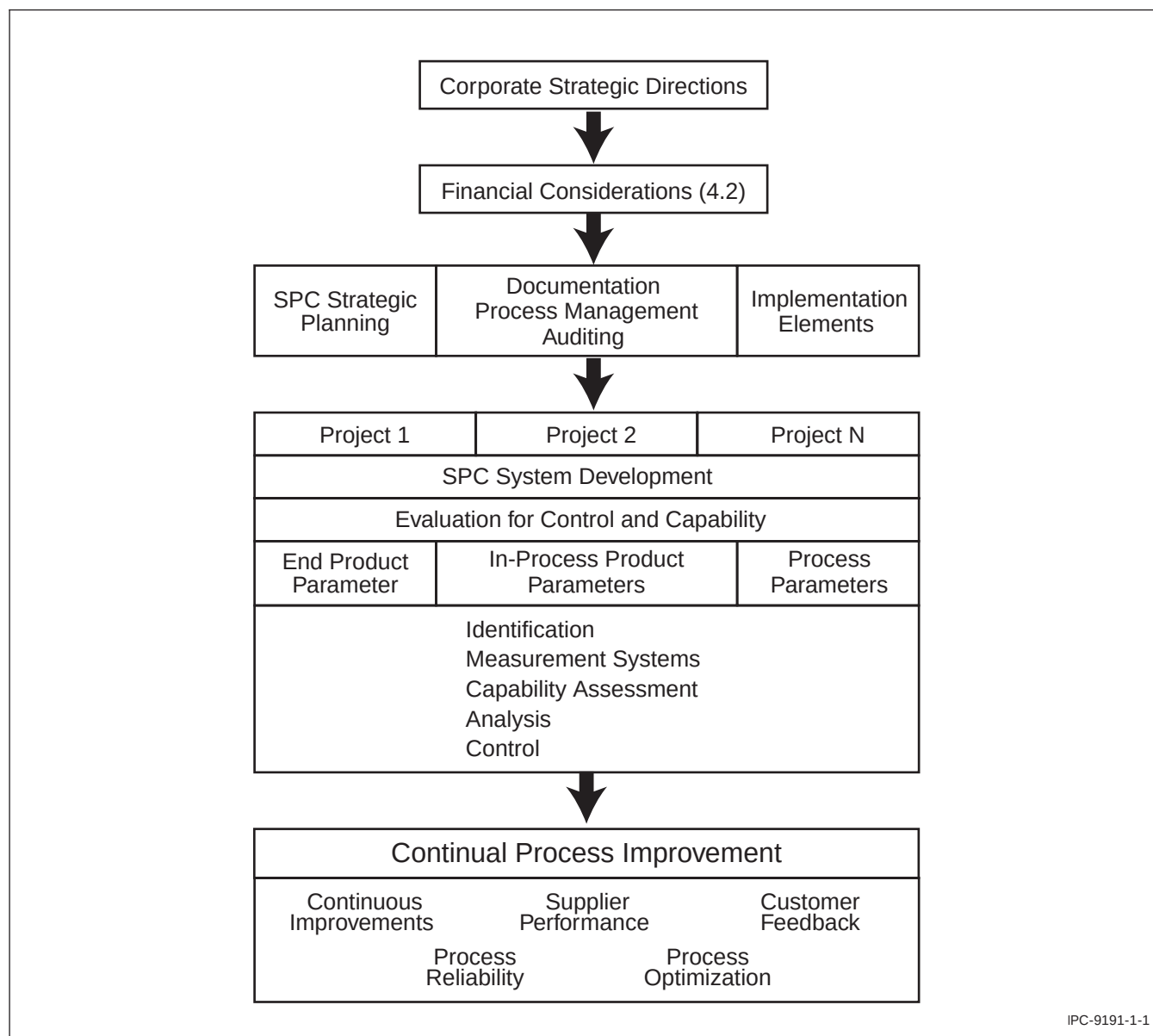


Figure 1-1 SPC Implementation Strategic Plan Example

ISO 7966:1993, *Acceptance Control Charts*

ISO 8528:1991, *Shewart Control Charts*

ISO 8402:1994, *Quality Management and Quality Assurance - Vocabulary*

The documents in 2.1 form a part of this specification to the extent specified herein. Later issues of or amendments to these documents become part of this specification unless otherwise stated. If a conflict arises, IPC-9191 takes precedence. Appendix A is a listing of other suggested reference material.

2.1 IPC

IPC-9192 Implementation of Statistical Process Control Applied to Interconnection Structure Base Material

IPC-9193 Implementation of Statistical Process Control Applied to Printed Board and Interconnection Structure Manufacture

IPC-9194 Implementation of Statistical Process Control Applied to Printed Board Assembly Manufacture

IPC-9199 SPC Quality Rating

3 TERM(S) AND DEFINITION(S)

For the purpose of this standard, the definitions given in ISO 3534-1, ISO 3534-2, ISO 3534-3, and ISO 8402 apply.

Provided for informative purposes to aid the user, Annex A is a glossary of terms that are used in this document but are not yet defined in the issues of those vocabulary standards available as of this document's publication.

4 SPC OBJECTIVES AND ORGANIZATION

4.1 SPC Objectives

4.1.1 General Statistical Process Control has one or more objectives:

1. To increase knowledge about the process;
2. To steer a process to behave in the desired way;
3. To reduce variation of final-product parameters, or in other ways improve performance of a process.

4.1.2 Specific Depending on the market being served, nature of product, process technology, and customer needs, effective implementation of SPC reduces cost and increases profit in the following ways:

- (a) By managing the process most economically, with the aim of greater consistency and improvement.
- (b) By reducing variation around target in either a final product or process output parameter.
- (c) By transferring variation in an in-process product parameter to a controllable or manipulated process variable, and compensating for variation in the in-process product parameters (used in some control engineering applications). Again, the final goal is increasing consistency in final-product parameters.
- (d) By providing signals and evidence of how a process is behaving, and how it is likely to behave.
- (e) By assessing and quantifying what quality and consistency levels the process is currently capable of producing.
- (f) By identifying when and where to look for assignable causes or make preventive process adjustments, and when not to.
- (g) By pointing to potential root causes or failure modes and their sources, identifying sources of poor yield or variability, and detecting assignable causes. In this function, SPC increases speed of detection and reduces troubleshooting costs.
- (h) By providing information that helps identify when assignable causes are present. In this function, SPC helps in reducing or removing the effects of assignable causes and in effectively implementing corrective action.
- (i) By controlling and/or reducing random cause variation through process design changes and other systematic changes to procedures.
- (j) By increasing knowledge of how the system of causes affects the process, to help make improvements to the process.

4.2 Financial Motive for SPC The strongest motive for SPC is financial: to increase good process outputs produced for a given amount of resource inputs. Ways to mea-

sure financial costs and benefits of SPC implementation against the alternative include, but are not limited to:

- (a) Collecting producer costs such as cost of scrap, screening, rework, equipment repair, down time, and outages.
- (b) Collecting consumer costs incurred over the life cycle of the product.
- (c) Estimating the amount of business and jobs lost because dissatisfied customers turn to competitors or refuse to pay a premium for perceived greater quality.
- (d) Estimating benefits to other parts of the organization, (such as design and development, marketing, production, installation and servicing) from the feedback and information that SPC brings.
- (e) Quantifying benefits to all parts of the organization from faster troubleshooting and greater potential for process or product innovation.

A quality cost/benefit system has several aspects to it; the most important are the informational and control aspects. In its informational aspect, the system should identify sources of quality costs/benefits and report its results to a wide range of users.

In addition, the information from the quality cost/benefit report is used to establish cost control, avoidance, and reduction programs. This cost analysis can then be used to identify key areas to include in the strategic plan for implementation of SPC. See 4.2.1 through 4.2.4 for the four major costs of quality categories and see Figure 4-1 for a typical cost of quality report format.

4.2.1 External Failures External failures are the cost of unsatisfactory quality detected after the product leaves the company (see Figure 4-1). Some examples of external failures are:

- Warranty changes
- Field evaluation and training
- Product reliability
- Insurance
- Premium freight costs
- Responding to customer complaints
- Customer service
- Return expenses
- Product recall
- Liability Exposure

4.2.2 Internal Failures Internal failures are the cost of unsatisfactory quality associated with the manufacturing of a product (see Figure 4-1). Some examples of internal failures are:

- Scrap
- Rework



DESCRIPTION	ESTIMATES	
	Total Cost	As % of Sales
EXTERNAL FAILURE COSTS		
1. Material Review		
2. Corrective Action		
3. Rework/Freight		
4. Customer Service		
5. Loss of Contract		
Subtotal	\$	%
APPRAISAL COSTS		
1. Tests		
2. Organization Inspection		
3. In-Process Inspection		
4. Final Inspection		
5. Maintenance/Calibration		
Subtotal	\$	%
INTERNAL FAILURE COSTS		
1. Design		
2. Organization		
3. Material Review		
4. Corrective Action		
5. Scrap		
6. Rework		
Subtotal	\$	%
PREVENTION COSTS		
1. Design		
2. Purchasing		
3. Planning		
4. Administration		
5. Training		
Subtotal	\$	%
	Total Cost	As % of Sales
External Failure Cost Subtotal		
Internal Failure Cost Subtotal		
Appraisal Cost Subtotal		
Prevention Cost Subtotal		
Total Cost of Quality		

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Figure 4-1 General Cost of a Quality Report

- Material review
- Design failure
- Down time
- Failure analysis
- Retest/reinspection
- Engineering changes
- Tooling repair

4.2.3 Appraisal Appraisals are costs associated with the evaluation of a product (see Figure 4-1). Some examples of appraisals are:

- Receiving inspection
- Source inspection
- In-process inspection
- Final inspection
- Calibration costs
- Maintenance of test/inspection equipment
- Quality audits
- Product test
- Outside lab evaluations
- Life testing

4.2.4 Prevention Prevention includes costs associated with deferring nonconforming products (see Figure 4-1). Examples of prevention costs are:

- Quality planning
- Process control elements
- Training
- Development of quality information equipment
- Product design verification
- System development and maintenance
- Preventive maintenance
- Housekeeping
- First article verification
- Capital equipment
- Supplier qualification program

4.3 Relationships

4.3.1 Relationship Between Traditional and Automated Process Control The general SPC objectives are shared both by traditional Shewart control methods and by automatic process control based on a more complex model. The SPC elements can be used either to reduce variation in a process parameter or a process output; or to transfer variation to an adjusted or manipulated process input (for example, as in the chemical industry). The objective of reducing variation around target in final-product parameters is the same whether the process and/or product has specification limit.



4.3.2 Relationship to Final Product Conformance-To-Specification SPC helps to minimize efforts required to assure final product conformance-to-specification (such as screening, sorting, sample inspection, 100% inspection, and/or testing) in the following ways:

- (a) Identifying cause-and-effect relationships between final product, in-process product (or process output), and process input parameters.
- (b) Enabling controls to be set up as early in the process as possible.
- (c) Minimizing process variation, based on knowledge acquired from A and on control actions taken in B above.

When the system is properly executed, SPC is used to identify and either eliminate or dampen process disturbances. Depending on the processes' characteristics and the forces driving deviations from targets, SPC may not completely eliminate the need for some screening or sampling inspection operations to detect accidental disturbances, such as operator error or automatic control system interruptions, or later problems, such as handling errors, that must be prevented from reaching the customer. Extension of SPC elements to more widely defined processes affecting quality has been shown to minimize costs associated with such screening or inspection.

Depending on the capability and stability of the process and on the level of nonconformity risk deemed acceptable by the customer, SPC may be used to reduce, for example, sample size and/or sampling frequency associated with process data collection and monitoring. If sample size and/or sample frequency are chosen optimally and nonconformity risk decreases, SPC may be used to minimize or eliminate screening and inspection of final product. Accumulated knowledge acquired from SPC data can guide the supplier toward a reduction in the process's operating limits. In turn, this reduction results in less product variation being detectable or measurable at the customer's site. The supplier's organization may use the accompanying cost savings and competitive advantage of SPC to do any remaining screening or inspection in a more efficient way.

Depending on progress made implementing SPC on a particular project, a supplier may prove the product meets specifications with one or a combination of the following:

1. Quality conformance evaluations and acceptance sampling with feedback (algorithmic or procedural) to the process
2. Final-product parameter monitoring and control
3. In-process product parameter monitoring and control
4. Process parameter monitoring and control, for those parameters identified as correlating with final-product parameters

SPC system development. This guideline outlines the SPC system elements that should be adopted by an organization establishing an SPC system. SPC is an evolutionary program that is continuously improving and always under development. The elements outlined in this guideline are used to drive improvement in the overall quality system.

Figure 4-2 shows the logical path used in developing a quality system from a detection focus to a preventive/continuous improvement system using the SPC tools.

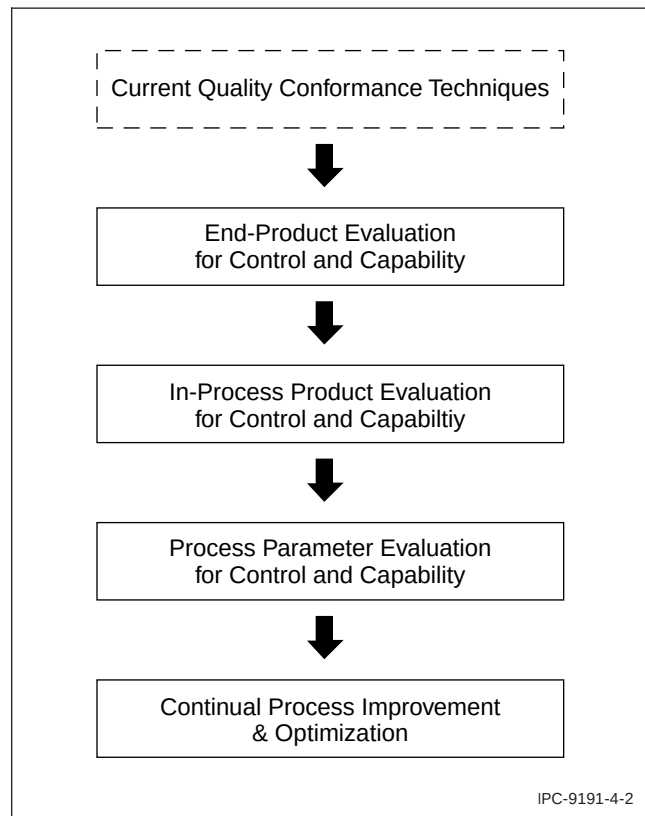


Figure 4-2 Systematic Path for Implementation of SPC

Note: Statistical control, correlation, and capability of all three sets of parameters should be pursued simultaneously, not necessarily in any chronological order.

Table 4-1 shows the cost benefit of a preventive/continuous improvement approach using the tools of SPC versus a traditional detection based quality system. Figure 4-3 shows a prevention based process flow chart, whereas Figure 4-4 shows a flow chart of detection based processes.

4.4 SPC Organization

4.4.1 Organizing for SPC Implementation SPC implementation activities such as process data collection, process control, parameter correlation, and capability assessment improvement should be performed:

- (a) Through projects selected based on specific criteria

Table 4-1 Preventative/SPC Based Quality System vs. Detection Based Quality System

	Number of Inspections	Number of Processes Controlled	Throughput Yield	Defects per Unit	Inspection Cost % of Unit Cost	Representative Flow Chart
Inspection Approach	6	0	84%	.17	20%	Figure 4-4
Prevention/SPC Approach	1	6	91%	.09	7%	Figure 4-3

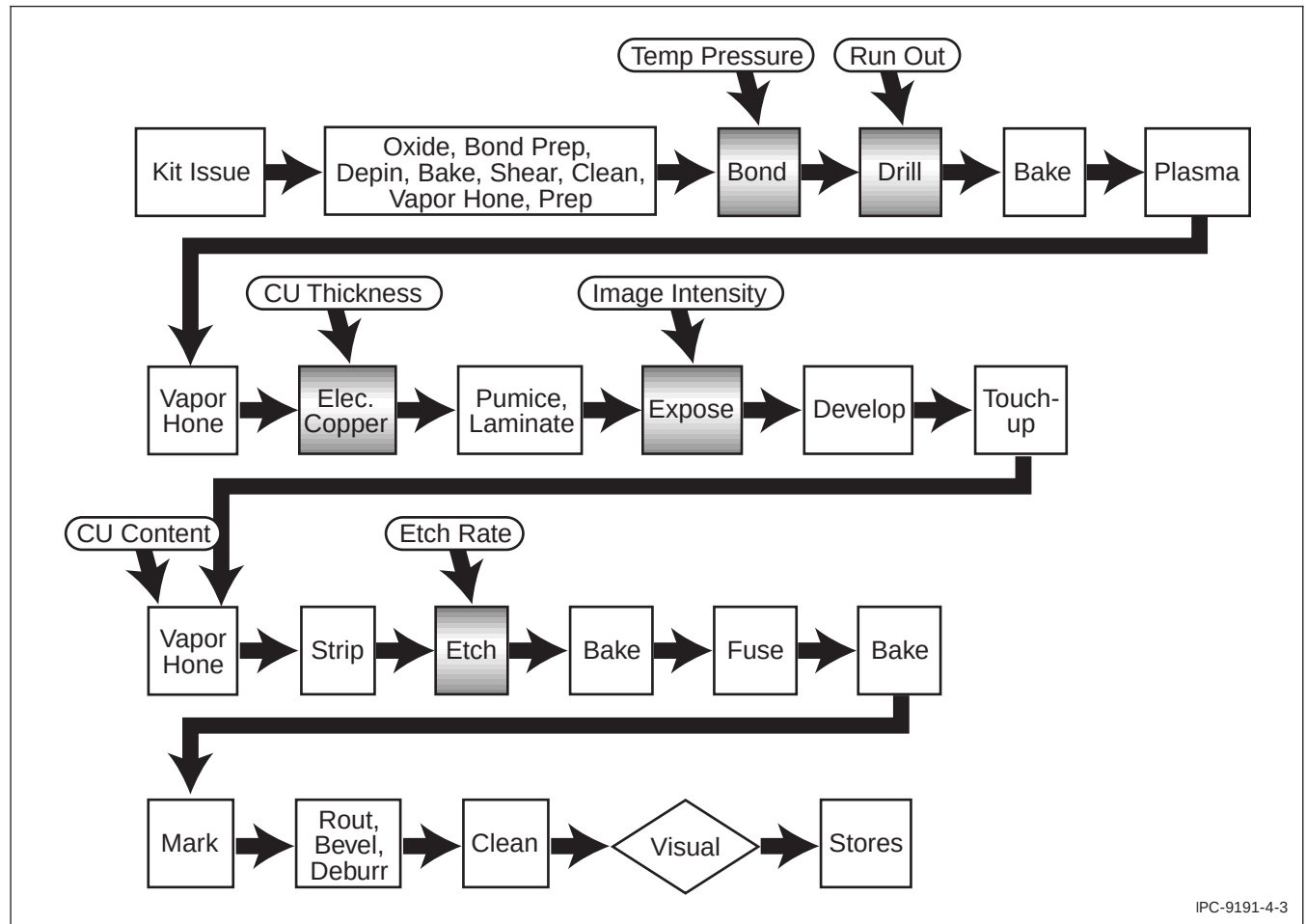


Figure 4-3 Prevention/SPC Based Process

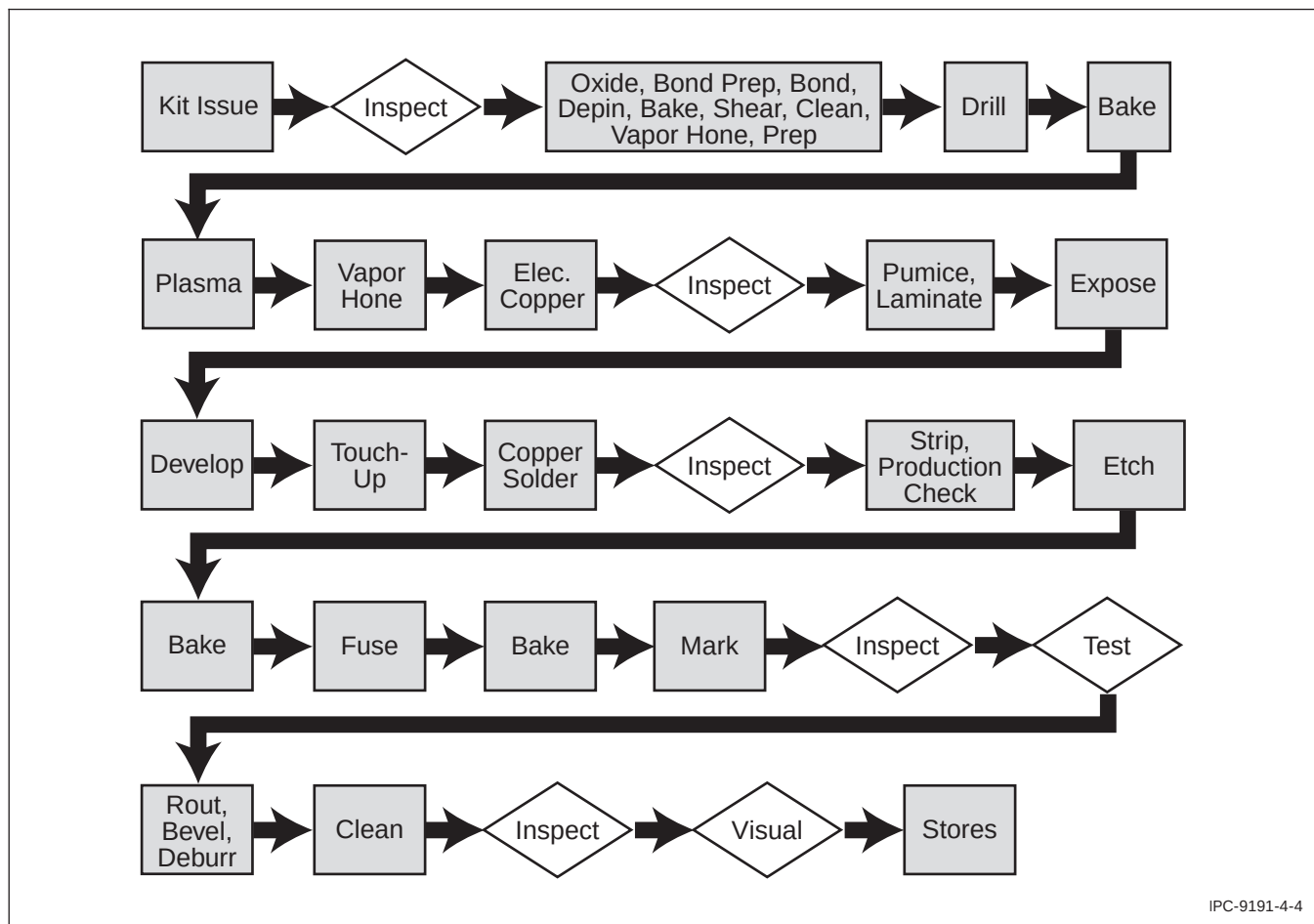
(b) Through work on processes linked in a successive stream or linked in a product supply chain. (For example, this may be done by choosing a final product parameter and organizing SPC efforts focusing on one set of parameters, then moving to another set successively upstream in the supply chain.

4.4.2 Strategic Planning The purpose of an SPC strategic plan is to provide a systematic approach to accomplish product control through SPC. The SPC strategic plan should be dynamic and adaptable to unpredicted changes and planned changes to production practices and techniques and management objectives.

The SPC strategic plan should address all of the elements identified in Figure 4-5. It is recommended the SPC strate-

gic plan identify individual projects that accomplish the objectives in 1.1 by using the SPC system development path shown in Figure 4-2.

Objectives of the SPC strategic plan should be to replace current quality conformance techniques with identification of cause-effect relationships between final product, in-process product, and process parameters. Driving parameter statistical control further up the process stream is more efficient and effective than relying on quality conformance and inspection. Figure 4-5 is an example of how the elements of SPC in this guideline may be used to form an SPC strategic planning framework. This diagram may serve as a basis for an SPC strategic plan.



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Figure 4-4 Traditional Inspection/Detection Based Process

5 CONDITIONS FOR STATISTICAL PROCESS CONTROL

5.1 Management Support The supplier's management should document, implement, and maintain its continuing support for SPC. This includes, but is not limited to, the following:

- (a) Improving the process, based on periodic review of both SPC results and audit reports. The supplier should ensure that management SPC policy is understood, implemented and maintained at all levels in the organization.
- (b) Using and improving data to drive decisions about the process.
- (c) Supporting recording of, and reaction to, process disturbances and/or out-of-control points, without penalty.
- (d) Appointing and supporting SPC coordination responsibility.

5.2 Understanding of SPC Tools and Methods The supplier should design, implement and review programs that provide, but are not limited to, the following:

- (a) Awareness in SPC tools and methods for all employees (including management) involved with SPC.

(b) Training to make SPC skills appropriate to employees' job functions and to their interaction with the process.

(c) Ensuring sufficient expertise is available to understand the objectives, application, and risks associated with the statistical and algorithmic control techniques chosen.

Employee training is a critical element in the success of any SPC system. Training is important for several reasons. First, application of statistical tools without adequate training could lead to inappropriate conclusions and poor tool effectiveness. Second, training can provide motivation to all employees towards improvement of products and processes. Experience has shown most effective time to conduct training is just prior to project implementation or just-in-time (JIT). With JIT training, employees are able to quickly apply what they have learned. It should also be noted training is not just for the employees who work with product/processes, but all levels of employees should receive training on SPC, including management. The organization should ensure training is conducted by qualified instructors as agreed upon between customer and supplier.

Table 5-1 shows an ongoing training plan, whereas Figure 5-1 gives an example of an SPC training flow chart.