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A FRAMEWORK FOR THE IMPLEMENTATION OF AN ISO 9000  
BASED CERTIFICATION PROGRAM FOR PRINTED CIRCUIT  
BOARDS MANUFACTURERS

by

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B.Sc. Zagazic University, 1987

A thesis submitted in partial fulfillments of the requirements  
for the degree of Master of Science  
in the School of Industrial Engineering  
in the College of Engineering and Computer Science  
at the University of Central Florida  
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## **ABSTRACT**

ISO 9000:2000 is the newest version of the ISO 9000 family of standards. Unlike the 1994 version, it does not distinguish between servicing, testing and designing standards. It emphasizes quality improvement rather than quality control and briefly explains how to implement the Plan-Do-Check- Act (PDCA) cycle for improvement and the use of statistical techniques to improve the quality of process and product instead of controlling the quality of the output. The thesis explains why companies need to be certified and how to implement quality improvement programs.

The objective of this thesis is to provide generic certification guidelines for printed circuit board manufacturers, based on ISO 9000:2000 standard. This standardized framework could assist companies in achieving ISO 9000 certification. Since every manufacturer has its own proprietary set of controls on their processes, these generic guidelines provide an opportunity for the user to plug in their own information and to write their own processes.

Another objective of this thesis is to introduce a methodology for the implementation of the various methods and tools that can be applied for process improvement in printed circuit boards manufacturing.

Quality improvement tools that assist in process modeling and variability reduction are introduced as well as the different aspects of automated quality as means to reduce or remove the effect of human error on process performance. Other continuous improvement tools that are used to optimize, monitor, and control the processes are also presented as a major part of an ISO 9000 based quality management system.

To my Mother, in the Memory of my Dad and to all my Friends

## **ACKNOWLEDGMENTS**

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In addition, special thanks to Dr. Linda Malone for her continuous encouragement; Dr. Ghaith Rabadi; Donald Woodworth, Quality Manager at Tyco of Melbourne; Wally Weburg, Process Engineer at Advanced Quick Circuits; John Brady, Process Engineer at Lockheed Martin of Ocala Division and Tom Tate, Process Engineer and Statistician at Tyco of Melbourne for their encouragement and assistance. And finally, the author would like to express his undying love and gratitude for his mother, late father and his wife, whose love, encouragement and support have been the root of his success.

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## CHAPTER 1: INTRODUCTION

### 1.1 History of ISO (The International Organization for Standardization)

International standardization began in the electro technical field when the International Electro technical Commission (IEC) was created in 1906. The International Federation of the National Standardizing Associations (ISA), which was set up in 1926, carried out pioneering work in other fields. The emphasis within ISA was heavily on mechanical engineering.

ISA's activities ceased in 1942, owing to World War II. Following a meeting in London in 1946, delegates from 25 countries decided to create a new international organization "the object of which would be to facilitate the international coordination and unification of industrial standards". The new organization, ISO, began to function officially on 23 February 1947 and started as a non-governmental organization.

The first International Standard of Organization was published in 1951 with the title, "Standard reference temperature for industrial length measurement".

Now the International Organization for Standardization (ISO) is a worldwide federation of national standards bodies from some 130 countries, one from each country.

The mission of ISO is to promote the development of standardization and related activities in the world with a view to facilitating the international exchange of goods and services, and to develop cooperation in the spheres of intellectual, scientific, technological, and economic activity. ISO's work results in international agreements, which are published as International Standards.

## 1.2 Need for International Standardizations

The existence of non-harmonized standards for similar technologies in different countries or regions can contribute to the so-called "technical barriers to trade". Export-minded industries have long sensed the need to agree on world standards to help rationalize the international trading process. This was the origin of the establishment of ISO.

International standardization is well established for many technologies in such diverse fields as information processing and communications, textiles, packaging, distribution of goods, energy production and utilization, shipbuilding, banking, and financial services. It will continue to grow in importance for all sectors of industrial activity for the near future.

International standards are needed for the following reasons:

- Worldwide progress in trade liberalization.

Today's free-market economies increasingly encourage diverse sources of

supply and provide opportunities for expanding markets. On the technology side, fair competition needs to be based on identifiable, clearly defined common references that are recognized from one country to another, and from one region to the other. An industry-wide standard that is internationally recognized and developed by consensus among trading partners serves as the language of trade.

- Interpenetration of sectors.

No industry in today's world can truly claim to be completely independent of components, products, and rules of application, etc. that have been developed in other sectors. Bolts are used in aviation and in agricultural machinery; welding plays a role in mechanical and nuclear engineering, and has penetrated all industries. Environmentally friendly products and processes, and recyclable or biodegradable packaging are pervasive concerns.

- Worldwide communications systems.

The computer industry offers a good example of technology that needs to be quickly and progressively standardized at a global level. Full compatibility among open systems fosters healthy competition among producers, and offers real options to users since it is a powerful catalyst for innovation, improved productivity, and cost cutting.

- Global standards for emerging technologies.

Standardization programs in completely new fields are now being developed. Such fields include advanced materials, the environment, life sciences, urbanization, and construction. In the very early stages of new technology development, applications are often documented but functional prototypes do not exist. Here, the need for standardization is in defining terminology and accumulating databases of quantitative information.

- Developing countries.

Development agencies are increasingly recognizing that a standardization infrastructure is a basic condition for the success of economic policies aimed at achieving sustainable development. Creating such an infrastructure in developing countries is essential for improving productivity, market competitiveness, and export capability.

Industry-wide standardization is a condition existing within a particular industrial sector when the large majority of products or services conform to the same standards. It results from consensus agreements reached between all economic players in those industrial sectors such as suppliers, users, and often governments. They agree on specifications and criteria to be applied consistently in the choice and classification of materials, the manufacture of products, and the provision of services. The aim is to facilitate trade, exchange, and transfer technology through:

- Enhanced product quality and reliability at a reasonable price.
- Improved health, safety and environmental protection, and reduction of waste.
- Greater compatibility and interoperability of goods and services.
- Simplification for improved usability.
- Reduction in the number of models, and thus reduction in costs.
- Increased distribution efficiency.
- Ease of maintenance.

Users have more confidence in products and services that conform to International Standards. Assurance of conformity can be provided by manufacturers' declarations, or by audits carried out by independent bodies.

### 1.3 ISO's Achievements

Some of ISO achievements include:

- The ISO film speed code, among many other photographic equipment standards, has been adopted worldwide making things simpler for the general user.
- Standardization of the format of telephone and banking cards means the cards

can be used worldwide.

- Tens of thousands of businesses are implementing ISO 9000 that provides a framework for quality management and quality assurance. The ISO 14000 series provides a similar framework for environmental management.
- The internationally standardized freight container enables all components of a transport system - air and seaport facilities, railways, highways, and packages - to interface efficiently. This combined with standardized documents to identify sensitive or dangerous cargoes makes international trade cheaper, faster and safer.
- M, kg, S, A, K, mol, cd, and rad are the symbols representing the eight base units (meter, kilogram, second, ampere, Kelvin, mole, candela, and radian) of the universal system of measurement known as SI (System International of Units). The SI system is covered by a series of 14 International Standards. Without these standards, shopping and trade would be haphazard and technological development would be handicapped.
- Paper sizes. The original standard was published by DIN in 1922. Now used worldwide as ISO 216, standard paper sizes allow economies of scale with cost benefits to both producers and consumers.
- A well-designed symbol conveys a clear-cut message in a multilingual world. The same symbols for automobile controls are displayed in cars all over the world, no matter where they are manufactured.

- Safety of wire ropes used on oilrigs, on fishing vessels, in mines, in all types of building operations, for lifts and cable cars, etc. ISO International Standards systematically define basic characteristics such as size, surface finish, type of construction, tensile grade of the wire, minimum breaking load, and linear mass. Standardization of performance or safety requirements ensures that user requirements are met while allowing individual manufacturers the freedom to design their own solutions for meeting these basic needs. Consumers then benefit from the effects of competition among manufacturers.
- The ISO international codes for country names, currencies, and languages help to eliminate duplication and incompatibilities in the collection, processing, and dissemination of information. As resource-saving tools, universally understandable codes play an important role in both automated and manual documentation.
- The diversity of screw threads for identical applications used to represent an important technical obstacle to trade. It caused maintenance problems, and lost or damaged nuts or bolts could not easily be replaced. A global solution is supplied in the ISO standards for ISO metric screw threads.

The mission of ISO is to promote the development of standardization and related activities in the world with a view to facilitating the international exchange of goods and services, and to developing cooperation in the spheres of intellectual, scientific, technological, and economic activity.

ISO's work results in international agreements, which are published as International Standards.

#### 1.4 ISO 9000:2000

In 2000, a new version of the ISO 9000 family was introduced. It was developed “to assist organizations, of all types and sizes, to implement and operate effective quality management systems”. The new 2000 family of the ISO standards includes:

- ISO 9000: Quality management systems – Fundamentals and vocabulary, provides the fundamentals and terminology of quality management systems.
- ISO 9001: Quality management systems – Requirements, specifies the needed requirements that an organization needs to provide products that aim to enhance customer satisfaction.
- ISO 9004: Quality management systems – Guidelines for performance improvement, provides guidelines that help improve organizational performance and customer satisfaction.

Within the ISO 9000 family, the following eight quality management principles are emphasized:

1. Customer focus
2. Leadership
3. Involvement of people
4. Process approach

5. System approach to management
6. Continual improvement
7. Factual approach to decision making
8. Mutually beneficial supplier relationships

In addition, the ISO 9000:2000 family includes several interesting features, such as:

- The term “quality assurance” no longer is included in the standard.
- More emphasis is placed on customer satisfaction and continuous improvement, in addition to product quality assurance.
- ISO 9001: 1994, ISO 9002: 1994, and ISO 9003: 1994 have been replaced by ISO 9000: 2000.
- The titles of the standards have been modified “to reflect the comprehensiveness of the quality management system”.
- The standards adopted a process approach “when developing, implementing and improving the effectiveness and efficiency of a quality management system to enhance interested party satisfaction by meeting interested party requirements”.
- The term “supplier” used in ISO 9001: 1994, has been replaced in ISO 9000: 2000 by the term “organization” and refers to “the unit to which this

international standard applies”. Also the term “subcontractor” has been replaced by the term “supplier”.

The ISO 9000: 2000 lists the following quality management system requirements:

Quality management system:

1. Managing systems and processes
2. Documentation:  
General requirements:
  - a) Quality manual
  - b) Control of documents
  - c) Control of records
3. Use of quality management principles
4. Management responsibility:
  - a) Management commitment
  - b) Customer focus
  - c) Quality policy
  - d) Planning
  - e) Quality objectives
  - f) Quality management system planning
5. Responsibility, authority, and communication
  - a) Responsibility and authority
  - b) Management representative

- c) Internal communication
- 6. Management review
  - a) Review input
  - b) Review output
- 7. Resource management
  - a) General guidance
  - b) People
  - c) Infrastructure
  - d) Work environment
  - e) Information
  - f) Suppliers and partnerships
  - g) Natural resources
  - h) Financial resources
- 8. Product realization
  - a) General guidance
  - b) Processes related to interested parties
  - c) Design and development
  - d) Purchasing
  - e) Production and service operations
  - f) Control of measuring monitoring devices

## 9. Measurement, analysis, and improvement

- a) General guidance
- b) Measurement and monitoring
- c) Control of nonconformity
- d) Analysis of data
- e) Improvement

Most PCB manufacturers have been registered in accordance to ISO 9002, since they are in the production and servicing they now have to comply with the recent ISO 9000:2000. The design of the PCB is done most of the times by the buyers. Since the printed wiring board business is a unique one, most of the processes in the industry are very similar to each other with the exception of some special processes.

### 1.5 Need for Research

Most of the differences between the manufacturers are in the speed, quality, performance and the price of the PCB. This is why the development of a generic ISO based quality system guidelines for the industry is feasible. In the following chapters the discussion will be on providing guidelines for the implementation of ISO 9000:2000 and how to adhere to its requirements.

Based on a survey of the following eleven internationally recognized PCB manufacturers, a need to establish guidelines for ISO certification was obvious

Below is a list of the surveyed manufacturers:

- Technotronics of Longwood, Florida
- Act of Tempe, Arizona
- Tropical Circuits of Ft Lauderdale, Florida
- Northern Telecom of West Palm Beach, Florida
- Lockheed Martin of Ocala, Florida
- Digital Equipment of Greenville, South Carolina
- Intergraph of Huntsville, Alabama
- Harris of Palm Bay, Florida
- Tyco of Stafford, Connecticut
- Tyco of Shanghai, China
- Advanced Quick Circuits of Melbourne, Florida

The following are cited conclusions:

- None of them had implemented the new ISO 9000:2000
- Basic processes are identical except for the proprietary settings

- All surveyed companies are ISO 9002 certified except for Tyco of shanghai, China
- Some manufacturers are specialized in quick turn, some in production and some in advanced manufacturing
- All surveyed companies are planning in the near future to replace their quality system with the new ISO 9000:2000
- There are no formal quality improvement plans established. Quality control is the most dominant practice in all the surveyed companies
- Special processes make PCB manufacturers distinguishable from others
- Some manufacturers are striving to add more of the special processes to their existing system

Based on such a need, this thesis provides a framework for the manufacturers to assist them in their implementation of the new ISO 9000:2000 certification. In addition, it can be used to expand manufacturers capabilities since it introduces knowledge of all processes of the printed wiring circuit boards. In the following chapters, each of the requirements for ISO 9000:2000 is discussed in terms of guidelines for implementation.

## CHAPTER 2: QUALITY MANAGEMENT SYSTEM

### 2.1 Introduction

When the PCB manufacturer desires to establish a quality system, it must be effective throughout the whole company. This Quality system must be flexible so it can accommodate changes to customer needs, expectation, and advancement in technology. Every Company has a unique Quality system and some are more effective than others. A quality system is an indicator of management ideas and philosophy towards quality of performance and ideology. An ideal quality system may implement different ideas and principles such as Deming's 14 points for management, Taguchi's engineering approach to quality, Jurans' trilogy or Crosby's 14 steps. An operating procedure on how to implement all of the different elements of the above philosophers will be discussed in the following sections.

### 2.2 Quality Management Systems and Processes

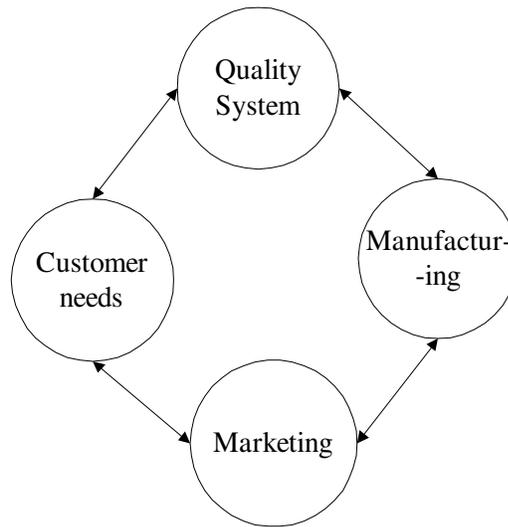
The Quality management system and related procedures described in this section complies with ISO 9000:2000 section 4 paragraph 4.1.

### 2.2.1 Implementation

The Plant manager will implement a quality system that interfaces product, service, and technology and will ensure the availability of resources when the department managers need it.

The quality system must be a proactive one; it should be established, maintained and updated to reflect the customer needs and technology development. The quality system will be precise and effective and have strategic goals. The Plant manager will establish a vision statement to have a clear understanding on where the organization stands and where it is heading. An example of a vision statement is as follows: " The company vision is to be recognized by all our customers around the world as the standard of excellence for PCB by the year 2002". As for the company's mission statement, an example is that "ABC Company will provide competitively priced products and services by empowering each employee to exceed the customer's expectation for quality, service, and features while providing a fair return to our investors".

The quality system must be functioning as one entity in the organization as shown in Figure 2.1. It will also be an active connection between the functional departments in the plant. It is the responsibility of all members of the organization to adhere, implement, and update the quality system. If any of the processes must be done outside the plant by a subcontractor, the same quality system must be applied to the manufactured products and processes.



**Figure 2.1:** Quality System

### 2.3 Documentation Requirements

All documents in any company that is seeking ISO certification must be controlled. ISO 9000 clearly describes how documents and records can be controlled. The generic procedure discussed in this section describes the activities of the document control department.

This quality system will comply with the documentation requirement of ISO 9000:2000 section 4 paragraphs 4.2.1, 4.2.3 and 4.2.4.

#### 2.3.1 Implementation

The quality management system will be documented in a controlled operating procedure. All processes and related functions will be documented in this procedure. A

detailed planning and functioning of the processes will be documented in controlled work instructions. The quality representative is the sole caretaker of the companies document quality system. He/She will prepare the operating procedure and related work instructions with the assistance and corporation of all the department managers.

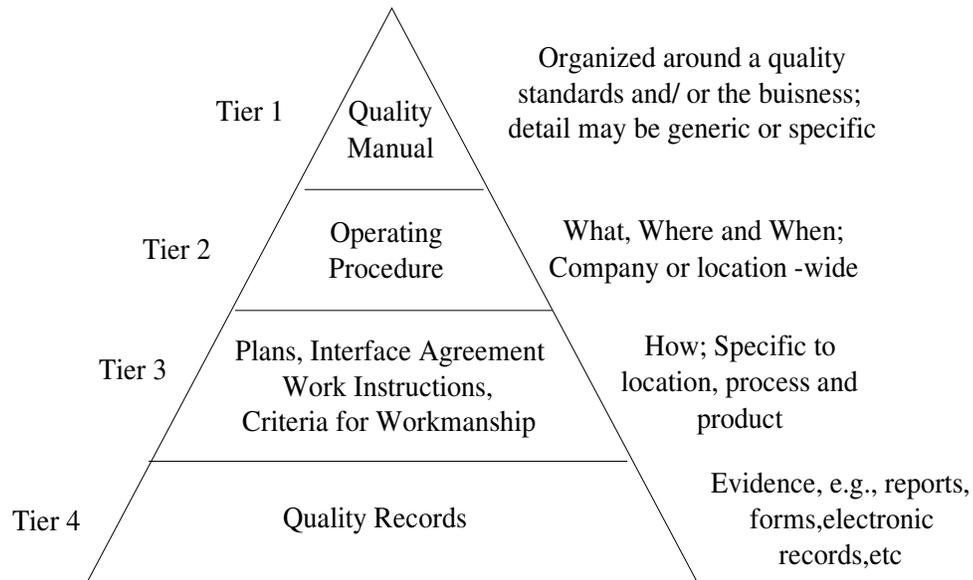
Departments' activities and process specifications will be documented in the quality manual with the assistance of process engineers and department supervisors, leads, and managers. Department managers will do the final approval on the work instructions that describe their process activities. All customers' supplied artwork and electronic media will be under the responsibility of the methods engineering department. A generic quality system structure will have a structure as shown in Figure 2.2.

## 2.4 Quality Manual

The Quality manual described in this section will comply with ISO 9000-2000 Quality Management System section 4 paragraph 4.2.2.

### 2.4.1 Implementation

Each chapter included in the quality system manual will be given a unique serial number. A revision letter in which it is updated every time there is a change in the related documents will head each chapter. Once a related document is updated the old copies will be rendered obsolete and destroyed immediately.



**Figure 2.2:** Quality Systems Documentation Structure

## 2.5 Control of Documents and Records

The Control of documents and records operating procedure described in this section will comply with ISO 9000:2000 Quality Management System section 4 paragraphs 4.2.3 and 4.2.4.

### 2.5.1 Implementation

The quality department manager and his assignee will control the documented quality system, operating procedure, work instructions, records, and related forms. The

operating procedure and related forms are subject to the approval of the Plant manager prior to issuing a new revision.

The quality manager assignee ensures that all work instructions and operating procedures comply with ISO 9000:2000. He/She also insures that a standard writing format is used.

Controlled copies of the operating procedures will be distributed to all department managers and every controlled copy is uniquely numbered. A master list of all the controlled documents will be with the quality manager and his/her assignee. Uncontrolled documents can be issued for training purposes only and should be destroyed thereafter. All military and commercial standards will be controlled and distributed by the quality manager assignee. Copies of those controlled standards will be with the quality manager assignee and with the methods engineering department.

The plant management will approve modifications to the controlled copies of the operating procedure. Uncontrolled issues of the operating procedure are available but not to be used as reference document and will not be updated. Uncontrolled documents will be marked with a stamp that bears the mark of uncontrolled documents.

The incoming document control employee will be responsible for controlling all customer supplied drawings and artwork. The employee will assign a unique number to each drawing arriving from the customer. He/She will also make copies of customer drawings and distribute them to various departments for manufacturing purposes.

Contract review quotes and records will be retained for a period of time that is set by the

sales department manager. Department managers can request changes in their work instructions by submitting a formal request to the quality manager to change the work instructions. A generic form for a document change request example is shown in Table 2.1. The plant manager is responsible for insuring that all the employees are adhering to the quality manual. He/She or his/her designees have the authority to approve any changes or addition to the operating procedure. The operating procedures structure is an important aspect in documenting the company's activities. The operating procedures must explain the company's activities and describe the management responsibilities. The plant manager must be aware of all the activities performed in his/her plant.

**Table 2.1: Request for Change in Work Instructions or Processes**

From: To: Name of requestor: Date:	Details of changes requested Manager Signature Process engineer signature Date signed
---	--

## CHAPTER 3: MANAGEMENT RESPONSIBILITY

### 3.1 Introduction

Management responsibility must be defined for all companies. The most common question an ISO auditor asks is "If you have a problem who do you ask or report to". The answer should be precise and clear. The plant manager responsibility varies from one company to the other. ISO 9000 defines some of the most important responsibilities.

### 3.2 Management commitment, Customer Focus and Quality Policy

The management commitment and quality policy will be documented to comply with ISO 9000:200 Quality Management System section 5 paragraphs 5.1, 5.2 and 5.3.

#### 3.2.1 Implementation

The company leaders must have a clear and consistent understanding of where their organization now stands and a concise and consistent vision of where it will stand in the future.

The plant manager will be responsible for creating a quality policy that must be understood and learned by all the employees of that company.

The quality policy is a blanket statement that is widely publicized and is brief so both internal and external customers can remember it readily. The policy is often endorsed and signed by the plant manager. An example of a quality policy would be as " ABC Company will strive to produce quality products that exceeds the customers expectations " or " ABC Company will consistently provide products and services that meet the quality expectations of our customers". The Vision statement could be stated as " the company's vision is to be recognized by all our customers around the world as the standard of excellence for PCB by the year 2002". As for the company's mission statement, an as example is that " ABC Company will provide competitively priced products and services by empowering each employee to exceed the customer's expectation for quality, service, and features while providing a fair return to our investors".

Management must be committed to create and implement the quality management system in place. Some of the quality gurus like Deming, Juran, and Crosby emphasized that management commitment are a must in order to achieve an effective quality management system. Management can follow either Deming's 14 points or Crosby's 14 steps for management. Juran, Shigeo Shingo, and Taguchi also have some contributions to management. Their ideas and principles will be discussed later in the proceeding chapters.

### Deming's 14 points for management:

A brief explanation of Deming's ideas is provided below.

- Leaders must state their organization's values and beliefs. They must create statements of vision and mission for the company based on these values and beliefs. The values and beliefs plus the vision and mission statements provide a frame reference for focused, consistent behavior and decision making by all stakeholders of the company.
- It is management responsibility to create an atmosphere that fosters intrinsic motivation. Management at the company should function to optimize the system so that everyone wins, not just the stockholder's wealth in the short term.
- Management must eliminate the need for inspection on a mass basis and build quality into the processes that generates the product needed for the companies' customers. Mass inspection does not do anything to decrease the variability of the quality characteristic of products.
- In order to reduce cost, award business to single source suppliers and work with them to reduce the variability and optimize their processes. This way, prices would drop and every one wins.
- Improvement and innovation of the system of production and service requires statistical and behavioral methods that should be used by everyone

in the company. Implement the PDCA (Plan, Do, Check, Act) cycle to improve and optimize the company processes.

- Management must make long-term commitment to their employees that include the opportunity to take joy in their work and pride in the outcome. Job skill training is a system whose aim must be optimization of the system of interdependent stockholders. Training, like quality and safety, is a line function not a staff function. Data should be used to guide the training plans for employees. The training needs of employees must be optimized to effectively allocate resources and to optimize the system.
- The aim of leadership should be to help people, machines, and gadgets to do a better job.
- Any system of management will not work properly in a fear filled atmosphere. It must be viewed as a method that provides opportunities for improvement.
- Breaking down barriers will often involve helping people see and understand the paradigms of other people and new paradigms. Eliminate slogans, exhortations, and numerical targets. Eliminate quotas or work standards and management by objectives.
- Work standards are negotiated values that have no bearing on a process or its capability. Changes in the capability of the process are not considered. Consequently the work standards don't reflect the potential of the new

system. Also, work standards create pressure to work at a given speed. This pressure inhibits employees desire to improve beyond the work standards because they believe management will raise their quotas.

- Remove barriers that rob people from their rights to pride of workmanship.
- Leaders are obligated to improve and educate themselves and their employees to optimize the system of interdependent stakeholders.
- Applying these points to any company will effectively increase the employees moral and will bear its fruit on the quality of the products being produced. Consequently cost will be driven down and both productivity and yield will increase (Kolarik William, Creating Quality, 1988).

Another quality guru had some ideas on how effective management can be achieved. Philip Crosby provided a 14-step model for management. It can be summarized as follows:

Step One: Management commitment

Action: Discuss the need for quality improvement with management people, with an emphasis on the needs for defect prevention. There are plenty of movies, visual aids, and other material available to support this communication.

Accomplishment: Helping management to recognize that they must be personally committed to participating in the program raises the level of visibility for quality and ensures everyone's cooperation as long as there is some progress.

### Step two: Quality Improvement Team

Action: Bring together a representative from each department to form the quality improvement team. These should be people who you can speak for their department in order to commit that operation action. Preferably, the department heads should participate-at least on the first go around.

Accomplishment: All the tools necessary to do the job now are together in one team. It works well to appoint one of the members as the chairman of the team for this phase.

### Step Three: Quality Measurement

Action: It is necessary to determine the status of quality throughout the company. Quality measurement for each area of activity must be established where they do not exist and reviewed where they do. Quality status is recorded to show where improvement is possible, where corrective action is necessary, and to document actual improvement later on. Non-manufacturing measurements, which are sometimes difficult to establish, might include the following:

Accounting: Percentage of late reports, computer input incorrect, and errors in specific reports as audited.

Data Processing: Key punch cards thrown out for error, computer downtime due to error and rerun time.

Engineering: change orders due to error, drafting errors found by checkers, late release.

Finance: Billing errors, payroll errors, and account payable deductible missed.

Hotel front desk: Guests taken to unmade rooms and reservations not honored.

There are innumerable ways to measure any procedure. The people doing the work will respond with delight to the opportunity to identify some specific measurements for their work. If a supervisor says that his/her area is completely immeasurable, he/she can be helped by asking how they know who is doing the best work, how they know whom to keep and whom to replace.

Accomplishment: Formalizing the company's measurement system strengthens the inspection and test functions and assures proper measurement. Getting the paperwork and service operation involved sets the stages for effective defect prevention where it counts. Placing the results of measurement in highly visible charts establishes the foundation of the entire quality improvement program.

#### Step Four: Cost of Quality Evaluation

Action: Initial estimates are likely to be shaky and so it is necessary now to get more accurate figures. The comptroller's office must do this. They should be provided with detailed information on what constitutes the cost of quality. The cost of quality is not absolute performance measurement. It is an indication of where corrective action will be profitable for a company. The higher the cost, the more corrective actions need to be taken.

Accomplishment: Having the comptroller establish the cost of quality removes any suspected bias from the calculation. More important, a measurement of quality management performance will be established in the company's system.

#### Step Five: Quality Awareness

Action: It is time to share with employees the measurements of what non-quality is costing. This is done by training supervisors to orient employees, and by providing visible evidence of the concern for quality improvement through communication material such as booklets, films, and posters.

Accomplishment: The real benefit of communication is that it gets supervisors and employees in the habit of talking positively about quality. It aids the process of changing, or sets the basis for the corrective-action and error-cause –removal steps.

#### Step Six: Corrective Action

Action: As people are encouraged to talk about their problems, opportunities for correction come to light, involving not just the defects found by inspection, audit, or self-evaluation, but also obvious problems-as seen by the working people themselves –that require attention. Those problems must be brought up in meetings and resolved by supervisors.

Accomplishment: Individuals soon see that the problems brought to light are being faced and resolved on a regular basis. The habit of identifying problems and correcting them is the beginning.

#### Step Seven: Establish a Committee for the Zero Defects Program

Action: Three or four members of the team are selected to investigate the Zero Defects (ZD) concept and ways to implement the program. The quality manager must be clear, right from the start, that Zero Defects is not a motivation program. Its purpose is to

communicate to all employees the literal meaning of “zero defects” and the thought that everyone should do things right the first time. This must be transmitted to every member of the team. In particular, the group that seeks out ways to match the program to the company’s personality.

Accomplishment: Improvement comes with each step of the overall program. By the time the ZD day is reached, as much as a year may have gone by and the initial improvement will be flattening out. At that point the new commitment to an explicit goal takes over, and the improvement begins again. The implementation ensures that the goals of the program will be firmly supported by the company’s through leaders.

#### Step Eight: Supervisor Training

Action: A formal orientation with all levels of management should be conducted prior to implementation of all the steps. All managers must understand each step well enough to explain it to their people. The proof of understanding is the ability to explain it.

Accomplishment: Eventually all the supervisors will be tuned into the program and realize its value for themselves. Then they will concentrate their action on the program.

#### Step Nine: Zero Defect Day

Action: The establishment of a ZD as the performance standard of the company should be done in one day. That way everyone understands it the same way. Supervisors should explain the program to their people, and do something different in the facility so everyone will recognize that it is a “ new attitude”.

Accomplishment: Making a day of the ZD commitment provides an emphasis and a memory that will be long lasting.

Step Ten: Goal Setting

Action: During meetings with employees each supervisor requests that they establish the goals they would like to strive for. Usually, there should 30 to 60, and 90 –day’s goals. All should be specific and capable of being measured.

Accomplishment: This phase helps people learn to think in terms of meeting goals and accomplishing specific tasks as a team.

Step Eleven: Error Cause Removal

Action: Individuals are asked to describe any problems that keep them from performing error-free work on a simple, one –page form. This is not a suggestion system. All they have to list is the problem; the appropriate functional group will develop the answer. It is important that any problems listed be acknowledged quickly-within twenty-four hours.

Accomplishment: People now know that their problems can be heard and answered. Once employees learn to trust this communication, the program can go forever.

Step Twelve: Recognition

Action: Award programs are established to recognize those who met their goals or perform outstanding acts. It is wise not to attach relative values to the identification of problems. Problems identified during the error-cause-removal stage should all be treated the same way because they are not suggestions. The prizes or rewards should not be financial, what is important is recognition.

Accomplishment: Genuine recognition of performance is something people really appreciate. They will continue to support the program whether or not they, as individuals participate in the awards.

Step Thirteen: Quality Councils

Action: The quality professionals and team chairpersons should be brought together regularly to communicate with each other and to determine actions necessary to upgrade and improve the solid quality program being installed.

Accomplishment: These councils are the best source of information on the status of programs and ideas for action. They also bring the professionals together on a regular basis.

Step Fourteen: Do it Over Again

Action: The typical program takes a year to eighteen months. By that time, turnover and changing situations will have wiped out much of the education effort. Therefore, it is necessary to set up a new team of representatives and begin again.

Accomplishment: Repetition makes the program perpetual and, thus, “part of the woodwork”. If quality is not rained in the organization, it will not happen (Crosby, Philip, Quality is free, 1979).

### 3.3 Quality Planning and Objectives

The plant manager must have a precise quality system plan. The goals must be set and the objectives made clear. This procedure will document how management can create,

plan, and implement strategic goals and objectives. This quality system planning and management objectives will comply with ISO 9000:2000 section 5 paragraph 5.4.

### 3.3.1 Implementation:

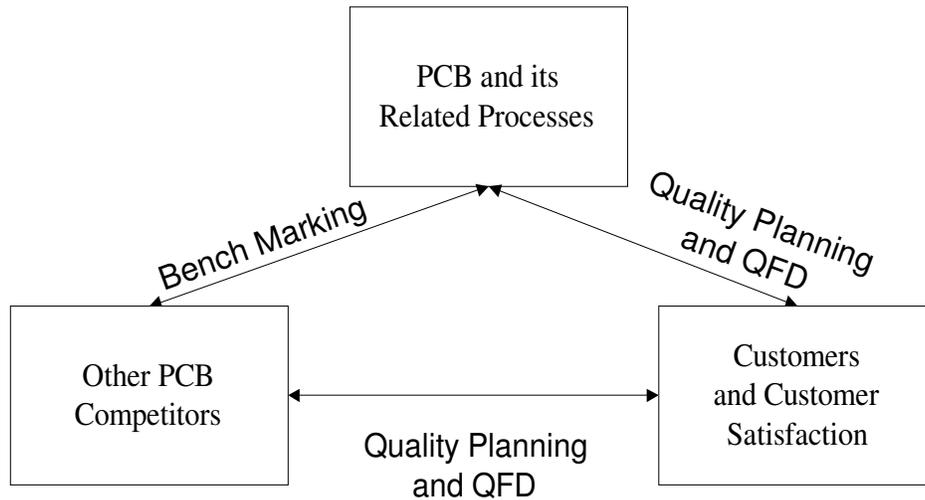
The plant manager will set the goals and objectives of the company. Quality planning is performed and implemented as shown in Figure 3.1.

Utilizing Juran approach to quality planning; a quality plan may be created as follows:

- a) Identify customers and make a list of all active customers
- b) Discover customer needs from their point of view
- c) Translate those views in to action
- d) Establish units of measurement
- e) Establish measurements of customer needs and expectation
- f) Develop and enhance the PCB production and service
- g) Optimize the PCB design
- h) Develop process that can meet the customers' requirements and specifications
- i) Optimize process capability
- j) Transfer the PCB to operations and test it

The plan stresses quality targets and competitive analysis of the PCB features. Once the PCB features are identified the method moves to plan and optimize the processes of production (Gitlow Howard and Oppenheim, 1995).

The general processes of planning the manufacturing of PCBs' will be discussed later in the proceeding chapters.



**Figure 3.1:** Quality System Planning

### 3.4 Management Responsibility, Authority and Communication

The quality system and all related activities described in this section of the quality manual complies with the requirements of ISO 9000:2000, as specified by Section 5.0 Quality management System Requirements, Paragraph 5.5- Management Responsibility. The Responsibility, authority, and management organization of the company will be described in this section. It will also describe the special responsibilities for internal quality audits and reviews.

### 3.4.1 Responsibility and Authority

The plant general manager will be directly responsible for all activities, quality of the products, and services provided by the company. An organizational chart will be presented for describing the responsibilities of quality as shown in Figure 3.2. The quality system will be monitored and executed by a management assignee who will report to the plant manager directly for its effectiveness. All the managers and supervisors are responsible for the implementation of the quality system related to their activities. Quality is the responsibility of all the employees in the organization. The plant manager will assign the quality manager to maintain and update the operating procedure and all of the related controlled documents. He/She will also be assigned to implement all the SPC and improvement plans.

### 3.4.2 Management Review and Analysis

This part of the quality management system complies with ISO 9000: 2000 Quality Management system section 5 paragraph 5.6 Management review.

### 3.4.3 Implementation

Every month there will be a management review that monitors the effectiveness of the quality system and to set goals that improves the quality system. Department managers will have the responsibility of answering the corrective actions

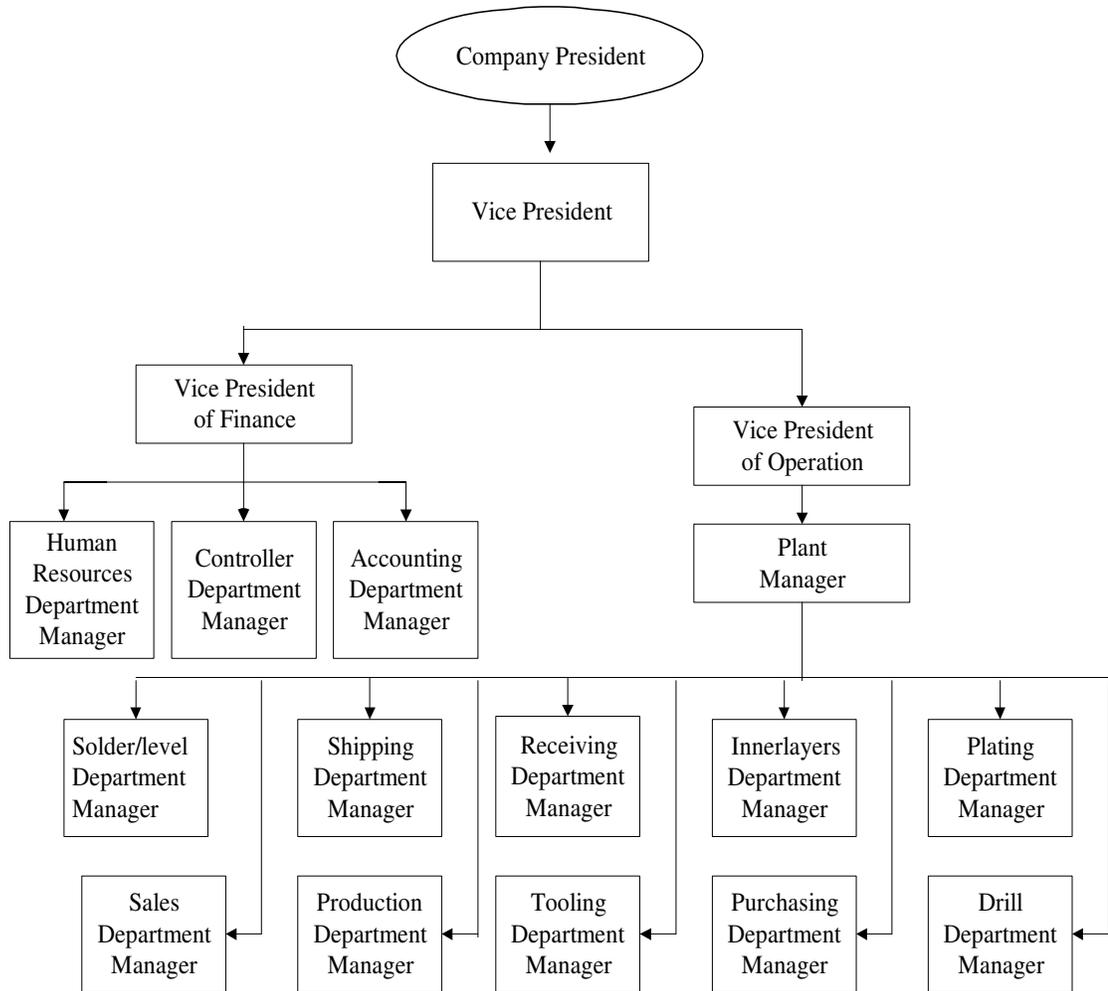
that are directed to them from the internal quality audits and will have a grace period to answer these corrective actions.

The quality manager assignee will maintain the internal audit schedule and analyze the quality system findings. The quality department for a certain period of time will retain records of the findings. Daily management review will be adjourned for reviewing product yield, scrap, rework, on time delivery, and production schedules.

Every week there will be a management meeting to discuss the related problems and major scrap. It will also set goals for the following week on how to improve the processes and ways to improve yield. The plant manager will review and analyze bi-weekly charts for trend analysis, restarts, and delivery performance. Department managers will discuss ways to eliminate the findings from the customer audits. Problems will be discussed openly and managers will give their inputs on the problems and the most efficient way to eliminate them. The plant manager will set dates for resolution of these findings. Department managers will deploy their efforts to quickly remove any barriers that hinder the resolution of any findings.

Every meeting will include a 10 minute follow-up review time to determine how the department managers are going on solving the customer related problems. The plant manager will ask for recommendation from the department managers on how the system may be adjusted to optimize its operation. Minutes of all management review meetings will be recorded and maintained by the quality assignee for a period of time.

This later operating procedure for management responsibilities and authority is the foundation of the company operating procedure because it defines who will be assigned the task of documenting, improving, and maintaining the quality system.



**Figure 3.2:** Generic Organization Flow Chart

## CHAPTER 4: REOSURCE MANAGEMENT

### 4.1 Introduction

This chapter discusses management responsibility in allocating sufficient resources needed to improve the quality of manufacturing, products, and achieve total customer satisfaction. Human resources have a direct input in finding and allocating resources. Since resources are also found in personnel talent and technical expertise, by an effective search the human resources department can enhance the company's resources and ultimately the entire company will benefit.

Keeping up with the company infrastructure is another great task. The maintenance department has an indirect role in the quality system chain. Although this role is a hidden one, it contributes to the overall performance of the company. This chapter will introduce ways to increase productivity through estimating mean time to failure for some of the important equipment.

Another contributor to resources is the safety aspect of the work environment. A better and safe work environment yields a productive and efficient atmosphere. When the company reduces the cost of work related injuries, employees enjoy a safe environment.

## 4.2 Management Resources

Allocation of management resources in this quality system manual will comply with ISO 9000:2000 Quality management system section 6 paragraph 6.1.

### 4.2.1 Implementation

Resources should be regarded as an important aspect. They cannot be wasted and cannot be stored. They have to be used in an efficient manner and distributed equally among all departments. If all of the resources are combined, it will effectively increase production, profit, and investors' confidence.

The plant manager will review all management requests for new equipment and hiring extra employees. The department managers will fill out a form as shown in Table 4.1 for the sole purpose of allocating more funds for the purchase of new equipment.

**Table 4.1:** Request for Fund Allocation Form

Name of the department:
Name of the department manager:
Is the fund allocation for extra personnel or for equipment purchasing:
Name of the equipment needed:
Cost of the equipment:
Process engineer name:
Maintenance department approval:
Reason for buying new equipment:
Reason for hiring extra personnel:
Is the personnel temporary or permanent:
If the personnel is temporary what is the duration for the assignment:
What is the cost of the new assignment:
What is the benefits of the new assignment:

Department managers must submit a study report to accompany the allocation form; this report will describe the reasons, benefits, and cost reduction that will incur from the new equipment. The department managers may consult with the process engineers to submit study charts that support their cases.

The plant manager will consider all allocation fund forms in a timely manner. Once the fund is approved, the purchasing department will contact the department manager to conduct the search for a supplier. The department manager may recommend the supplier of the new equipment. The quality department will give its input on the suppliers rating. Finally the purchasing department will choose the supplier for the recommended equipment.

Department managers will contact the accounting department once the equipment is up and running to send the payments of the equipment to the suppliers.

The plant manager will monitor customer satisfaction by creating a team whose sole purpose is to come up with a format that can measure customer's satisfaction.

### 4.3 Human resources

Human resources department is an interrelation department. It is the department that brings employees together as a whole company. The department's responsibility varies from one company to the other. Human resources is a vital and indispensable department in any organization. The most important responsibility for the department is the search for qualified employees to help build the companies' strategic goals and

ambition. The department also serves the employees that are employed and help them in their needs. In recent years the human resources department has become an extending hand to the employees and became the bank of information regarding their activities, records, training records, educational records, and in big companies health records. The information that is kept must at all times be in a secure area with selective people allowed to have access to them. The human resources department is also responsible for writing and initiating all the company policies regarding attendances, tardiness, dress codes, standard of conduct, and training records. The following operating procedure would be a generic procedure for a company that is involved in any PCB building, although most of the practices can still be applied to any industry. The quality system and related documents that describes this department complies with ISO 9000:2000 Quality Management Systems section 6 paragraph 6.2.

#### 4.3.1 Responsibility and Authority

The human resources manager is responsible for all the human resources activities and deployment of all policies. The plant manager will be informed and participate in forming all company policies. He/She will also sign all company policies prior to being enforced. He/She may seek legal advice from government agencies or other firms prior to releasing the policies. The human resources manager will form a committee to create or change any company policy. The committee members will be selected from all the

organization departments and will vote on accepting or rejecting the policy. The plant manager will ultimately accept or reject any policy.

#### 4.3.2 Implementation

The human resources manager will create training manuals for the employees and his/her department will be responsible for keeping these records. An example of a training manual form is shown in Table 4.2

**Table 4.2:** Employee Training Record

Employee name: Employee badge number: Employee social security number: Type of training performed: Award received: Employee grade: Employee participation:	Period of the training: Date the training was completed: Employee level of education: Training cost: Training benefits: Manager's signature: Employee signature:
--	--

The human resources manager will also create dress code policies that are applicable to the PCB plants where some clothing is not appropriate. An example of such policies is that all employees that work in the manufacturing areas must wear closed toe shoes, no loud music allowed, no tank tops are allowed. The human resources department will work concurrently with the safety department in having a bi-annual training seminar. The seminar will introduce to the employees the "how to" prevent

back injuries, evacuation procedures, and how to use fire extinguishers. The safety department will require all new employees to undergo a training session to familiarize them with how to handle the chemicals they will use during their regular job activities.

All new employees will undergo a separate job seminar that explains to them the quality system of the organization and the basic concepts of its operation. The department managers are responsible for training the new employees. Every department has its job related checklist. The checklist will list all the equipment and tools the new employee will be trained on. The training checklist will be forwarded to the human resources for record keeping. Employee's records will be kept as long as the employee is employed by the organization. If the employee is no longer employed by the organization the records will be kept for a minimum of three years.

Other policies that the human resources manager can create are the standards of conduct of an employee in the company. Such policies describe how the employees must maintain and commit themselves to highest standards of conduct and ethics. The company must have an open communication line with all the members of the organization. This will build trust and confidence among the employees.

Human resources manager will establish a standard of conduct policy. This policy will discuss where employees can get assistance for their problems whether personal or work related. This policy will require that all employees must be treated equally and with respect regardless of their position or rank. The standard of conduct policy will also explain the confidentiality of the business. No proprietary information

regarding the company practices or processes should be disclosed. The policy will also describe how the company will ensure safe working conditions for all of its employees.

#### 4.4 Maintenance

Maintenance department be will responsible for maintaining the operation of the processes and equipment in optimum conditions at all times. In order for the equipment and processes to operate efficiently at all times, a planned and systematic approach to regular maintenance will be taken. The maintenance department manager will be responsible for all maintenance activities in the organization. All projects will be worked on basis of its priority. The plant manager will assign a project manager to prioritize all ongoing projects.

The maintenance department manager will submit an analysis report describing the cost of equipment and manpower to finish the required project or installation. The department goals are to seek to improve process and equipment performance in the long run. A proactive view of quality requires considering reliability of the equipment and processes as it relates to expected performance rather than on historic basis. Maintenance department goals should be concerned with sustaining equipment performance through preventative maintenance policies and practices before they fail.

Reliability and maintability of the processes and equipment deal with the development of effective diagnosis and repair procedures, repair training and spare parts in inventories. This section of the operating procedure will explain the operation of the

maintenance department to comply with ISO 9000:2000 Quality Management System section 6 paragraph 6.3.

#### 4.4.1 Implementation

Maintenance department function is to maintain and repair all equipment in the organization. Equipment in the plant will be on a scheduled maintenance program. The schedule will list all the equipment and machines that require periodic maintenance.

Example of such a schedule is shown in Table 4.3.

**Table 4.3: Schedule Maintenance Log**

Department: Machine number: Oven number: Microscope serial number: UV machine number: Date machine is scheduled for maintenance: Date last maintenance performed: Maintenance technician name: Settings of the machine being under maintenance: Is calibration department been notified for recalibration:
---

The maintenance department manager will be responsible for the following tasks:

- a) Establishing maintainability policies
- b) Training procedures and staffing maintenance technicians

- c) Develop plans for conducting maintainability demonstrations
- d) Collect data and analyze failure rate
- e) Take part in the design of the processes and where they are located
- f) Conduct maintainability trade off studies
- g) Monitor maintainability activities by subcontractors
- h) Provide consulting service to other technicians
- i) Document maintainability and construct a scheduled maintenance for the equipment and processes

Critical processes such as solder level will have standby equipment. Standby equipment are those that only function when the original equipment fails. Some processes require parallel configuration systems.

Basic evaluation of series and parallel system reliability is as follows.

A series system is shown in Figure 4.1.

The reliability of the system is given by

$$R_{sys} = (1 - P)^n \quad (4.1)$$

Where p is the probability of equipment failure and n is the number of components.

A parallel system as shown in Figure 4.2.

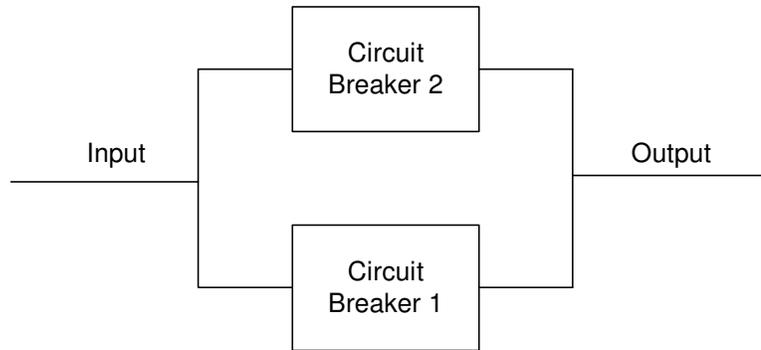
The reliability of the system is given by

$$R_{sys} = 1 - P^n \quad (4.2)$$

Where p is the probability of equipment failure and n is the number of components.



**Figure 4.1:** Series System



**Figure 4.1:** Parallel System

Once the reliability of a system is calculated we can estimate the mean time to failure of the equipment.

$$MTTF = \int_0^{\infty} R(t)dt \quad (4.3)$$

Now we can use the mean time to failure of the equipment to set the scheduled preventative maintenance.

The reliability of a machine may also be calculated from the failure rate, where failure rate is the rate at which the failure of a machine occurs.

The reliability then can be calculated from the equation

$$R(t) = e^{-\lambda t} \quad (4.4)$$

Where  $\lambda$  is the number of defects or errors and  $t$  is the time it took to fail.

The probability density function is equal to  $f(t)$ . The hazardous rate, which is the instantaneous failure rate equal to the PDF divided by the reliability function. If we are able to calculate any of the two functions the third will be able to be calculated.

Reliability Function as a function of the hazardous rate:

$$R(t) = e^{-\int_0^t h(t)dt} \quad (4.5)$$

MTBF (mean time between failure) can also be estimated, which is equal to one divided by the failure rate.

$$MTBF = \frac{1}{\lambda} \quad (4.6)$$

Where  $\lambda$  is the failure rate

MTTR (mean time to repair a machine) can be estimated, which is equal to one divided by the repair rate

$$MTTR = \frac{1}{\mu} \quad (4.7)$$

Where  $\mu$  is the repair rate

Thus to calculate the Availability of a processes that has several machines we use the equation.

$$A = \frac{MTTR}{MTTF + MTTR} \quad (4.8)$$

Availability of a process is equal to process uptime divided by the addition of process uptime and process down time. When equipment or a tool needs repair, employees will complete a maintenance request form. This form will describe the part needing repair and any systems exhibiting on the equipment.

## CHAPTER 5: PRODUCT REALIZATION

### 5.1 Introduction

This section of the quality management system will describe how the PCB is developed and how its processes are designed.

Any process is a sequence of activities or an activity that has an input and an output. Management should define the required outputs of processes, and should identify the necessary inputs and activities required for their effective and efficient achievements.

The interrelation of processes can be complex, resulting in process networks. To ensure the effective and efficient operation of the organization, management should recognize that the output of one process may become the input to one or more other processes. Planning and development of the PCB manufacturing processes will comply with ISO 9000:2000 Quality management system sections 7.

### 5.2 Planning and Development Realization

The tooling department is responsible for planning all the required steps to manufacture the PCB to meet customer requirements and expectation. The operating procedure will document the tooling department process and all other processes that are involved in developing of the PCB.

### 5.2.1 Implementation

The process engineers will develop processes needed to manufacture the PCB's. Planning and developing the process must meet all quality requirements and objectives. All processes must be documented and controlled. Continuous verification of the processes performance and monitoring of the equipment and measuring tools will be part of the processes. All the department managers in compliance with ISO 9000:2000 section 7 paragraphs 7.1 will keep records of the processes performance.

Any customer related processes would be documented and maintained by the quality department. In the event that the processes must be changed to manufacture the PCB, the customer must be notified prior to implementing the changes. Once the customer grants the approval, the processes can be changed and the documents will be updated to reflect the changes.

Once the confirmed order has been received from the customer, the tooling department will review the customer specification and requirements. Methods engineering will make up a work order traveler that will state the processes needed to manufacture the PCB's. Special customer requirements may also be contained in the work order.

#### Methods Engineering

Every new customer will be assigned to a method engineer. The method engineer will complete a form that specifies how the PCB will be built. A sample of this form is shown in Table 5.1.

**Table 5.1: Methods Engineering Instructions For Building the PWB**

Customer name: Customer part number: Revision of part number: Tracking number: Engineer name:
Type of boards: (military, commercial) Specifications used: Number of layers: Type of material: (FR4, FR5, ployimid, kevlar, cyanate ester) Test type :( surface mount, clamshell, net list test, thruhole Test, flying probe test) Drill sizes: Finished hole sizes: Type of holes: (plated through or non plated through holes) Art work supplied: (customer supplied or pen plots) Numerical count rout, NC rout: (slots, holes, cutouts, plated slots, plated edges) Hole fill artwork of buried vias: component side, solder side. Pre machining: slots, plated edges, plated slots. Increase pad, fiducial size: percentage of increase. Type of solder mask: liquid imageable, peelable mask, dry Film, wet mask Legend: component side, solder side, both sides. Copper weight: Minimum copper thickness: Board thickness and tolerance: Number of layers: Prepreg thickness: Core thickness: Number of boards on a panel: Panel size: Location of customer's marking: solder side, component side, and both sides.

**Table 5.1: Methods Engineering Instructions For Building the PWB( Continue)**

Date code required:
Part number and revision location on board:
Logo or cage code marking on boards:
Number of coupons on a panel:
Coupons location:
Circuit width requirement and tolerances:
Percentage needed to blow artwork to meet customer requirement.
Inner layer minimum circuit width:
Outer layer minimum circuit width:
Minimum Inner layer annular ring:
Minimum outer layer annular ring:
Gold required:
Type of gold required: deep gold or electroless gold
Gold thickness required:
Nickel requirements:
Via holes plugged: plug with mask or tent vias
Solder requirement: solder level or solder plate
Solder thickness:
Oil reflow requirement:
Special machining requirement: bevel, slots, web rout, scoring.
Bevel requirement:
Slot width and length:
Web dimension:
Scoring requirement:
Dielectric impedance requirements:
Source inspection requirements:

Once the methods engineer is finished designing the layout of the circuit board all the paper work will be forwarded to the tooling certification department.

The method engineer will then generate a work order describing all the processes needed to fabricate the PCB and will forward the inner layer work orders to the tooling

certification department. An example of a work order that has the basic processes for manufacturing PCB is in Table 5.2

Cam and Photo

Once the gerber data is downloaded and certified, the members of the cam department will download the information to the photo department to create the artworks necessary for PCB fabrication. The photo department will print copies of the artwork and distribute it to the various departments. All artwork generated by the photo department will be certified by the tooling department prior to its release. Detailed work instruction for the cam and photo department will be written and constructed by the tooling department manager. The exposure and temperature of the photo department machines will be set and documented by the process engineer.

**Table 5.2:** Generic Inner Layer Work Order

Tracking number: Number of layers: Customer name: Part number and revision: Copper requirement: Material type:	Material part number, mfg and traceability: Layer cleaning: Layers resist: Innerlayer print: Innerlayer develop:
---	--

Tooling Certification

The function of the tooling certification department is to certify the jobs for release to production. A checklist can be generated to assure that the innerlayer and

outerlayer work order conforms to the customer blue print and drawings. Tooling certification department members will also ensure that all the specifications and requirements of special processes are recorded on the work order.

If a job is rejected, a form will be completed and returned with all the paper work to the method engineer for verification and correction. The cam department will download all the information necessary to print the artwork on the gerber files to working artwork. This working artwork must be certified for use on the production floor by the tooling department. An example of such a form is shown in Table 5.3

#### Drill Certification

A member of the tooling certification department will certify the master panel for drill sizes and drill specification typical to the customer blue print and specifications. The drill certifier will ensure that all hole sizes are accounted for and are in the correct location. He/She will also check that tooling holes are not drilled into the boards since the tooling holes are only used to assist in manufacturing. All coupons will also be checked for hole misregistration and location.

In case there is any rejection in the drill certification department, the job will be sent back to the cam department for correction. Once the corrections are made the member will certify the panel.

Inner layer Artwork Certification

Inner layer artwork will be certified for correct plots and misregistration. Certifiers will match customer silver artwork with the production artwork that is used in manufacturing.

**Table 5.3:** Method Certification Deviation Form

Customer: Part number: Revision: Certifier: Methods engineer:	Tracking number: Problem: Solution Date in: Date corrected:
---	---

Outer layer certification

Outer layer artwork will be certified by matching it with the customer artwork or the artwork generated from the gerber data.

Solder Mask and legend artwork Certification

The working artwork will be matched to the customer artwork for verification of the solder mask location and legend misregistration. If legend is found to be on surface mount pads, the artwork can be modified after the customer is notified.

Cycle time can be measured in this department by tracking the time the jobs are in for certification and when the jobs leave the area.

Once the job is certified the methods certifications members will forward the innerlayer work orders to the receiving department to start the production processes.

### Receiving

The receiving department employee will determine the material needed for production from the inner layer work order. The member will check for copper weight, copper thickness and type of material and will write the stock number of all materials used on the job in the work order. He/She will also stamp the material with a tracking and a lot number for traceability. The job is then moved in the computer to the next operation. The member will sign, date, and stamp the work order before moving the material to the next operation.

### Inner Layer Clean

The members will insert all layers in the rolling machine for cleaning. For optimum conditions the process engineers will preset the speed of the machine. The process engineers will also determine the technical parameters needed for optimum operation. The chemicals used will be monitored by the chemical lab for the correct concentration and ph balance. The chemical lab will take samples twice a day from the tanks to insure its concentration is typical to the work instruction.

Once the panels are cleaned the members will sign, stamp, and date the work order and move the job to the next operation.

## Innerlayers

The function of the innerlayer department is to print the innerlayer artwork generated by the photo department on the panels.

All innerlayer will be masked by resist (a material that is impervious to or resists attack by etchant) prior to printing. The mask is a photo resist which is a polymer that is activated using ultra violet radiation. It is used to put a circuit image on a printed circuit board. It can be a positive or negative image. Its main function is to keep acid from adhering to or attacking the copper under the developed photo resist.

The speed of the roller will be determined and documented by the process engineer.

The members of the innerlayer department must insure that the artwork is aligned to the panels prior to printing the images. The detailed work instruction for the innerlayer department will be created and administered by the department manager. The equipment settings for roller speeds, temperature, time of exposure, pressure, intensity of the exposure and the stouffer settings will all be set and documented by the process engineer.

The process engineer prior to the use of the equipment must approve any deviation or change of the settings. A written request of the change must be forwarded to the document control department to update the work instruction.

The process engineer can reduce the rejects and rework of the department by optimizing the settings of the process. Design of experiments can be applied to this department to determine the most influential variable that has the most effect on the

process. After the process engineer collects some data using a designed experiment, a normal probability chart can be constructed to determine the most influential variables.

An example of a normal probability chart of effects is shown in Figure 5.1. Once the major variables are determined, a method of steepest ascent can be used to determine the settings of these variables that achieve optimum condition. The innerlayer department members will sign, stamp, and date the work order and move the printed panels to the develop department.

#### Developing

The function of the develop department is to develop the resist off the panels. The develop machine will be set by the process engineer who will determine the settings that would achieve optimum production conditions. Design of experiments can also be applied to assist the process engineer in his quest for optimum performance. The chemical lab will ensure that the correct concentrations of the chemicals are according to the documented procedure set by the process engineer. This is done by analyzing samples from the tanks twice a day. If chemicals must be added to correct the concentration required.

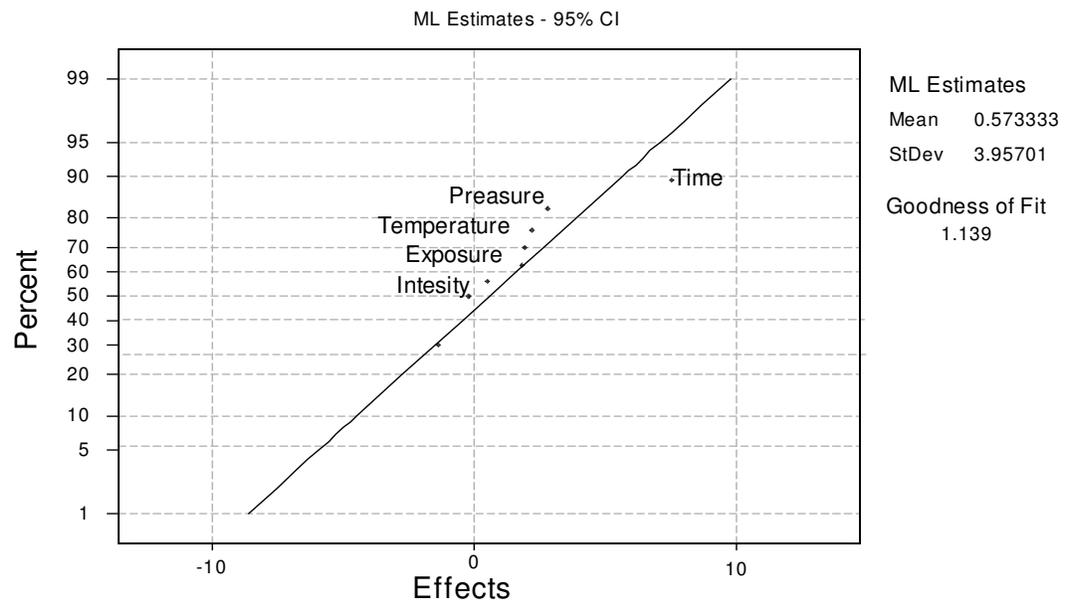
A written request will be forwarded to the chemical technician instructing him with how much chemicals are needed. The chemical lab will verify the addition of the chemicals by conducting more tests. The members of the developing department will sign, stamp, and date the work order prior to moving the job to the next operation.

## Etching

The etch department function is to etch away the excess copper and leaves the traces of the required circuits and pads on the PCB. Some of the definitions regarding etch are:

Etch rate: the speed at which copper is etched from the PCB. Etch rate is influenced primarily by the type of etchant, spray pressure, ph, temperature, and type of laminate.

Etch factor: The ratio of the etch depth to the amount of undercut.



**Figure 5.1:** Normal Probability Chart of the Effects

Etching chamber: is the front part of an etcher that is enclosed and that contains the chemicals, spray manifolds, and spray nozzles. Etchant: is the chemical pumped into the spray manifolds and released onto the panels through the spray nozzles.

The etch department will also strip the excess resist off the panels after the etch operation. The process engineer will set up all the settings required to perform the operation. The variables that effect this operation are the temperature and concentration of the chemicals, speed of the rollers, the amount of copper to be etched away from the panels, and the copper weight of the panels.

The members of the etch department will verify the circuit width after etch by using calibrated beta scopes. If the circuit width needs more etching the roller speeds will be reset in order to achieve the correct etch requirement. The members will obtain the etch requirement from the work order and on the completion of the work they will sign, date, and stamp the work order prior to moving the job to the next operation.

#### Post Etch Punch

The function of this operation is to punch the panels with slots that will align the panels during the press process.

The calibration of this machine is of great importance since any deviation from the correct location will results in misregistration of the innerlayers. The members of this department will calibrate the machine prior to its usage every day. The software of the calibration is a computerized self-calibration. The process engineer will document the

process of this operation in the work instruction. The members will sign, stamp, and date the work order prior to moving the job to the next operation.

#### Automated optical Inspection (AOI)

This department is responsible for inspecting the panels for any shorts, burs, nicks, cuts, opens, and copper fines on the panels. The members will set up the machines according to their documented procedure. The machines typically inspect the panels 100 percent. If any defects are detected a mark will be left on that suspected defect. The AOI department inspection team will verify the suspected defects and rework it if needed.

The AOI machine must re-inspect the panels again after the rework is done to ensure the integrity of the panels. The members will sign, stamp, and date the work order prior to moving the job to the next operation.

#### Brown Oxide

This department function is to coat the inner layers with brown oxide, the purpose of the brown oxide is to protect the inner layers from handlings and to assist the prepreg in adhering to the inlayer panels for good bonding.

The members of this department will immerse the PCB panels into the tanks for a certain period of time by utilizing calibrated timers. The sequence of the panel's immersion will be according to their documented written work instruction.

The process engineer will determine the optimum time needed for the panels immersion for all brown oxide operations. The chemical lab will monitor the tanks concentration and ph. The chemical lab will take two samples daily to verify the

concentration of the tanks per the process engineer specification. The chemical lab will notify in writing the chemical technician if any of the tanks needs additives or needs to be leached out. The member of the brown oxide department will sign, date, and stamp the work order and move the job to the lay up department.

### Lay up

This department is responsible for putting the layers together to form the multilayer PCB. The layers will be sandwiched with prepreg (dielectric). The function of the prepreg is to form an isolated barrier between the layers of the PCB. The prepreg is made out of epoxy and kept refrigerated at all times. The temperature of the refrigerator will always be constant. The calibration department will monitor the refrigerator temperature and the prepreg will always be rotated when new prepreg arrives. Any new incoming prepreg will be labeled with the thickness, date of arrival, and expiration date.

The members will ensure the correct layers are on top of each other sandwiched with prepreg. The P.E (Post Etch) punch operation shows its advantage in the lay up operation. The members will align the layers according the punches made by the P.E punch, without this alignment the layers will be misregistered. The next step is verifying that the prepreg thickness is complying with the work order specifications.

Once the lay up is complete, the entire lay up will be sandwiched between two metal plates and pressed under vacuum. The metal plates will protect the PCB from direct contact to the press plates. The members will set the temperature of the plates and

the pressure of the press according to their written work instruction. The process engineer predetermines these settings through the use of design and experiments for optimum performance. The members will sign, date, and stamp the work order prior to moving the job to the press department.

### Press

The function of this department is to press together the layers of the PCB. The process engineer will set the press time, press pressure, and temperature. The controlled work instruction will include all the parameters values and tolerances. The press pressure has a direct relation on the PCB overall thickness. The operators must check the work order for the required overall thickness prior to pressing the layers together. The operators will move the jobs to the next operation after signing, dating, and stamping the work order.

### Break Down

The function of this operation is to break down the PCB layers from the metal frame. The process engineer sets the time needed to cool the panels. The operators will measure the warp and twist of the panels after it had been cooled. They will also verify the PCB thickness using calibrated micrometers. The operators then sign, date, and stamp the work order and move the job to the next operation.

### Rout Down

The function of this operation is to rout off the excess material from the panels. The operators will use the software provided to them from the tooling department. The

operators will sign, date, and stamp the work order prior to moving the job to the next operation.

### Drilling

The function of this operation is to drill holes per customer requirements and specifications. The holes are drilled to interconnect circuitry on different layers. The holes are also used to insert components in them. Some of the holes requirements are too small to meet with the common CNC machines. Such small diameter holes (less than .012 mil) are now drilled using laser or punching processes for micro via holes.

The drilling process using CNC machines are done by writing software that targets the machines on the location of holes need to be drilled. The CAM departments usually create this software where the gerber data from the customer is translated to compatible software for the CNC machines. The operators will load the software into the machine and will ensure that the correct drill bit sizes are used to drill the required holes. Then they will place the panels on the drill machine and start the software program supplied to them from the Cam department. After drilling one panel the operator will verify the location of the drilled holes using the X ray machine.

Once the hole location is verified to be in the correct location the operator will proceed drilling the rest of panels. If the X-ray machine shows any misregistration the operator can change the location of the drilled holes to accommodate the misregistration.

The feed and speed of the machines will be determined and set by the process engineer. He/She will also document the settings in the work instruction.

The most critical element that affect the hole integrity are the feed and speed, quality of the drill bits, type of drill bits, how many layers the PCB is and how many panels are stacked on top of each other. All of these variables have a direct impact on the integrity of the holes. The operators will check the drilled holes using calibrated pin gages.

After the drill operation is completed the operator will sign, date, and stamp the work instruction and move the job to the next operation. A generic flow charts diagram for the drill department is shown in Figure 5.2. This flow chart will be used as a pictorial summary of the flow and decisions that comprise this process.

#### Special Operations (Laser Drilling)

This operation is only for buried microvia holes. The tooling department will generate the software for the CNC machine. The process engineer will document the settings and the work instructions for the laser drill operation. The drill operator will set the required laser beam according to the type of material being drilled. There are two different laser beams, one to drill thru the copper and the other to drill thru the epoxy laminate. Once the layers are drilled the operator will move the job to the next operation after signing and dating the work order.

#### Drill Inspection

The function of this department is to ensure that the panels drilled are free from any defect. The operators will inspect the panels and utilize a check sheet as shown in Table 5.4. The operators will notify their supervisors in the event of any rejects are

found. The supervisor will determine if the panels can be reworked or scrapped. If the panels are scrapped, production control department must be notified to order a restart.

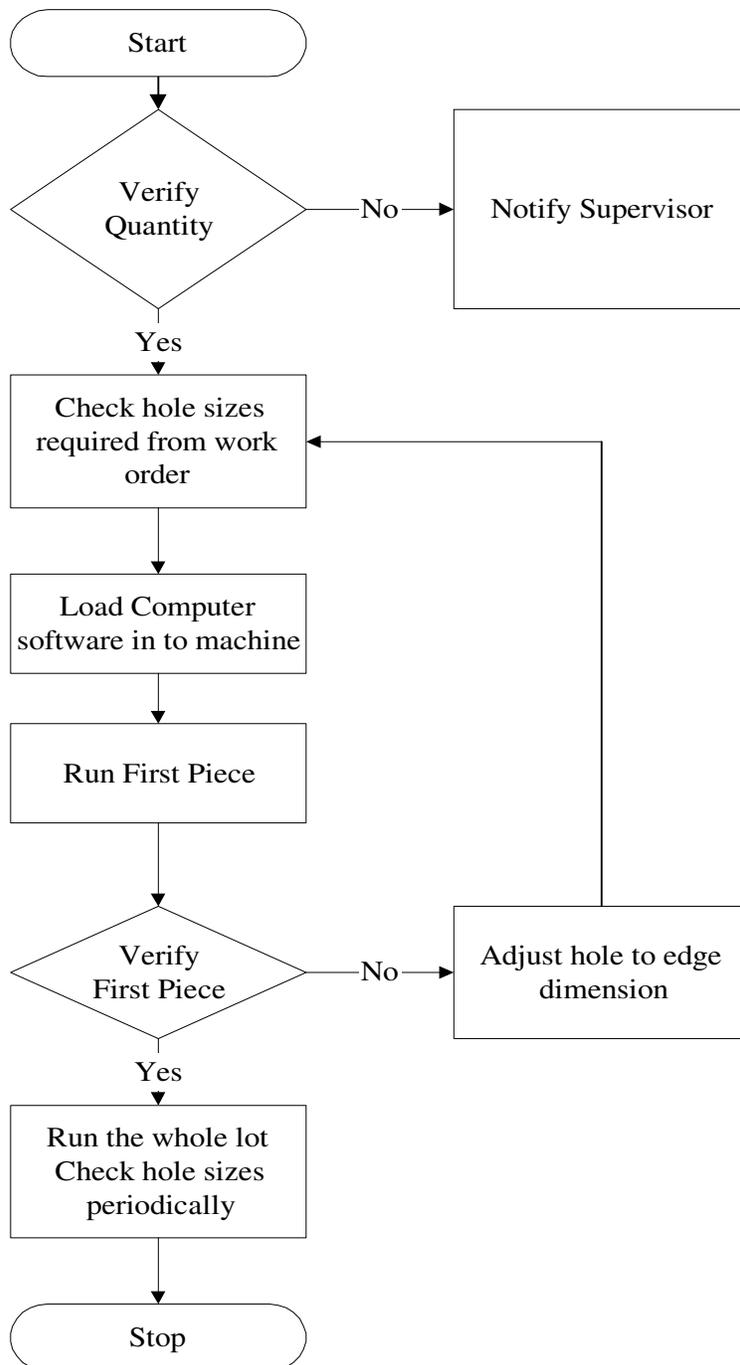
All defected panels must be labeled as defective. The operators will sign, stamp, and date the work order and move the job to the next operation.

**Table 5.4:** Generic Check Sheet for Drill Inspection

Customer name: Customer part number and revision: Tracking and lot number: Undrilled holes: Mislocated holes:	Misregistration: Wrong hole size: Burr in holes: Inspector name: Date inspected:
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Hole Cleaning

Hole cleaning generally refers to a process called desmear and/or the closely related process of etchback. Desmear removes the melted resin smear that results from the friction of the drill bit cutting through the material. If the smear covers the copper that extends to the barrel of the hole, it would prevent interconnection between it and the subsequently metallized hole. During etchback, resin smear will be removed and glass fibers are etched. The result is that the copper on the innerlayers protrudes out into the barrel of the hole. This allows for what is known as a "3-point" connection after metallization. Deburring and scrubbing are performed immediately before or after desmear or etchback.



**Figure 5.2:** Generic Drill Department Flow chart

During drilling, copper burrs may be raised on both sides of the panel by the action of the drill entering and exiting the material. The burrs are sanded smooth on a deburring machine, which consists of a sanding wheel and a conveyor. In wet deburrers, copper dust is carried off in a waste stream. Dry machines usually are outfitted with vacuum units.

Deburring is more correctly considered a surface preparation step rather than hole cleaning. Scrubbing is performed as a surface preparation step prior to electroless copper (and during other stages, such as before solder mask). Scrubbing may be performed similarly to deburring, except a much less aggressive surface abrasion occurs. Pumice or aluminum oxide scrubbers, which direct a high-pressure spray of abrasive particles at the PWB, are also used for surface preparation.

#### Dep “ Depositing of Electroless copper”

The function of this operation is to provide interconnection between layers. The holes must be coated or plated with a conductive substance. The PCB dielectric itself is not conductive, so a non-electrolytic deposition method is required. Afterwards, electroplating is performed to plate the copper to the specified thickness.

Until recently, electroless copper has been used almost exclusively to metallize the holes. Direct metallization (DM) processes were introduced in the 1970s, but reports of higher costs and inconsistent quality kept manufacturers from experimenting with an unproven process.

New interest in alternatives to electroless copper was ignited in 1992, when OSHA amended a standard for occupational exposure to formaldehyde, a known carcinogen. With few exceptions, electroless copper uses formaldehyde as the reducing agent. Alternatives to electroless copper now include palladium-based systems.

Carbon/graphite-based systems, electroless nickel, conductive polymer, and non-formaldehyde-based electroless copper. Based on the survey results, however, it is apparent that the electroless copper process is still entrenched as the predominant method of making holes conductive, although its use appears to be declining. Most manufacturers use electroless copper for through-hole metallization, and some use the graphite process, palladium, and carbon-based systems.

Electroless copper baths can be divided into two types: heavy deposition baths (designed to produce 75 to 125 micro-inches of copper) and light deposition baths (20 to 40 micro-inches). Light deposition must be followed immediately by electrolytic copper plating. The main constituents of the electroless copper chemistry are sodium hydroxide, formaldehyde, and a copper salt. When light deposition is applied, the next process step must be electrolytic copper plate. This is either a full panel plate (the typical 1 mil is plated in the holes and on the surface) or a "flash" panel plate, designed only to add enough copper to the hole barrels to survive the imaging process. Flash-plated panels return to copper electroplating after imaging to be plated up to the required thickness.

This double plating step has made heavy deposition the more common electroless copper process. The operators will stack the panels in racks and dip the panels in the

tanks for the specified period of time. Once the operators are done with the depth cycle the panels are rinsed and moved to the next operation.

The chemical lab technicians will monitor the tanks chemicals. They will obtain samples from the tanks twice a day and analyze them to ensure the chemicals correct concentrations and ph balance. The process engineer will set the chemicals concentration, dwell time, and temperature. He/She will also document all the parameters and its tolerances in the documented work instruction.

#### Resist coat “Outerlayers”

The function of this department is to coat the outer layer of the PCB with a special mask to protect the copper from being etched away during the etch process. The operators will laminate the outer layers of the panels with resist by sliding the panels through a laminator machine. The operators will inspect the laminated panels for wrinkling of the film, scratches, uneven lamination, and any other abnormality in the film. If the operators find any defects on the panels they will strip the resist off the panels and rerun the panels again through the laminator. Stripping the resist off the panels prior to print process is done by running the panel through the developer.

Prior to lamination of the resist, the operators will check the temperature settings and conveyer's speed of the machine. The process engineer will be responsible for determining the optimum settings for the equipment to produce optimum performance and will document all the settings in the controlled work instruction. When the process engineer is performing design of experiments on the process settings, the temporary

setting changes must be controlled and the quality department must be notified. The operators will sign, date, and stamp the work order prior to moving the job to the print department.

### Print

The function of the print department is to print the certified outer layer artwork on both sides of the panels. This process will print the image of the circuits and pads of the outer layers on the resist. The operators will verify the Stouffer settings (The intensity of the UV radiation) prior to printing any job. After verifying the intensity of the UV machine the operators will align the artwork on both sides of the panels and print the image.

The time required to cure the resist, the intensity of the UV, and temperature of the machine will be determined by the process engineer. The process engineer will document the required settings of the machines in the work instruction. The operators will inspect the printed panels for any print misregistration or any resist scratches. Finally the operators will sign, date, and stamp the work order and move the job to the next operation.

### Develop “Outerlayers”

The develop department operation is to develop off the resist and leave the areas that will be copper plated exposed. The operators will check the speed of the conveyer and temperature of the chemicals prior to inserting the panels in the developer. The conveyer speed setting and the chemical temperature setting are determined by the

process engineer and documented in the controlled work instruction. After the panels go through the developer tanks, they will pass through a couple of rinse operations then an air blower will dry them. The operators are to inspect the panels once they are out of the machine for any scratches or contamination on the resist. The operator will sign, date, and stamp the work order and move the job to the copper plate operation.

The chemical lab department will monitor and analyze the chemicals concentration twice a day, in the event that chemicals need to be added or changed, the chemical lab will notify the chemical technician with a written request of the requirements needed. The tanks should be leached once a week to avoid contamination of the chemicals. The work instructions will document the process of leaching and the lab analyzes results.

### Copper Plate

The function of this operation is to copper plate the panels with the required copper thickness. The operators must check the copper requirements from the work order. The copper deposited on the boards and in the holes is dependent on, the current passing through the anodes, the time the panels are kept in the bath tank, the concentration of circuits on the panels, temperature of the bath, and the chemical concentration. The process engineer will document the process parameters and the time required to plate the panels in the work instruction. The operators will run the panels through the copper tanks and will routinely pin gage the plated holes for the correct sizes.

After the panels are plated with the required copper, they are to be rinsed by passing them through couple of rinse operations. The operators will sign, date, and stamp the work order prior to moving the job to the next department.

### Solder Plate

The function of this department is to solder plate all the exposed copper circuits. The function of the solder plate operation is to protect the copper circuits from being etched away when the panels go through the etch process. The etch chemicals will attack all the exposed copper but will not etch any solder circuits. The operators will check the timers' calibration, tank temperature settings, chemical concentration, current settings, and voltage setting of the process prior to running any panels.

The operator will notify the process engineer if there are any problems with the process. The process engineer will document the required process settings in the controlled work instruction. Any changes of the settings must be controlled and documented in the work instruction. The operators will put the panels in the specified racks and dip the panels in the cleaning, micro etch, cleaning, solder tanks, and cleaning tanks respectively. The panels will always be timed while they are in the tanks.

Once the panels are solder plated the operator will inspect the panels for skip plating and scratches. Finally the operators will sign, date, and stamp the work order before moving the job to the next operation.

The chemical lab department will monitor and analyze the chemicals concentration twice a day, in the event that chemicals need to be added or changed, the

chemical lab department will notify the chemical technician with a written request of the change or addition to the specified tanks.

### Resist Strip

The function of this department is to strip the resist (film) off the panels. The operators will check the machine temperature settings, pressure, conveyor speed settings, and chemical concentration prior to running the panels through the tanks.

The process engineer will document all the setting requirements for the resist strip process in the controlled work instruction. The operators will adhere to the work instruction requirements. After the panels are dried and inspected for any resist residue, the operators will sign date, and stamp the work order and move the job to the next operation.

### Etching (Outer layers)

The function of this department is to etch away all the exposed copper off the panels. The circuits that are plated with solder will not be etched away. The operators will check the etcher chemical concentration, tank temperature, conveyor speed, and pumps pressure prior to running any panels through it. The process engineer will document the entire process-setting requirement in the controlled work instruction. The operators will check the PCB's circuit width, minimum spacing between the circuits with a calibrated beta scope per the work order requirements. The operators will also inspect the panels for any other defects such as over etch, copper spray, nicked circuits, and cut circuits. If any defect is found, the boards will be identified as a scrap by punching a hole

through it. The operators must fill a scrap report and document what caused the defect and how many boards are affected by it. Finally the operators will sign, date, and stamp the work order and move the job to the next operation.

### Second Drill

The function of this operation is to drill all the unplated holes of the PCB. The operators will utilize the software supplied to them from the tooling department to set up the drill machine. The operators will verify the tooling holes needed to be drilled and the sizes of the drill bits from the work order. The panels are then stacked on the drill machine and drilled. After the panels are drilled the operators will verify the drilled holes using calibrated pin gages. The operators will sign, date, and stamp the work order prior to moving the job to the next operation.

### Solder Strip

The function of this operation is to strip the solder off the panels. The panels are laid on a conveyer to move it in to a solder strip chamber. The chamber contains chemicals and nozzles. The chemicals are pumped into the nozzles and then sprayed on to the moving panels. The panels are then moved into other rinse cycles for cleaning purposes.

The conveyer speed, temperature of the chemicals, and the amount of chemicals sprayed on the panels are set by the process engineer. The process engineer will document the parameters of this process in a controlled work instruction. The panels will be inspected by the operators to ensure that there is no solder residue. Finally the

operators will sign, date, and stamp the work order and move the job to the next operation.

### Solder Mask

The function of this department is to apply solder mask on to the boards. The mask purpose is to protect the laminate from handling damage; it is also used as an isolator between the pads and circuits to prevent sparking or shorts. The members will determine the type of mask required from the work order and customer requirements. The three most common types of mask are liquid photo imageable mask, dry film mask, and wet mask. The liquid imageable mask is a mask that is cured by thermal process and ultra violet radiation. The dry film mask is a film that is cured by ultra violet radiation. The wet mask is cured using the thermal cure process. The operation of the liquid imageable mask is to process the panels through a chamber that coats mask on the panels. The panels are then removed and baked for a short period. The next operation is the print process where the members utilize the mask artwork certified by the tooling department to print the image of the required exposed surfaces on the panels.

The print process operation is similar to the printing of the resist in the earlier process of the PCB manufacturing. The artwork is aligned on the panels and pushed in a printing chamber where UV radiation will cure the clearances on the artwork.

The process engineer will set the time the panels are in the chamber and the intensity of the UV radiation. The controlled work instruction will contain all the

information necessary for the operators to perform their tasks. After print, the panels go through a develop process to get rid of the non-desired mask on the surfaces of the panel.

The developer is a machine that sprays caustic on the panels through nozzles. The caustic will remove the undeveloped mask. The panels then go through a couple of rinse processes for cleaning. The process engineer will determine the settings for the developer conveyer speed, caustic temperature, and amount of caustic sprayed. The controlled written procedure will include all of the parameters needed to operate the developer. The process engineer will document any changes of the developer parameters and the procedure will be updated accordingly. The members will bake the panels for a short period of time then will run them through the UV machine for a final cure.

The operation of the wet mask is similar to the legend application. The operators will use the certified artwork to shoot a screen made out of a mesh. The screen is then developed and the undesired emulsion will be removed by pressured water. The operator will align the mesh on to the panels and the mask is spread on top of the mesh. The operators will use a squeegee to spread the mask evenly on the mesh. The ink will go through the mesh on to the boards.

The operators must inspect the panels for any mask misregistration or mask on pads. The panels are then baked for a short period of time and the other side of the panels is screened the same way. The operators then move the panels for final bake.

The dry film mask operation is done by stretching the film on the panels, then heat-treated to conform it. The operators will use the certified artwork to print the image of

the circuits on the panels. This operation is performed by aligning the artwork on the panels then sliding the panels into a UV chamber. The UV is then activated and the artwork image is printed on the panels. The process engineer will determine the exposure time and the intensity of the UV. He/She will also document all the process parameters and tolerances in the controlled work instruction. The panels are then run through a developer to develop off the unwanted mask. Next they run through a thermal cycle and UV for final cure.

A special operation sometimes is performed in the mask department; this operation is called “Hole Fill” operation. The purpose of this operation is to make the top surface of a hole as if it is a pad. This would allow a surface mount component to be soldered on top of a hole per customer requirement. The operators will fill the holes either with a conductive material or non-conductive material. Then the panels will be dipped in the Dep tanks to have a layer of copper then the panels are to be copper and solder plated as normal.

The process engineer will document this special process and its settings in the controlled work instruction. The operators will sign, date, and the work order prior to moving the job to the next operation.

#### Solder Level

The solder level department function is to apply solder over the bare copper. Prior to solder leveling or hot oiling process, the panels must be baked in the oven for

some time to prevent thermal shock to the boards. The oven temperature and the time needed to bake the panels will be determined and documented by the process engineer.

For the solder level method, the panels are dipped into flux and then moved towards another machine that has molten solder. Once the solder is passed on the boards, hot air knives are used to blow away the excess solder from the pads and holes. The boards are then cleaned and the holes are pin gaged to determine if they meet the specification or not. If the holes are plugged or they are filled with solder, the hot air knives are to be adjusted to blow more hot air to clear the holes. The employees will log in a logbook the jobs moved into their area, sign, date, and stamp the work order prior to moving it to the next operation.

For the hot oil method, the panels have plated tin /lead. First, the panels are dipped in flux then they are dipped in a hot oil tank for a period of time set by the process engineer. The panels are then removed from the tank and cleaned. The job is then moved to the next operation. A generic flow chart for the solder level department is shown in Figure 5.3

#### Silver, Copper, Tin Coat

These are special operations done to protect the copper from oxidation and migration and they are not usually done on regular basis. These operations are usually done before the boards are shipped to the customer and after they passed final inspection.

The process of these operations is similar to solder copper plate, where the panels are coated with a thin layer of silver, copper, or tin coat per customer requirement. The

panels or boards are handled with gloves and they are to be bagged immediately in plastic bags. The process engineer will document the special processes and its settings in the controlled work instruction.

### Nickel Plate

The function of this operation is to electrolessly plate the PCB with nickel, the purpose of the nickel-plating is to achieve optimal gold adhesion to the pads or circuits per customer specifications. It also acts as a barrier between the gold and copper to prevent migration between the two metals.

The members of this operation must check the nickel requirement from the work order. A special written procedure by the process engineer will be constructed for any special operations for different types of materials of the PCB. The operators must also check the tanks for their required temperatures settings prior to use. The operators will solder strip the panels by dipping them in the required solder strip tank for a period of time set by the process engineer. The panels are dried then pumice scrubbed to roughen the copper surface and achieve good nickel adhesion. The panels are then dipped in the nickel bath for certain period of time. The dwell time is always dependent on the nickel requirement and the quantity of panels to be plated.

The members will inspect the panels for step plating, background plating, and nickel thickness and record the readings on a nickel-plating form as shown in Table 5.5.

The process engineer will determine the dwell time needed for nickel plating. The dwell time in the nickel tank can be calculated from the formula dwell time. The

controlled written procedure will include all the dwell times and tanks temperatures needed for the nickel operation.

The process engineer is responsible for updating or changing the tanks temperature or dwell time. Any changes must be controlled and documented in the work instruction. The members will sign, date, and stamp the work order after the completion of nickel-plating operation and move the job to the next operation.

Gold plate

The function of this operation is to plate the PCB with gold using immersion gold. This type of plating does not deposit enough gold on the board. The steps to perform the immersion gold are the same steps to perform the nickel plating except that the panels will be dipped in the HCL tank, then in the gold tank after nickel plating.

The reason for dipping the panels in HCL is to roughen the nickel surface to accept the gold deposits. The members will x ray the panels to measure the gold thickness and document the readings in a gold form as shown in Table 5.6

**Table 5.5:** Generic Nickel Reading Form

Tracking number: Part number: Customer name: Date: Operator name:	Nickel reading panel1 in micro inch: Nickel reading panel2 in micro inch: Nickel reading panel3 in micro inch: Average nickel reading in all panels.
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**Table 5.6: Generic Gold Reading Form**

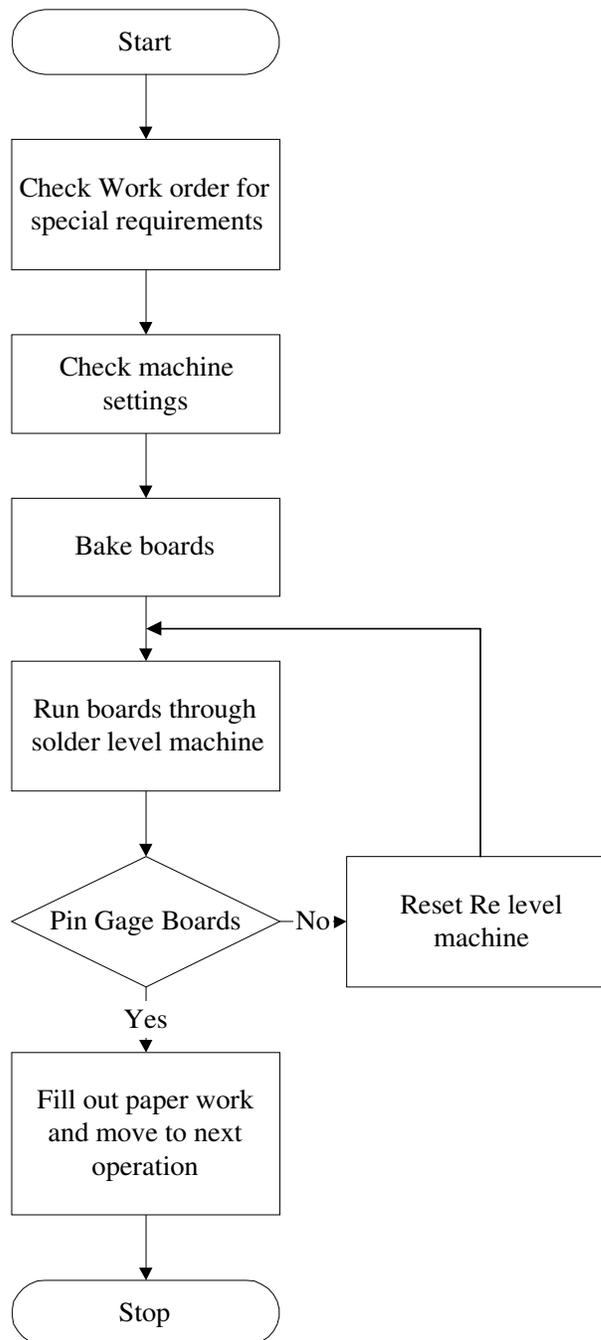
Tracking and lot number: Part number and revision: Date: Operator name:	Gold reading for panel 1: Gold reading for panel 2: Gold reading for panel 3: Average of the gold reading in all panels:
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The process engineer will document in the work instruction the settings for the gold tank temperature and dwell time. If more gold is needed to be plated on the boards a different method of gold deposits must be used. The other method is using electrolytic gold deposits. The main factors that influence the gold deposit in this operation are the time the panels are kept in the tank, the concentration of the gold tank, and the current passing through the panels. The process engineer will document in the detailed work instruction the required settings for this operation. The operators must adhere to these requirements in order to meet the specified gold deposits.

Finally the operator will verify the amount of gold deposited on the PWB using the X ray machine and document the readings in the gold form then move the job to the next operation.

#### Legend

The legend department function is to apply the legend to the boards per customer specifications. The members will review the work order to determine the type and color of ink needed to be applied to the PCB.



**Figure 5.3:** Generic Flow Chart for The Solder Level Department

The employee will apply the date code to the mesh, then shoot the artwork on a mesh screen and clean the undesired emulsion from the mesh with pressured water.

Prior to using the ink, the employees must check its expiration date. Any expired ink must be disposed of immediately. The process engineer will determine the mesh sizes needed for the type and color of the ink, he will also set the time needed to expose the mesh. The calibration department will calibrate this machine for the intensity of the light needed to cure the mesh.

The employees will then set up the screening equipment with the mesh on it. The ink is then applied to the mesh by using a squeegee where it will be pushed through the mesh on to the boards. One side at a time will be silk screened and put in the oven for curing. When the second side is silk-screened both sides will be fully cured. The employees will log in a logbook the time the boards were put in and the time they were removed from the oven.

The process engineer will set the oven temperature and document the legend processes in the work instruction. After the boards were pulled out of the oven the members will then sign, date, and stamp the work order and move the job to the serialization department

### Serialization

The serialization department function is to ensure that all boards and coupons are serialized for traceability purposes. The serialization department employees will check the work order for any special customer requirements regarding serialization. The

members will also cut microsection from the serialized coupons and hand them over to the microsection department.

Depending on the customer requirements the members will choose the correct type and color of the ink and the size of the characters. If the ink needs to be mixed, the members will follow their work instructions for the correct mixture. There are two types of inks, one is cured through the UV process and the other is cured by thermal process.

The UV machine is calibrated by the calibration department for the amount of intensity the bulbs will emit to cure the ink. The thermal ink will be baked in an oven with a temperature and time pre determined by the process engineer. The members will complete the serialization form after serializing the boards. The form will contain the beginning and end of the serialized boards plus the part number and revision. An example of such a form is shown in Table 5.7. After the members fill out the serialization form they would sign, date, and stamp the work order then move the boards to the rout department. A generic flow diagram for the serialization department is shown in Figure 5.4

**Table 5.7:** Generic Serialization Form

Customer name: Part number and revision: Date code: Serial number starts from:	Serial number ends at: Operator name: Tracking and lot number:
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### Microsection

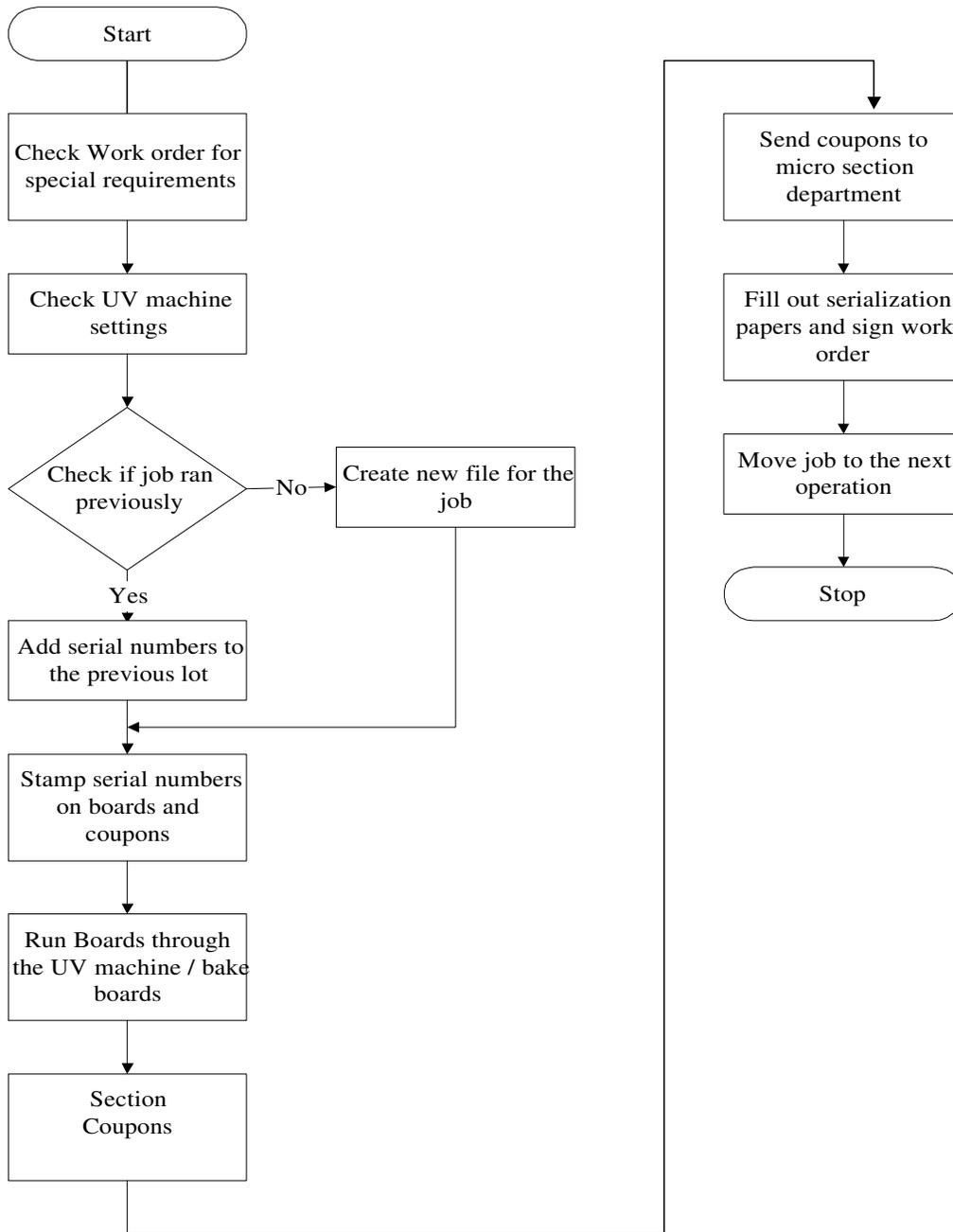
This operation is dedicated to reading all the microsection of the PCB's. The members will prepare the sections given to them by the serialization department. The preparation of the sections is done by setting, grinding, polishing, etching, and baking the microsection. The members will read the microsections per the work order requirements and customer specifications.

They will also complete a microsection report that includes all their readings. Such a form is shown in Table 5.8

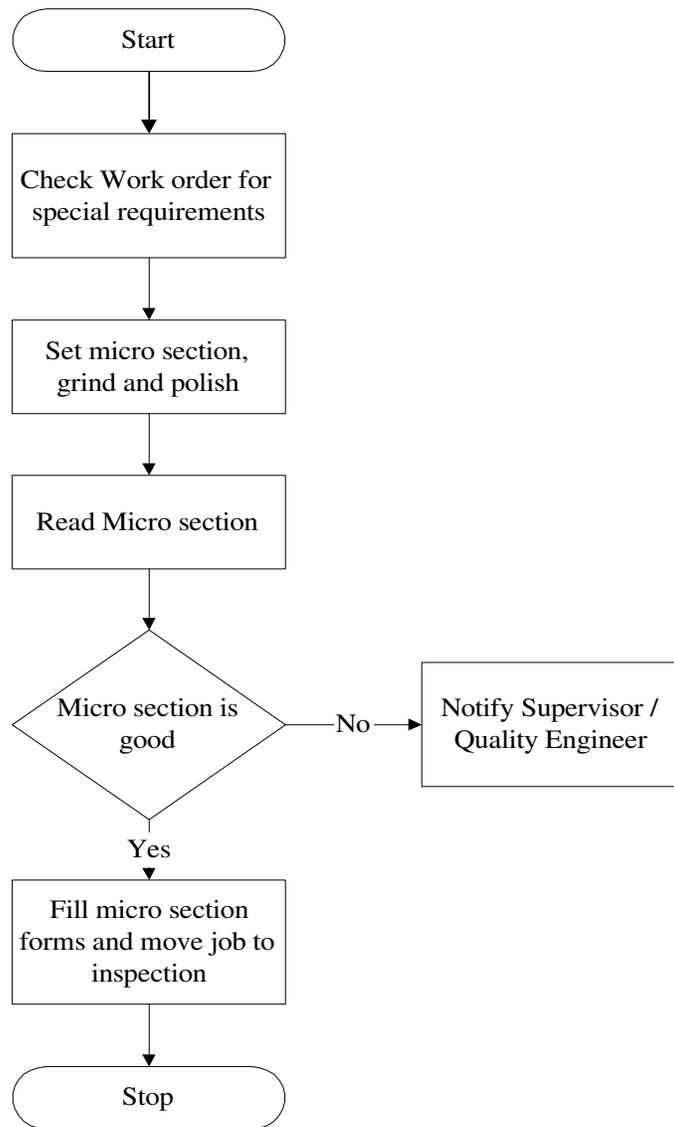
If the inspectors find any rejects in the microsections the whole panel is rejected and scrapped. The inspectors will hand the reports the final inspection to remove the scrapped panels from the lots and label them as non-conforming material. The microsection work instructions will be maintained and updated by the quality department manager. A generic flow diagram for the microsection department is shown in Figure 5.5

### Rout:

The rout department is responsible for routing the boards off the panels. The employees must measure a first piece for all customer requirements of the boards dimension prior to routing the entire lot. The quality department will certify the first piece. The rout employees must constantly monitor the routing of their panels incase of a machine error.



**Figure 5.4:** Generic Serialization Department Flow chart



**Figure 5.5:** Generic Microsection Department Flow Diagram

The tooling department will program the machine so that the rout department employees are only to run the disk supplied to them with the print and specification package.

The job is then moved to the board wash for cleaning. The members will also verify the work order for customer special requirements and if the job needs special machining they are to sign, stamp, and date the work order and move the job to the special machining operation. Other wise the job is to be moved to the test department.

The rout department work instruction will be documented and maintained by the rout department manager. Any updates to the work instruction must be done through the quality department.

### Special Machining

The special machining department will perform the complicated operations that are required by the customer. Some of the special operations are scoring, beveling, milling, and boring. A qualified machinist will perform these operations. All special machining jobs will be certified for a first piece by the quality department. The special machining work instruction will describe in details how to perform these activities. The rout department manager will maintain and document the department work instructions.

The boards will then be moved to the test department after signing, dating, and stamping the work order.

### Electrical Test

The electrical test department function is to test the PCB for any shorts or opens in their circuitry. The gerber data is downloaded to the test-engineering department from the cam department. The test engineers will program the test machines to test the PCB.

There are several types of tests to be performed on the boards, net test, comparison test, golden board, and flying probe test. The comparison test is done by comparing all the boards to each other. The disadvantage of this kind of test is that if all boards have the same defect the boards will still pass test

A golden board test is when the customer supplies a board that has already had been checked for opens and shorts and the entire lot is compared to that single golden board.

A net test is a test where the location and connection of all the circuitry is downloaded from the original customer design to the test machine. The test machine will compare every board tested to the customer net circuitry supplied from the gerber data.

**Table 5.8:** Generic Microsection report Form

Customer name: Part number and revision: Date code: Date: Customer specification: IPC or military Serial numbers of panels: Copper thickness: Circuit width: Annular ring: Innerlayer misregistration:	Dielectric thickness: Post separation: Voids: Etch back: Laminate voids: Invar separation: Lay up: Copper weight: Operator signature:
---	---

A flying probe test is a test where every single pad or hole is tested by comparing its connections to another pad or hole to the customer supplied gerber data. This kind of test is very tedious and takes a lot of time but it is very advantages to other kind of tests since every board circuitry connection is compared to the customer circuitry connections.

The test programming is done by verifying all the circuit connections of the layers. And then creating compatible software to be used on the test machines. The operators will test the PCB and if any rejection is found either it is reworked or scrapped. They will also inspect the boards for any test pin damage. If any pin damage is found they are to adjust the amount of pressure of the clamps on the boards.

Any reworked PCB will be retested to verify that the rework was done successfully. Any scrap PCB will be labeled with the reason of scrap or test failure, PCB part number, customer name, and quantity of scrapped PCB. The operators will fill out a test report as shown in Table 5.9; this report will be evidence of the test performed, they will also document the reasons the boards failed in the yield sheet.

**Table 5.9:** Generic Electrical Test report Form

Customer name: Customer part number and revision: Quantity tested: Type of test performed:	Quantity passed: Quantity failed: Quantity reworked: Operator name and signature:
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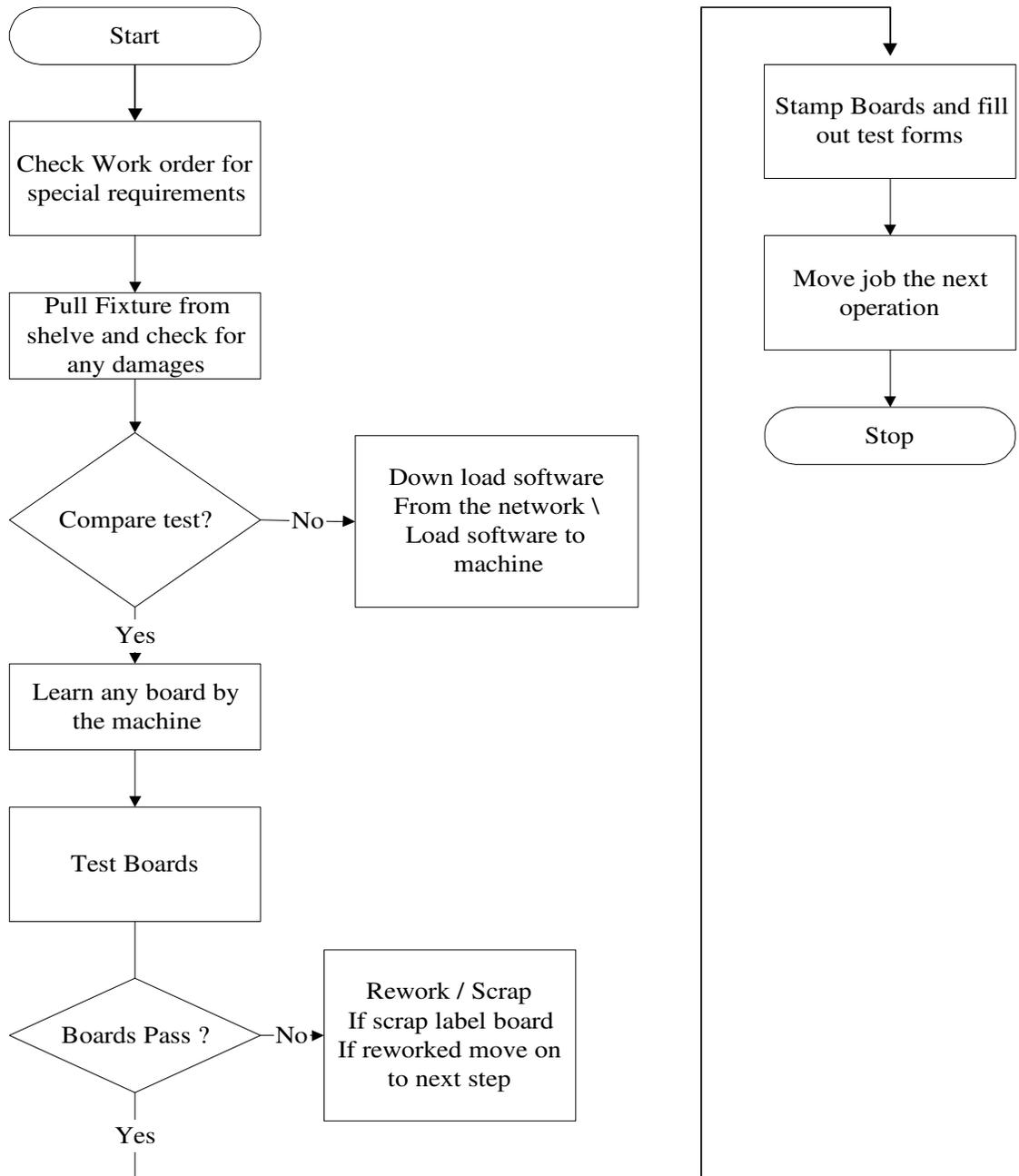
The test department will also test the dielectric impedance of the boards by testing the coupons that belong to the panels from where the boards were routed. The operators will sign, date, and stamp the work order and move the job to final inspection. A generic electrical test flow diagram is as shown in Figure 5.6.

### 5.3 Sales and Order Entry

The sales department in any company is the first contact with the customer. The customers' first impression of this department will influence the level of customer satisfaction. The sales department employee's role is a very important role in taking customer orders and quotes.

A generic quality manual for the sales department and contract review will be introduced in this chapter. Also some of the quality tools to improve and assist the sales department to achieve total customer satisfaction will be introduced.

The generic quality manual will describe how sales employees in any PCB company can conduct their jobs and how to document their activities. It will also show how to document purchase orders and customer requirements. Some generic checklists will be introduced to assist the employees in their quote process. A unique number with the issuer signature and management approval should uniquely identify this generic manual. All the pages in the manual will be sequentially numbered and controlled by the quality manager assignee. It will also be signed, read, and understood by all the employees in the sales department.



**Figure 5.6:** Generic Electrical Test Flow Chart

This quality system manual will describe the steps necessary to perform sales activities and order entry and is evidence that this system complies to Section 7.0 Quality system requirement paragraph 7.2-Customer related Processes ISO 9000:2000.

#### 5.3.1 Responsibility and authority

Assigned employees are responsible for adhering to the requirement of this procedure. The sales manager will maintain and oversee this procedure to ensure the assigned sales employees are implementing it.

#### 5.3.2 Implementation

- a) Initial Review, when sales personnel receives a request from the customer for an initial quote on a PCB, the information, drawings, quality clauses, artwork, and a draft purchase order are send from the customer to the sales representative for reviewing and quoting. If additional drawings are required to complete the quotation, a request will be made to the customer at this time.
- b) Electronic data such as gerber files and net lists will be forwarded to the CAM department for their review and assistants in the quoting stage if required. Again this is done because the sales representatives may not know how much information is needed to build the PCB.

- c) The sales coordinator will review the customer request to verify that all the customer requirements are clearly identified and the company has the capabilities to meet the identified requirements. The coordinator will fill out a quotation request.
- d) Electronic data such as gerber files and net lists will be forwarded to the CAM department for their review and assistants in the quoting stage if required. This is done because the sales representatives may not know the how much information needed to build the PCB.
- e) A generic form for the quotation is shown in Table 5.10.
- f) Orders must be classified in which specifications the customer would like to have his PCB built. The well-known specifications are IPC-6012 class 1,2,3. MIL – STD –55110, RB-276 and DOD 2002. When a customer waives any provisions in any of the specifications, a written authorization is obtained prior to manufacturing the PCB and a copy is forwarded to the document control and retention department.
- g) The sales representative will forward the quotation to the customer after the initial review. Each quotation is kept on file for a period of time, which is the same period for the validation of the quote.
- h) In case the quote is rejected, all the electronic media, data, drawings, and specifications that belong to the customer will be returned.

- i) Once an agreement is made on the quote, the customer will be asked to supply credit references to confirm the customer identity and ability to pay for the product built. Each new customer is assigned a unique number that will be referenced to it for any further communication for reorder and traceability purposes.

**Table 5.10: Generic Quotation Form**

Company name:
Date:
Quote number:
Customer name:
Part number:
Description of part ordered:
Number of layers:
Type of material: (FR4, kevlar, polyamide)
Type of test performed :(single side, double side, gerber net test, golden board test, customer supplied net list test)
Board type: (single sided, double sided, multilayer with or without blind and or buried vias)
Type of solder mask: (LPI, dry film, wet mask)
Type and color of legend
Board size:
Type of assembly: (heat sink, pins, clips)
Gold and nickel:
Insulators:
Line width:
Specs: (Mil-p-55110, IPC-6012)
Type of solder: (solder coat, reflow solder)

- j) Once the order is confirmed, the sales representative will issue an order entry form and will complete all the information necessary and forward it to the order entry department along with all the materials used for the initial quotation. Copies of the order form will be distributed to production control and order entry. Order entry personnel will verify that all the information on the order form is correctly entered in the computer.
- k) Once the purchase order is received, the sales representative will review it. If any discrepancies are found the customer and the engineering department must be notified immediately.
- l) When rerun orders are called in by a customer, the sales representative will review the initial purchase order for any changes from the prior purchase order and a rerun order form is completed and forwarded to the order entry department.
- m) Retention of all sales orders paper work and documents shall be retained for a period of time determined by the department manager.

The step described above complies with Quality Management System Section 7.2 requirement paragraph 7.2.1 Determination of requirements related to the product, 7.2.2 Review of Requirement related to the products, 7.2.3 Customer Communication for Customer related Processes ISO 9000:2000.

### 5.3.3 Order Entry and its activities

Order entry representative will be assigned to enter the information from the order form into the computer. The representative will be responsible for assigning the unique numbers to the customer and log the number assigned in a customer number logbook. This logbook must be controlled under the document control umbrella. This operating procedure describes the steps necessary to perform order entry.

### 5.3.4 Responsibility and Authority

The assigned employee is responsible for adhering to the requirements of this operating procedure.

### 5.3.5 Implementation

- a) Order entry employee will review the order entry form and check that all the requirements are met.
- b) They will assign a new sales order number to every new order and enter this number in the computer system. They will also enter all the information from the order form into the computer system.
- c) Distribute copies of the order entry to production control and sales department; all the customer-supplied data will be forwarded to the tooling department.
- d) The order entry employee will log in a logbook the order number it was taken.

e) When a customer requests an engineering change, the sales representative will complete a change order form and forward a copy to the order entry, production control and tooling department. In case the tooling department verify that the change may effect the product running in production, the production control employees will be responsible for purging the PCB or put the production on hold until the changes are put into effect.

Customer satisfaction in this process is of a great importance. Time, accuracy, and competitive pricing are the leading factors for customer approvals on quotes. In order to speed the response time, the sales representative should collect and get all the information needed for its quoting from the first contact. No time will be wasted and multiple calls sometimes annoy the customers.

A check sheet for every sales representative is a plus. This check sheet should contain the most important information needed to give an accurate and speedy quote. A pareto chart can be established to determine how many calls are needed to complete a quote. Another Pareto chart can be implemented to find out the sales representative who has the most successful quotes that end up with an order. This would cause a constructive competitiveness among the sales department employees.

Response time to the customer can be monitored by sending periodic surveys that collects customer input on the efficiency, accuracy, and response time from the sales representative. Training sessions can be erected for that sales member that needs it.

As for pricing competitiveness, the sales manager can implement benchmarking techniques.

Benchmarking is defined as the continuous process of measuring products, services, and practices against the toughest competitors or those companies recognized as industry leaders. It is the search for industry best practices that leads to superior performance. A generic bench marking process is as follows:

- a) Planning: identify the process being bench marked and in our case will be the sales department. Identify the comparative organizations. Also identify the data needs.
- b) Analyze: collect data and calculate the price gap. Project the future performance on how to reduce prices.
- c) Integration: communicate findings with other department managers and ask their assistances. Establish functional goals and develop action plans.
- d) Action: implement the action plans and monitor the progress, recalibrate the benchmarking if necessary and attain leadership position.
- e) Maturity: integrate benchmarking with all the department managers, (Kolarik William, Creating Quality, 1988).

This was a generic benchmarking process, some of the data sources that will assist in the benchmarking are found in literature and research publications, conferences presentation and interchanges. It also can be found in product literature, trade association publications, surveys, interviews, and facility tours. Benchmarking encourages

emulation of successful practices and abandonment of unsuccessful practices across board areas of operations as excessive pricing. These were the most common quality tools that can be implemented to improve the sales department and to achieve total customer satisfaction.

## CHAPTER 6: PURCHASING AND IDENTIFICATION OF PRODUCTS

### 6.1 Introduction

This chapter describes how to develop a quality system procedure for both the purchasing and receiving departments of any printed wiring board manufacturer. Quality improvement tools are introduced to aid the selection of suppliers that provide quality products. Suppliers must submit evidence that the supplied products meet the purchase order requirements. Records of the evaluations of those suppliers will be kept and maintained according to the document and control procedures. This chapter includes the methods of traceability of customer-supplied products and documents and their existence in a quality system environment.

### 6.2 Purchasing Operating Procedure

The purchasing department procedure described in this section complies with ISO 9000:2000 Quality Management System, Section 7, Paragraph 7.4 Purchasing.

#### 6.2.1 Responsibility and Authority

The purchasing manager will be responsible for all related documents regarding

this procedure. The process engineers and department managers will be responsible for selecting the suppliers from which the materials and equipment will be used to manufacture the printed wiring boards.

Purchasing manager or his assignee must approve all purchasing requisition in order to control the process of purchasing materials and equipment.

The quality manager or his assignee is responsible for maintaining and updating the suppliers' performance report.

### 6.2.2 Implementation

When the process engineers and department managers submit purchase order requisites to the purchasing manager, they must submit an inquiry form about the supplier performance prior to purchasing any material. This inquiry form is a tool to measure the performance of the suppliers. An example of a generic inquiry form is shown in Table 6.1. This inquiry form can be used as a performance measurement tool on any supplier. Continuous monitoring of the supplier performance will be assessed from the delivered items. A chart for each supplier can be drawn and updated by a computer every time a product is received. Time and date of the delivery can be entered in the chart.

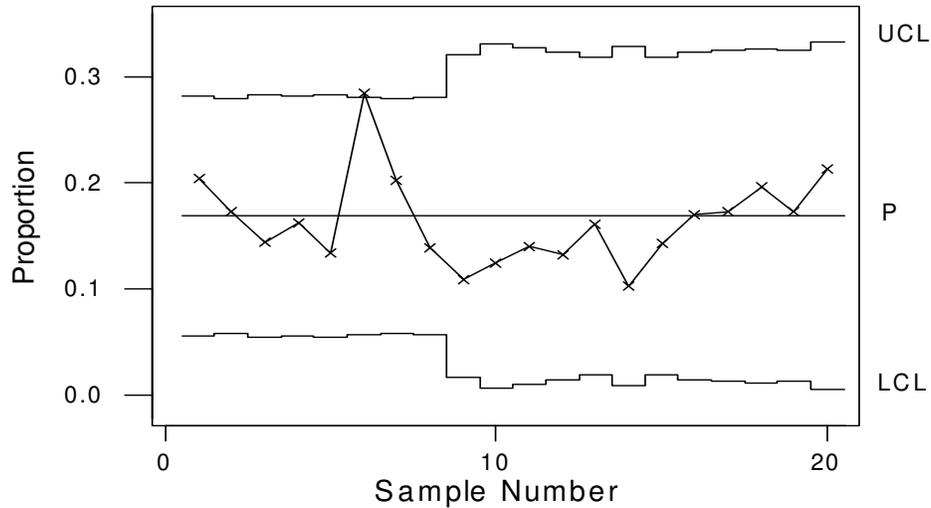
Another way of monitoring the suppliers performance is by means of control charts. Since the amounts of defectives are attributes a P charts can be constructed for the proportion of defectives of incoming materials - the number of defectives divided by the subgroup size.

**Table 6.1: Generic Supplier Inquiry Form**

Company name: Address: Phone and fax numbers:
Supplier name: Address: Phone and fax numbers:
<b>General Information</b>
How many employees in the organization? What is the type of products the company manufactures? Is the company certified to ISO 9000:2000? Did the company win any quality awards as Deming's prize? Can the company supply some of their customers for references? Does the company have a calibration system implemented? How long has the company in business? Can the company provide with calibration documents? Has the quality system been approved to any of the well-known standards? Does the company have a written quality system procedure? Does the company have a manufacturing procedures? What is the delivery time performance from the time the order placed until it is shipped? How is the incoming supplies is being monitored? How do the company trace the products manufactured? Is there any SPC tools being implemented?

P-charts track the proportion defective and detect the presence of special causes. Each entry in the worksheet column is the number of defectives for one subgroup, assumed to have come from a binomial distribution with parameters  $n$  and  $p$ . By default, the process proportion defective,  $p$ , is estimated by the overall sample proportion. This is the value of the centerline on the chart. The control limits are also calculated using this

value. Thus the supplier is always monitored through his delivery time and rejected materials. An example of such a control chart is shown in Figure 6.1



**Figure 6.1:** p Chart for Proportion of Nonconforming PCB's.

The supplier must meet the standard industry specifications and must show evidence of control on his processes. Once a point is out of control, a formal corrective action will be required from the supplier. If the supplier fails to institute a corrective and preventive action, he/she will be removed from the approved supplier list and an alternative supplier will be considered. The supplier must also have his/her quality system available for audit.

The following formulas are used to construct the control limits and it will be explained in detail in chapter 8.

p Control Chart (fraction of nonconforming)

$$\begin{aligned}UCL &= \bar{p} + 3\sqrt{\frac{\bar{p}(1-\bar{p})}{n}} \\LCL &= \bar{p} - 3\sqrt{\frac{\bar{p}(1-\bar{p})}{n}} \\CL &= \bar{p}\end{aligned}\tag{6.1}$$

On site surveys will be set to facilitate the supplier acceptance on the approved supplier list. The evaluation of suppliers is detailed according to ISO 9000:2000 Quality Management System manual, Section 7, Paragraph 7.4.1 Purchasing Processes.

### 6.2.3. Purchase Order Requisition for Product and Related Materials

All supplies must be purchased from the approved supplier list. Process engineers or department managers can request to purchase products and materials from the approved supplier list using a generic requisite form as shown in Table 6.2

The purchasing information must include as a minimum the purchase order, the name and address of the supplier, date of the order, method of shipment, requirements of approval of product, procedure, and equipment.

**Table 6.2: Generic Purchase Order Requisition Form**

Company name: Address: Phone and fax number:				
Suppliers' name:				
Purchase order number: Requested by: Date requested:				
Item	Description	Quantity	Dock Date	Price per unit

These requirements Comply with ISO 9000:2000 Quality Management System, Section 7.4.2 Purchasing Information.

#### 6.2.4 Receiving Department Operating Procedure

Once the manufacturing plant receives the product, the receiving member will acknowledge that the product has been received by logging in each product or material received in the computer on a spreadsheet or in a logbook to confirm the delivery. The receiving department will ensure that the material supplied is typical to specification.

##### 6.2.4.1 Responsibility and Authority

The department manager will ensure that this procedure is implemented and understood by all the employees in the receiving department.

#### 6.2.4.2 Implementation

Once the product is received, the assigned member will log the product received and the date it was received by. He/She will also inform the inspection department of the type of product received in case it needs inspection. All materials that are purchased and will be used in the manufacturing purposes must be inspected to determine its adherence to the specification in which it was ordered.

The receiving employee will be trained by the quality department to inspect the incoming materials. All foil and laminate materials will be inspected 100% for thickness requirement, cracks and scratches. The members will also have to update the supplier-rating chart via the computer by entering the number of defects found in each lot received. They will also track the time the product was delivered and the time when the materials were ordered via the computer. The receiving employee will forward a copy of the invoice to the purchasing department for payments and will retain the original for a period of one year. This Procedure will comply with ISO 9000:2000 Quality Management system section 7.0 paragraph 7.4.3 for Verification of purchased Products.

### 6.3 Optimizing the Purchasing and Receiving Processes

In order to make the purchasing department more efficient some quality tools must be applied. The equipment and materials purchased should not be based solely on the cost. Deming had already expressed his notions when he said in his 4<sup>th</sup> point to management to end awarding business based on price. This is a very important point

because if the process engineer or the department manager chooses to pick the least expensive product rather than the one with best quality they will end up with a finished product that may not meet the specifications. They will also risk reduction in productivity by spending time to rework the product if not scrapping it.

To select the best supplier some bench marking technique can be applied. Bench marking is defined as the continuous process of measuring products, services, and practices against the toughest competitors or those companies recognized as industry leaders. Hence benchmarking concentrates on both best performance and measurement. In this case benchmarking can be used to select the best supplier among all suppliers that would compete fairly to win the company's contract. By contacting the references that the supplier had submitted and by measuring their performances, the supplier's efficiency and quality rating can be predicted and measured.

The receiving department can be made more efficient by implementing a good training program to help the employees in identifying the flaws and rejects in the incoming materials. The training records will be kept and retained by the human resources department.

#### 6.4 Product identification and Traceability

Product identification must be valid for all products manufactured in any manufacturing plant. The method of identification is up to the user of this generic ISO standard. This operating procedure will describe how manufactured product is identified

and traced throughout the system as it complies with ISO 9000:2000 section 7.0 paragraph 7.5.3.

#### 6.4.1 Responsibility and Authority

The sales manager is responsible for assigning all new part numbers a new tracking number. This tracking number will be the means of identifying and tracing the new part number being manufactured throughout the processes. All employees will be responsible that this identification is not manipulated for any reason.

#### 6.4.2 Implementation

Each new part number is assigned a new tracking number by the order entry employee. This same tracking number will be stamped on all relating documents to this part number. A work order with this tracking number will be generated and will accompany the product from its inception until it is shipped out of the plant. The work order will then be retained for a minimum of 5 years in the quality department. If there is a reorder from the customer for the same part number, a continuing lot number is issued.

The receiving department employee will mark every inner layer with the tracking number, copper weight, and thickness. During the manufacturing of the printed wiring boards, the identification, inspection, and test will be maintained by means of authorized stamping, labeling, and marking. Authorized stamps will be issued and controlled by the assigned quality department employee.

### 6.4.3 Traceability

The receiving department employee will record on the work order the core thickness and copper weight. As for the finished printed wiring board, identification will be by the date code, serial number, company logo, and cage code. The identifications will be applied either by etching or silkscreen unless the customer specify otherwise as in some of the military hardware. When the PCB is required to be serialized, the serialization department will do this before the boards are routed and separated from the panels. Each board will be uniquely serialized and identified. A logbook will contain all the serialized work orders for future references. The logbook will be retained for a minimum of 5 years.

## CHAPTER 7: PRODUCTION AND SERVICE PROVISION

### 7.1 Introduction

All customer-supplied products must be controlled and identified. This operating procedure will ensure that ISO 9000:2000 is being implemented and that the customer-supplied property is controlled, identified, and protected. If any of the customer property had been damaged or is unsuitable, this will be recorded and the customer will be notified immediately. This operating procedure complies with ISO 9000:2000 Quality Management System, section 7.0 paragraph 7.5.4.

### 7.2 Customer Properties

Sales manager will be responsible for all blue prints and gerber data disks sent by the customer to help in the quotation phase. Tooling department manager will be responsible for all the materials that are being supplied by the customer to assist in the building of the PCB. The quality department manager will be responsible for all the equipment being supplied by the customer to help in the inspection phase. He/She is also responsible for maintaining the calibration, storage, and inspection system of all the equipment being supplied by the customer.

The quality manager will notify the customer if any of the equipment is lost, damaged or unsuitable for use.

### 7.2.2 Implementation

Customer supplied artwork, gerber data, quality clauses, and the departments that have the possession of such materials will control the equipment. Any surplus of the customer supplied material or scrap will be sent back to the customer as stated in the purchase order. All the data and materials being sent by the customer during the quotation phase will be returned immediately after either the completion of the order or after the quotation is declined.

The receiving department employees will assign a tracking number to all the materials and equipment received from the customer for traceability purposes. The location and the tracking number will be entered in the computer for an immediate identification of the whereabouts of the equipment or materials.

The receiving department employees would deliver the customer property to the quality department incoming inspection. Incoming inspection will inspect all incoming prepreg, copper foil, and mass laminates according to their work instruction. Once incoming inspecting is done, all the inspected property will be recorded again in an inspection logbook. All incoming heat sinks will be inspected by the same manner. After completion of the order any extra heat sinks will be returned to the customer.

The quality department will maintain a log of all customer-supplied equipment to ensure traceability. An example of such a log is shown in Table 7.1. If the incoming inspection employee finds any damage or defects in the customer products or equipment, he/she will fill out a form identifying what defects were found and a copy would be faxed to sales department for customer notification.

A sample form identifying the problems of any customer product or equipment is shown in Table 7.2. Once the equipment is found defective the inspector will fill out a label and mark the equipment as unsuitable for use. If the equipment were suitable for use, the inspector would record the incoming equipment in the customer property log and send a copy to the quality manager assignee for the control of the document.

**Table 7.1: Generic Customer Property Log**

Customer name: Date the equipment received: Description of the equipment received Part number of the equipment received: Inspector name: Is calibration required: Serial number: Date checked out	Name of person checking out: Date the equipment is due back to the owner: Method of shipment: Insured by: Name of sender: Date of sending the equipment back to the customer Inventory Date: Date checked in
--	---

**Table 7.2:** Customer Notification form for Defects in the products or Equipment

Company name: Address: Phone number Fax number				
Customer name: Address: Phone# Fax#				
Item name:	Item description:	Item Part number	Quantity	Type of defect

### 7.3 Inventories and Storage “ Preservation”

This procedure complies with ISO 9000:2000 Quality Management System section 7.5 paragraph 7.5.5.

#### 7.3.1 Responsibility and Authority

The receiving department manager will adhere to all the requirements of this procedure and is responsible for all equipment and material received from the customers. They will also be accountable for stocking customer properties. The quality manager and his assignee are responsible for checking the inventory and accountability for all customer properties.

### 7.3.2 Implementation

An inventory check for all customer properties will be done twice a year by the quality manager assignee for the controlled documents and procedures. The assignee will date the customer property log for every inventory check and sign in his name as the checker. Storage of all customer products will be in the storage area. All equipment will be assigned a number on the shelf for quick identification of the location of the customer property in the stock room. The stock room employee will complete a logbook with all stock. An example of such a logbook is shown in Table 7.3.

**Table 7.3:** Stock Room Log

Type of Stock	Date in	Date out	Signature	Stock number	Shelf number	Customer name

### 7.4 Control of Monitoring and Measuring Equipment

This section will introduce ways of controlling the inspection, monitoring and test equipment. The following operating procedure will describe in detail the methods used to control the equipment used in production whether it is used for test or in regular production. This procedure will be evidence that the quality system is complying with ISO 9000:2000 Quality Management System section 7 paragraphs 7.6.

#### 7.4.1 Responsibility and Authority

The quality manager is responsible for maintaining this procedure and he/she will assign a member of the organization to control the inspection, measuring and test equipment. The member responsibility will include measuring the accuracy of the equipment owned by the company or the customers according to standardized standards. The member will also keep up to date records on the accuracy and calibration of the equipment.

#### 7.4.2 Implementation

The quality department and the assignee member will adhere to this procedure in order to control the accuracy of all the devices and tools either in the inspection or in the manufacturing department. The calibration system of the company will have to adhere to some standards. The company has to specify what standards it is following. Before any changes in applying the standards, the customer and the government representatives have to be notified. To insure that the quality department is enforcing this procedure, semiannually audits will be carried out.

All the tools that are being used in determining the accuracy of the equipment will be maintained in an environmentally controlled room. This is to ensure that the tools are not subjected to any environmental factors such as humidity or temperature. The conditions and control of the rooms will be up to the quality manager and the assignee. The room temperature and humidity must be constant at all time. A tool list must be

made of all equipment and measuring tools to determine the location and the user.

Example of such a list is shown in Table 7.4. The member assigned must ensure that all labels and markings are distinct and clear on the tools assigned to the employees.

**Table 7.4:** Generic Company Tool List

Tool assigned to	Name of tool	Tool serial #	Date assigned	Calibration date	Calibration due On
Scot	Beta scope	001	5/2/2001	4/2/2001	10/2/2001
Mat	Caliper	002	5/2/2001	5/2/2001	11/2/2001

Once the calibration is done, a new label will be attached to the tool or equipment to identify the calibration date, serial number, and the due date for recalibration.

Some of the tools that are used in the measurement in any of the PCB manufacturer are listed as follows:

Micrometers are used to measure thickness.

Beta scopes are used to measure circuit line width in micro inch or to measure pads width and length.

Calipers are used to measure length, width, depth, thickness.

Beam balances are used to measure warp and twist.

Height gages are used to measure thickness, warp, and twist.

Force and tensile gages are used to measure the tensile strength of the copper foil.

CMM (coordinated measuring machines) are used to measure the hole-to-hole and boards dimensions.

Surface plates are used to measure flatness.

Vacuum gages are used to measure the amount of vacuum in any enclosed area.

Clock timers are mostly used to measure time increments.

Temperatures and humidigraphs are used to measure and monitor the temperature and humidity in ovens and rooms.

Amp and voltmeters are used to measure the amount of amps or volts measured.

Pressure gages are used to measure pressure.

Microscopes are used to measure microsections.

PH meters are used to measure the PH balance in any fluid.

Infrared temperature meters are used to measure the amount of infrared temperature that is subjected to the PCB to cure the solder mask and resist.

Refractometers are used to measure the amount of light refracted on a prism.

Score depth meters are used to measure the depth made by the scoring machines.

COMM (computerized optical measuring machines) are used to measure the boards dimensions and hole to hole locations.

Eye loops are used in measuring the PCB in mil inches and angles.

The assigned quality member or an outside calibration company will calibrate all of these tools. The assigned member will also send out a calibration due notice when the calibration of equipment or a tool is due. An example of such a form is shown in Table 7.5.

**Table 7.5: Generic Calibration Due Form**

Date:	Serial number of tool or equipment:
Tool or equipment:	Due date:

The department managers will notify the assigned quality member with which tools and equipment must be controlled. Lost and found tools will be recalibrated and returned to service.

## CHAPTER 8: MEASUREMENT, ANALYSIS AND IMPROVEMENT

### 8.1 Introduction

This chapter discusses different methods of measuring, analyzing, and improving the PCB and its processes. Quality tools that measure process performance and PCB capability will be introduced. Also, design of experiments, as an analyzing tool for the effects of different variables on processes will be introduced. Statistics and probability will be used to forecast processes and PCB performance. Control charts and improvement strategies are also going to be interjected in this chapter. Finally, a method for measuring customer satisfaction is going to be explained.

### 8.2 Monitoring, Measurement, and Internal Audits

This part of the operating procedure will describe how to document the methods of monitoring and measuring process performance per ISO 9000:2000 Quality Management System section 8 paragraph 8.2.

#### 8.2.1 Implementation

The quality department manager will be responsible for monitoring, measuring, and improving process performance throughout the organization. The quality manager

will set up an inspection department that will inspect the PCBs and will train the inspection department employees on how to inspect and identify defects of the PCBs.

The purpose of the inspection department is to collect valuable information on how the processes are being performed. The quality manager will assign a statistical application engineer to utilize the data collected from the yield sheets to monitor the processes performance. Prior to inspecting the PCBs the inspectors will always look up the customer's requirements from the work order. The most common defects in any PCB are shown in Table 8.1. The inspector will identify the rejects and inspect the PCB 100 percent. The inspector will record the finding in a yield sheet as shown in Table 8.2

Inspectors will label all scrap boards with part number, tracking, and lot number, quantity, and reason for scrap. This is done for traceability of the non-conforming material. Any PCB that requires rework will be sent to the rework department for reworking. The reworked PCB will be inspected again prior to shipping. The inspectors will sign and date the work order and move the job to the mechanical audit department and submit the yield sheet report to the auditors.

The mechanical audit department will verify the purchase order requirements; blue print instructions and specifications of PCBs. The mechanical audit is usually done on a sample from the lot inspected. The sample size is determined from the specifications or the customer requirements. Hole sizes and board dimensions will also be verified to the print. If the auditors find any discrepancy, they will notify the quality

engineer for resolution. They will also fill out an audit sheet of their verification of the print requirements. An example of this audit sheet is shown in Table 8.3

**Table 8.1: Most Common Defect in PCB**

Hole defects	Mask misregistration
Plating in non plated thru holes	Legend on pads
Voids “ No voids in military products”	Legend smear
Nodules	Expose trace
Undrilled holes	Solder level defects
Broken drill	Solder too thick
Over platted copper	Undersized holes
Drill misregistration	Solder too thin
Circuit defects	Solder out gassing
Nicks	Solder balls
Cuts	Failed solder ability
Annular ring	Exposed copper
Copper spray	Reflow dark holes
Burnt copper	Gold and nickel defects
Pitted circuits	Pitted gold
Copper fines	Low gold
Copper shorts	Low nickel
Handling damage	Gold too thick
Broken web	Nickel too thick
Damaged corner	Laminate defects
Test pin damage	Warp and twist
Damaged holes	Innerlayer misregistration
Damaged pads	Wrong material
Scratched solder mask	Brown oxide scratches
Damaged circuits	Test defects:
Solder mask rejects	Innerlayer shorts
Mask in plated through holes	Innerlayer opens
Mask on pads	Solder shorts

**Table 8.2: Generic Yield Sheet**

Customer name: Part number: Lot number: Tracking number: Quantity scrapped: Inspection date:	Quantity sent to rework: Reason for rework: Reason for scrap: Department responsible for the defects: Inspector name: Quantities of good boards:
---	---

For all military PCBs, mechanical auditors will complete a group A test report and attach it to the audit sheet. If any defects are found, the mechanical auditors will complete the yield sheet and submit it to the assigned quality engineer.

**Table 8.3: Generic Audit sheet**

Customer name: Part number and revision: PCB specification: Date audit is done: Auditor name and stamp: Date code of PCB: Serial number if applicable: Hole sizes: Slots dimensions: Bevel dimensions: Type of legend and adhesion:	Board thickness: Boards dimension: Gold thickness: Nickel thickness: Copper thickness: Warp and twist: Unsupported holes Annular ring: Solder mask type and color: Solder mask adhesion: Score dimension:
---	---

The auditor will then sign, date, and stamp the work order and move the job audit package. This section complies with ISO 9000:2000 Quality Management System, section 8 paragraph 8.2.4 Monitoring and measurement of Product.

#### Audit Package

The audit package department will put together the quality package per the customer requirement; it will include as a minimum a certification of conformance, test documents, audit sheets, and material certificate of conformance. The member will ship the microsections, microsection report, TDR coupons, TDR report, solder sample, and coupons if required.

Prior to moving the job to shipping the member will forward the yield sheet to the statistical application engineer. The member will then sign, date, and stamp the work order and move the job to the shipping department or to source inspection if required.

#### Source Inspection

If the purchase order requires the PCB to be sourced by the customer, the assigned member will contact the customer representative and inform him/her that the product is ready for source inspection. If any defects are found by the source inspector the yield sheet must be updated and submitted to statistical application engineer. After the job is sourced, the member will attach the source paper work to the quality package and move the job to the shipping department after signing dating and stamping the work order.

The statistical application engineer will utilize the information from the yield sheet to rate the various department performances. This step is one of many ways to measure processes performance. He/ She may utilize computer software such as Mini Tab or Microsoft Excel to construct pareto charts from the data collected on each of the manufacturing processes. A pareto chart of the departments responsible for the major defects can be constructed. The utilization of the reports and data will be described in detail in the improvement process operating procedure at the end of this chapter.

### Internal Audits

Internal audits are divided into two aspects, one is process quality audit and the other one is quality system audit. The process audit is performed to verify that the processes are working within established limits and its activities such inputs, actions and outputs are in accordance with the defined requirements of the work instructions. The auditor will check of conformance of personnel and equipment, to defined requirements such as time, pressure, composition, amperage, and chemical mixing.

Quality system audits are a documented activity to verify by examination and evaluation of objective evidence, that applicable elements of the quality system are appropriate and have been developed, documented, and effectively implemented in accordance with the specified requirements of the ISO 9000:2000. The quality system audit looks at everything within the quality system: the processes, the product, the services, customer service, design engineering, order entry, and training. It

encompasses all systems in the facility that assist in providing an acceptable product or services.

The internal auditor will audit the quality system twice a year. He/She will also generate a schedule for the departments to be audited and a checklist of what questions to be asked. A generic auditor schedule is shown in Table 8.4.

**Table 8.4:** Generic Internal Audit Schedule For a PCB Manufacturer

Name of Auditor:			
Department	Audit Date	Corrective Action Requests	Follow up Audit Date
Sales department			
Data entry department	1/1		
Tooling department	1/13		
Receiving/ shipping	2/1		
Department	2/13		
Inner layers department	2/20		
Plating department	3/5		
Etch department	3/13		
AOI department	3/20		
Press department	4/2		
Drill department	4/13		
Outer layers department	4/20		
Solder mask department	5/1		
Legend department	5/13		
Solder level department	5/20		
Serialization department	6/1		
Rout department	6/13		
Test department	6/20		
Inspection / product audit	6/25		
Department			

A trained auditor from a different department will audit inspection department.

The internal auditor will generate a checklist, which he/she may follow during the audit.

A generic checklist is shown in Table 8.5.

**Table 8.5:** Generic Checklist for Internal Audits

Auditor name Date audit performed Department audited	
Questions	Answers
Do you know what is the quality policy, the company mission statement? What procedure or work instruction applies to your job? How do you perform your tasks? Do you use any calibrated equipment? Do you fill out any paperwork? Is all the paper work controlled? Is the process SPC controlled? Who is responsible to maintain the SPC? If you have any problems how do you report to? Is all the equipment and tools are labeled and calibrated? What are the process settings? Are all the process settings documented and controlled and within tolerance? Is the area humidity and temperature controlled? Do you have any logbooks? What is the retention time for them?	

The internal auditor will request from the scheduled department manager to perform the audit, a referee may accompany the auditor and once the audit is done, the

internal auditor will arrange a meeting with the department manager to discuss the audit findings. If there is a discrepancy in the quality system; the auditor will issue a written corrective action to the department manager.

Department manager will be given an appropriate time to answer the corrective action. The internal auditor will write a report of the audit and all paper work pertaining to the department audit will be filed and retained for a period of time.

### 8.2.2 Measuring Processes Performances

It is impossible to fully understand a phenomenon that one cannot measure. Measurement provides the basis by which phenomena can be studied and ultimately understood. The quality manager will utilize the yield sheet to measure over all departments' performance while department managers and process engineers will be responsible for measuring their process capabilities.

Before understanding variation, determining its causes, and ultimately reduce it, it has to be measured. This section will discuss how to measure variation and deviation. A quality tool matrix shown in Table 8.6 can be very beneficial in determining which quality tool can be used.

Some of the quality measurement tools that can assist the manufacturers to measure their departments and processes performance are as follows:

**Table 8.6: Quality Tool Matrix**

Idea Creation Tools	Affinity diagram Brainstorming Brainwriting Relations diagram
Process Analysis Tools	Cost of quality analysis Critical to quality analysis Deployment flow chart Matrix diagram Story board Top down flow diagram Work flow diagram
Cause Analysis Tools	Fishbone diagram Pareto chart Scatter diagram Stratification Tree diagram
Planning Tools	Activity diagram Arrow diagram Flow chart Plan-do-check-act cycle Tree diagrams Work-flow diagram Quality function deployment (QFD)
Data Collection and Analysis Tools	Box plot Checklist Control charts Histograms Normal probability plots Process capability Run charts Scatter diagram Stratification Survey Failure mode and effect analysis (FMEA)

1) Check sheets:

Check sheets can be used as a measurement tool; they are used to record and classify observed data. A graphical check sheet is shown in Table 8.7. Process engineers can utilize this quality measurement tool to categorize the defects caused by their departments.

2) Histograms:

Histograms are graphical data summary tools which allow to group observed data into cells, or predefined categories, in order to discover data location and dispersion characteristic. This quality measurement tool is widely used by process engineers to determine their process variation. An example of a histogram is shown in Figure 8.1.

The construction of a histogram is a very simple process. First, the range of the data must be calculated by subtracting the largest value minus the smallest value

Second, the process engineers determine the numbers of cells or divisions and calculate the midpoints and boundaries. Third, place the observation into one cell and display the frequency of each cell with a vertical bar.

The most distinguishing feature of the histogram is its width. The width corresponds to the variation. The second important feature of the histogram is its center. The center corresponds to the central tendency, namely the average, or the median. Central tendency can be measured by measuring the average, which is the arithmetic average of all samples.

The arithmetic average is the most commonly used measure of the central tendency. It does however have certain drawbacks. It can be misleading for non-symmetric histogram where fifty percent is not the midpoint of the histogram. It is sensitive to erroneous values.

**Table 8.7:** Graphical Check Sheet

Department: Inner Layers Type of defect: Handling, shorts, opens, spacing, cracks. Total number of defects: Date: Inspector name: Tracking number:		
Type	Check	Subtotal
Handling	//// // // // // // /	18
Shorts	//// // // //	13
Opens	//// // // // //	20
Spacing	//// // // //	15
Cracks	//// // //	11
Total Rejects:		77

That is why before using a histogram one should check for approximate symmetry and screen for erroneous values. An alternate measure of the central tendency is the median. The median is less sensitive to erroneous values. It also can be used in non-symmetric histograms and can be graphically determined without any calculations.

Another measure of variation of a process is the standard deviation. While the standard deviations are harder to compute than the range, they are easier to interpret and use. Unlike ranges, as the sample sizes increase, the standard deviation does not tend to get larger. When the sample size increases is that the standard deviation tends to get closer to the true value. The standard deviation provides more accurate estimates of variation than the range, and it is the minimum variance unbiased estimator.

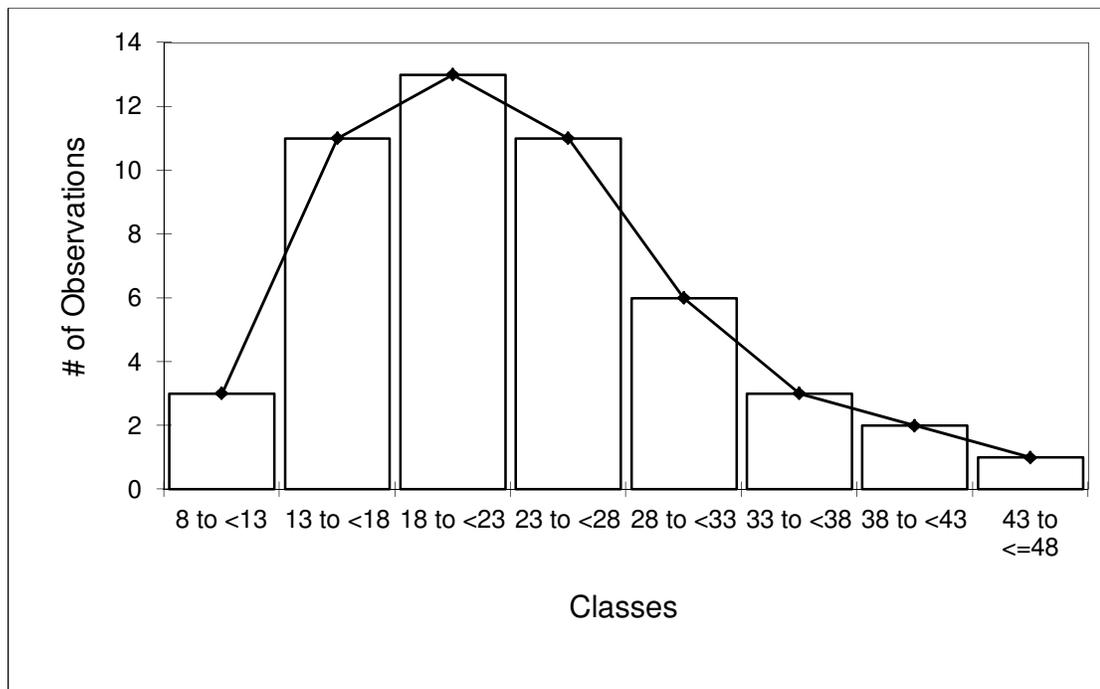
### 3) Scatter diagram:

Scatter diagram provides us the opportunity to view a data set in multiple dimensions in order to detect trends, spot best operating regions, and explore cause-effect relationships.

### 4) Measure of Relative Standing:

To measure a relative standing of an observation one can use percentile or z-score. The  $100p$ th percentile of a data set located so that  $100p\%$  of the area under the relative frequency distribution for the data lies to the left of the  $100p$ th percentile and  $100(1-p)\%$  of the area lies to its right. The median is the 50<sup>th</sup> percentile. The 25<sup>th</sup> percentile, the median, and the 75<sup>th</sup> percentile are called the lower quartile, the

midquartile, and the upper quartile, respectively for any data set. To determine the quartiles for any set of data the following process can be used.



**Figure 8.1:** Histogram for Observed Data

First, rank all measurements in the data in increasing order of magnitude.

Second, calculate the lower quartile, which is equal to  $\frac{1}{4}(n + 1)$  where  $n$  is the total number of measurements. Third, calculate the upper quartile, which is equal to  $\frac{3}{4}(n + 1)$ . Finally, measure the  $p$ th percentile which is equal to  $p(n + 1)/100$ .

The z –score is the other measure of relative standing and it can be measured for a sample taken or an entire population. The z -score describes the location of an observation relative to the mean in units of standard deviation. Negative z-score means that the observation lies to the left of the mean; positive z-score indicates that the observation lies to the right of the mean. The z-score can be calculated using the equation 8.1, and 8.2

Sample z-score

$$Z = \frac{y - \bar{y}}{S} \quad (8.1)$$

Population z -score

$$Z = \frac{y - \mu}{\sigma} \quad (8.2)$$

Where:

$S_i$  is the sample variance

$\sigma$  is the population variance

$\mu$  is the population average

##### 5) Box Plot:

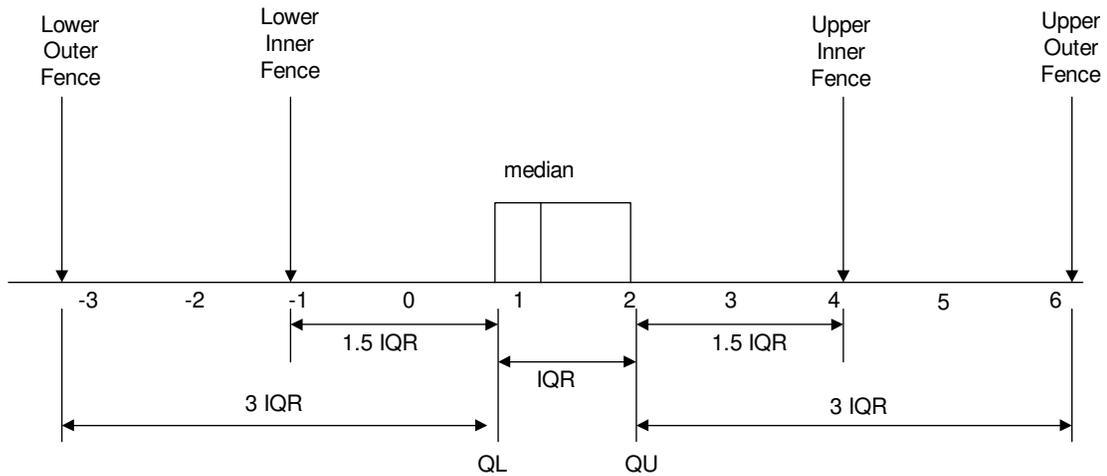
Sometimes inconsistent observations are included in any data set collected. One errant observation can cause havoc to the measurement process. If such an observation

is located outside the range of the data values it will be called an outlier. Such an outlier can be caused by incorrect measurement, data from different population, or the observation being a rare event. A box plot diagram as shown in Figure 8.2, can detect such an outlier. With this method, the process engineer can construct intervals based on a quantity called the interquartile range. The box plot consists of upper quartile, lower quartile, and interquartile. The interquartile is equal to the upper quartile minus the lower quartile. The box plot also consists of an inner fence and an outer fence.

Observations that are located between the outer and inner fence are called suspect outliers. The inner fence is located at a distance of 1.5 IQR (inter quartile range) below the QL (lower quartile) and above the QU (lower quartile), while the outer fence is located at a distance of 3 IQR below QU and above QL. Observations that are located outside the outer fences are called highly suspect outliers.

#### 6) Process Capability Measurement:

The plant manager will encourage the implementation of six-sigma concept throughout the entire plant. Process capability is a measure of how well the data collected fits between the upper statistical limit (USL) and the lower statistical limit (LSL). It also estimates future process performance, but only when such performance is consistent over time so as to allow for prediction of future performance. A stable process is predictable and it performs in a consistent manner.



**Figure 8.2:** Box Plot Diagram

A capability study on a stable process measures the consistent performance of the process. It is possible to measure past performance and to estimate the process potential. Past performance for any process can be measured by interpreting the yield sheet information on how many defects it produced.

Defects per million is a representation to determine how many products out of a 1,000,000 would be out of the control limits. Department managers will be responsible for measuring and improving their process capabilities and will train employees on how to collect and record data.

The processes that will be studied will be assumed that it follows a normal distribution. A method to measure a process capability is shown in Table 8.8. Since it is not practical to have a six sigma process without any deviation from the mean, the

measured process capability assumes that the normal distribution of the process is shifted + / -1.5 sigma. Defect per million opportunity (DPMO) can be calculated from Table 8.9. An example of a normal distribution with a shift of 1.5 sigma is shown in Figure 8.3.

Measurements start with collecting data from the process outputs. Department managers will train assigned members how to record collect data. There are different methods of measuring process performance. One method is to measure the variation exhibited by the output of any processes. Since no two units of any product produced are ever exactly alike, then it is very important to measure such differences

Measuring variations requires multiple measurements in order to estimate the differences. These differences are then plotted or summarized. One of the quality tools that can assist in measuring variation is histogram.

One of the problems in measuring process performance is determining the sample size. The solution to this problem depends on how wide the engineer wants the confidence interval to be. All half width of many confidence intervals is a function of the sample size and the estimated standard error.

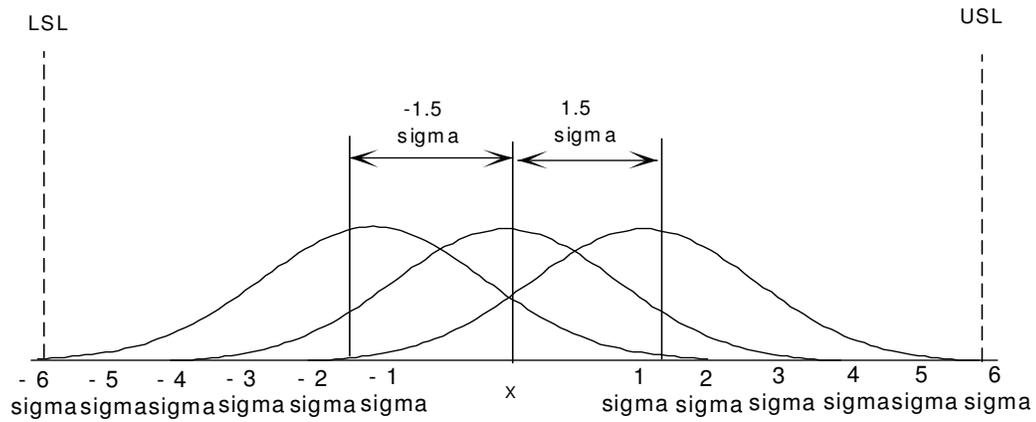
That is, the half width H of the small sample confidence interval for any mean  $\mu$  is given in equation 8.3

$$\text{Half width H of a small sample} = t_{\alpha/2} \left( \frac{s}{\sqrt{n}} \right) \quad (8.3)$$

The sample standard deviation and the population standard deviation can be approximated from past collected data.  $t_{\alpha/2}$  depends on the sample size  $n$ , and  $S$  is statistically computed from the sample data.

**Table 8.8:** How to Measure the Sigma Capability For Any Process

Step Number	What you want to compute	Equation	Answers
1	Which process you want to calculate its capability		The company capability
2	How many panels started the beginning of the month?		1283
3	How many panels shipped to the customer with no defect?		1138
4	Calculate the total yield of the processes in step 1	$P = \text{Step 3} / \text{Step 2}$	0.8870
5	Calculate the defect rate	$q = 1 - p$ $= 1 - \text{Step 4}$	$1 - 0.870 = .113$
6	Determine the number of potential problems that can create a defect in the PCB	Number of CTQ Number of Critical to quality characteristic	24
7	Calculate the defect rate per CTQ	$\text{Step 5} / \text{Step 6}$	.0047
8	Calculate the defect per million opportunity DPMO	$.0047 \times 1,000,000$	4,709
9	Convert the DPMO into sigma value using the rule of thumb for probability		4.1 Measured process capability
10	Draw conclusions		Over all processes needs improvement



**Figure 8.3:** Normal Distribution Shifted 1.5 Sigma

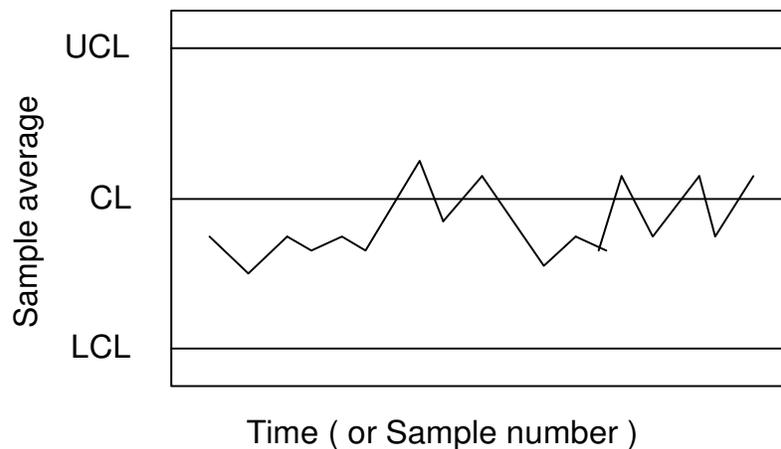
**Table 8.9:** DPMO

Specification Limit	Percent	Defective Per PPM
+/- 1 SIGMA	30.23	697700
+/- 2 SIGMA	69.13	308700
+/- 3 SIGMA	93.32	66810
+/- 4 SIGMA	99.3790	6210
+/- 5 SIGMA	99.97670	233
+/- 6 SIGMA	99.999660	3.4

The easiest way to decrease the width of the confidence interval is to increase the sample size  $n$ . The sample standard deviation and the population standard deviation can be approximated from past collected data. Generally speaking the larger the sample size, the more information the statistical application engineer will acquire. However, the larger  $n$  becomes the higher the cost of sampling will be.

### 8.3 Processes Monitoring

The plant manager will ensure that all processes are monitored and measured to achieve planned results. If planned results are not met, corrective action shall be taken to ensure conformity of the product. Process engineers will construct control charts to monitor their assigned processes and will determine the applicable control chart for their processes. Control charts are very useful in process monitoring; when unusual sources of variability are present, sample averages will plot outside the control limits. This is a signal that some investigation of the process should be made and corrective action to remove these unusual sources of variability taken. Systematic use of control charts is an excellent way to reduce variability. A typical control chart is shown in Figure 8.4.



**Figure 8.4:** Typical Control Chart

When the important variables are identified, and the nature of the relationship between the important variables and the process output is quantified, then an on-line statistical process- control technique for monitoring and surveillance of the process can be employed with considerable effectiveness.

Techniques such as control charts can be used to monitor the process output and detect when changes in the inputs are required to bring back to an in control state. Control charts for variable data can be constructed using the notations and formulas shown in Table 8.10. A single measurable quality characteristic such as weight, dimension, or volume, is called a variable.

When dealing with a variable quality characteristic, it is usually necessary to monitor both the mean value of the quality characteristic and its variability. Control of the process average or mean quality level is usually with the control charts for the means, or the  $\bar{x}$  chart. Process variability can be measured with either a control chart for the standard deviation, called the S chart, or a control chart for the range, called R chart.

Many quality characteristics cannot be represented numerically. In such cases, we usually classify each item as either conforming or nonconforming to the specification. Quality characteristic of this type is called attributes. The most widely used charts for attributes data are the p chart for fraction of nonconforming (defective), np control chart for the number of nonconformity, c control chart for the nonconformity or defect, and u control chart for the average number of nonconformities per inspection

unit. Equations 8.4, 8.5, 8.6, 8.7, 8.8,8.9,8.10,8.11, and 8.12 respectively show how to calculate the control limits for the corresponding control charts. Notations for attribute charts formulas are shown in Table 8.11

**Table 8.10:** Notations for Variable Control Charts Formulas

$B_4$ , is a constant calculated from tables.	$B_3$ , is a constant calculated from tables.
UCL, is the Upper control limit.	$\bar{X}$ bar is the average of measurement.
LCL, is the Lower control limit.	$\bar{\bar{X}}$ 2 bar is the average of the averages.
n, is the sample size.	$R$ is the range.
$\sigma$ , is the process standard deviation	$\bar{R}$ bar is the average of ranges.
$D_3$ , is a constant calculated from tables.	$A_2$ is a constant calculated from tables.
$A_3$ , is a constant calculated from tables	S is the sample standard deviation
$D_4$ , is a constant calculated from tables.	$B_3$ is a constant calculated from tables.

**Variable Data (  $\bar{X}$  and R Control Charts ) :**

$\bar{X}$  Control Chart

$$\begin{aligned}
 UCL &= \bar{\bar{X}} + A_2 \bar{R} \\
 LCL &= \bar{\bar{X}} - A_2 \bar{R} \\
 CL &= \bar{\bar{X}}
 \end{aligned}
 \tag{8.4}$$

R Control Chart

$$\begin{aligned} UCL &= \bar{R}D_4 \\ LCL &= \bar{R}D_3 \\ CL &= \bar{R} \end{aligned} \quad (8.5)$$

**Variable Data ( X and S Control Charts ) :**

X Control Chart

$$\begin{aligned} UCL &= \bar{\bar{X}} + A_3\bar{S} \\ LCL &= \bar{\bar{X}} - A_3\bar{S} \\ CL &= \bar{\bar{X}} \end{aligned} \quad (8.6)$$

S Control Chart

$$\begin{aligned} UCL &= \bar{S}B_4 \\ LCL &= \bar{S}B_3 \\ CL &= \bar{S} \end{aligned} \quad (8.7)$$

Where

$$S = \sqrt{\frac{\sum_{i=1}^n (X_i - \bar{X})^2}{n-1}} \quad (8.8)$$

**Table 8.11:** Notations for Attribute Control Charts Formulas

p bar is the average of nonconforming	u bar is the average number of conformity/unit
CL is the center line	c bar is the average number of nonconformity
UCL <sub>p</sub> ,is the Upper control limit for p chart	n, is the number of samples
LCL <sub>p</sub> ,is the Lower Control limit for p chart	

The following formulas are for attribute charts:

### Attribute Control charts

p Control Chart (fraction of nonconforming)

$$\begin{aligned}UCL &= \bar{p} + 3\sqrt{\frac{\bar{p}(1-\bar{p})}{n}} \\LCL &= \bar{p} - 3\sqrt{\frac{\bar{p}(1-\bar{p})}{n}} \\CL &= \bar{p}\end{aligned}\tag{8.9}$$

np Control Chart ( number of nonconforming)

$$\begin{aligned}UCL &= n\bar{p} + 3\sqrt{n\bar{p}(1-\bar{p})} \\LCL &= n\bar{p} - 3\sqrt{n\bar{p}(1-\bar{p})} \\CL &= n\bar{p}\end{aligned}\tag{8.10}$$

c -Control Chart ( count of nonconformances)

$$\begin{aligned}UCL &= n\bar{p} + 3\sqrt{n\bar{p}(1-\bar{p})} \\LCL &= n\bar{p} - 3\sqrt{n\bar{p}(1-\bar{p})} \\CL &= n\bar{p}\end{aligned}\tag{8.11}$$

u-Control Chart ( count of nonconformances/ unit)

$$\begin{aligned}UCL &= \bar{u} + 3\sqrt{\frac{\bar{u}}{n}} \\LCL &= \bar{u} - 3\sqrt{\frac{\bar{u}}{n}} \\CL &= \bar{u}\end{aligned}\tag{8.12}$$

There are other control charts that are used to monitor the process mean such as exponentially weighted moving average, and moving average control charts.

Construction of these control charts can be found in many textbooks.

The process engineers will use the control charts introduced to control their process. Control charts mentioned in this section are passive statistical method that is we watch the process and wait for some information that will lead to a useful change. However, if the process is in control, passive observation may not produce much useful information. The next section will introduce an active statistical method that will overcome such deficiency.

#### 8.4 Control of Non-Conforming Material

This procedure is detailed description of control of non-conforming product and is evidence that the system is implemented and complies with ISO 9000:2000 Quality Management System section 8 paragraphs 8.3. Department managers and process engineers are responsible for ensuring that the non- conformed product produced by their departments is recorded and controlled accordance with this procedure.

Department managers will train their employees how to disposition the non-conforming items. Training record will be retained in the human resources for the use of evaluating the employee's performances.

#### 8.4.1 Implementation

Nonconforming products will be recorded on the yield sheet and records will be maintained for analysis and process improvement. Process nonconforming will be recorded on SPC. Incoming inspection employees must identify all shipments that have discrepant paperwork as "On hold "and separate the material until the paper work is corrected. Any material that is nonconforming to the purchase order must be identified as "Non Conforming Material". Quality or process engineering will evaluate and disposition any discrepant material found at the incoming inspection. The disposition and appropriate corrective action is recorded in the incoming inspection logbook in support of the supplier monitoring system.

Any nonconforming items at final inspection or in process must be identified and separated. The inspectors will scrap or rework the defected item and record the finding in the yield sheet. If the inspectors are unsure of the characteristic of the nonconforming item they will seek advice from their supervisors or the quality engineers.

Nonconforming items will be labeled with the tracking and lot number.

The quality engineers will handle customer complaints and returned goods. Customer complaints will be recorded using the customer request for corrective action form as shown in Table 8.12. All PCBs that are reworked or used as is will meet the customer requirements. A returned material authorization (RMA) must be issued prior to the return of the PCB by the customer. All RMA's are numbered for traceability as shown in Table 8.13

**Table 8.12:** Customer Request for Corrective Action

Tracking number: Part number: Customer name: Department responsible:	Problem description: Action taken: Date closed:
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Upon receipt of the returns, the assigned quality employee will verify the quantities received, review the defects, and verify the effect of the returns on any work in process product or in stock. All stock boards must be inspected for the defect returned. The assigned employee will complete the RMA form and send the appropriate documents to the sales department.

**Table 8.13:** Return Material Authorization

RMA number: Customer name: Part number: Tracking and lot number: Price per board: Price per panel: Purchase order number: Quality engineer: Sales representative:	Disposition by: Date received: Sales order number: Invoice number: Reason for rejection: Method of shipment: Buyer's name: Buyer's phone and fax number: Corrective action taken:
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If the product is found unsuitable for use, the assigned quality employee must dispose of the product. The quality engineer will ensure that an appropriate corrective action is taken to prevent such occurrence of the defect.

## 8.5 Analysis of Data

This section of the procedure analysis of the data will comply with ISO 9000:2000 Quality Management System section 8, paragraph 8.4.

### 8.5.1 Responsibility and Authorization

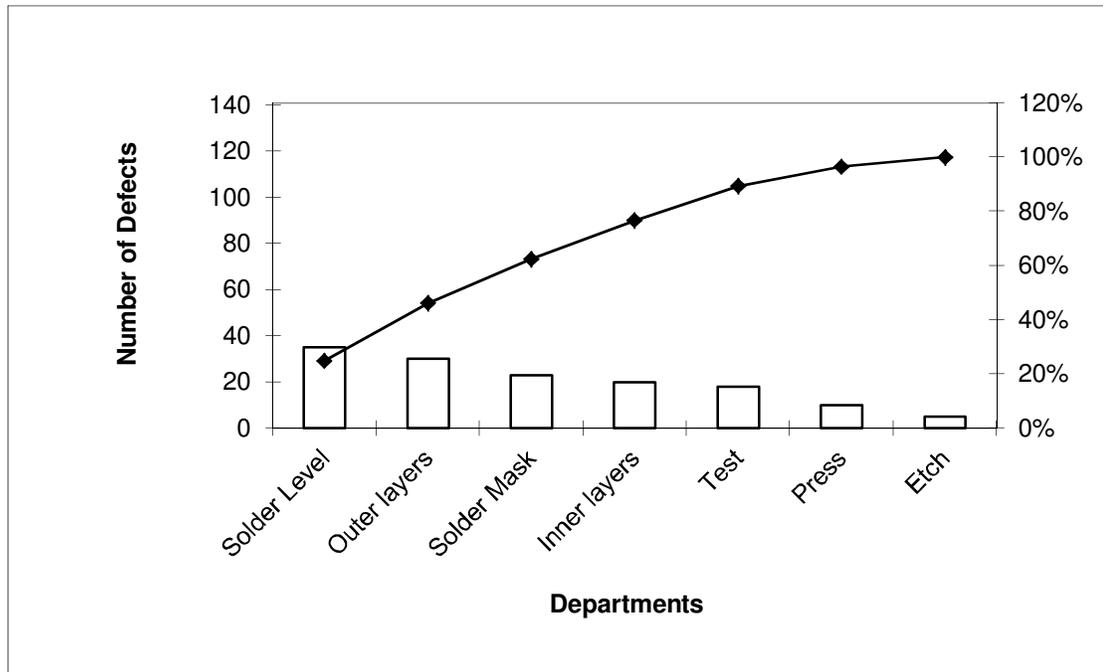
The quality manager will be responsible of measuring customer's satisfaction. Customers' satisfaction can be measured by collecting all the information and data that is related to them. Surveys, customer returns, corrective of actions, and customer communication can give and indication on what level the customer is satisfied. The quality manager will quantify all the qualitative data to give an estimate of customer satisfaction. Customer satisfaction can be monitored through a run chart to determine if it is in an ascending or descending process. Once the chart shows any descending indication, the quality manager should determine the cause and effect of such a case and immediately rectify it.

## 8.5.2 Implementation

Data analysis is an important process in any improvement plan. Processes cannot be improved unless all data collected and measured are analyzed. There are various quality tools that can assist in analyzing the measured data. Data measured and collected will be scrutinized to find out how to improve processes performance. Data that is statistically collected will give the process engineer an idea on how the processes are behaving. The data will indicate unusual behavior if the processes are out of control. It is up to the process engineer to analyze and determine why the processes are out of control. The following quality tools will assist the process engineer or the statistical application engineer in analyzing the data collected.

### 1) Pareto Charts:

Pareto charts are used to determine which of the processes contributes to the most defects. Utilizing the yield sheet information and plugging it in a pareto chart will visually determine which of the processes is more significant. An example of a pareto chart is shown in Figure 8.5 in this example. Conclusions can be drawn that the solder level department is significantly contributing more than any of the other departments to the defects. Process engineers and department managers should investigate and analyze the findings to determine the reason for such contribution. This type of chart will assist the process engineers in evaluating improvements, by comparing before and after data.



**Figure 8.5:** Pareto Chart

2) Cause and Effect Diagrams: Ishikawa diagram (Fish bone diagrams) :

The fishbone diagram relates causes and effects. The statistical application engineer can use this structure in a brain storming session to sort ideas into useful categories. An example of a cause and effect diagram is shown in Figure 8.6.

3) Failure Mode and Effect Analysis (FMEA) :

When the PCB or the processes fail to meet the customer requirements, an action must be taken immediately. The process engineer may use this tool to focus on failure modes, mechanism, and effects. FMEA is a qualitative tool, which can support

proactive quality strategies. It seeks to identify possible failures modes and mechanism, the effects or consequences that failure modes may have on performance, method of detecting the identified failure modes, and possible means for prevention. The net result from effective FMEA work is PCB and process action plans for elimination, or at least mitigation, of the failure modes. The process engineer can utilize FMEA in systematically evaluating his/her process at specified levels of the system complexity. The construction of FMEA is a tabulation of process functions or process equipment items, the failure modes for each, and the effects of the failures on the process. Hence, it identifies single failure modes that can cause, or contribute to the cause of nonconformance. An example of FMEA tabulation is shown in Table 14(1), and Table 14(2).

### 3) Logic Tree Analysis:

The process engineer can utilize this tool to identify process failure pathways, both human and mechanical that could lead to an identified fault event. Logic trees are useful in depicting graphically the logic required to establish and accomplish system performance goals and objectives.

### 4) Statistical Process Control Charts:

Control charts can also be used to analyze process performance. The process engineer can utilize control charts to identify the special causes that affect his process. Control chart will assist the process engineer in identifying the special causes from the common causes that affects his/her process. The process engineer must eliminate these

special causes and continuously reduce the effect of the common causes. The identification of the presence of special causes and their subsequent elimination brings the process into a state of statistical control.

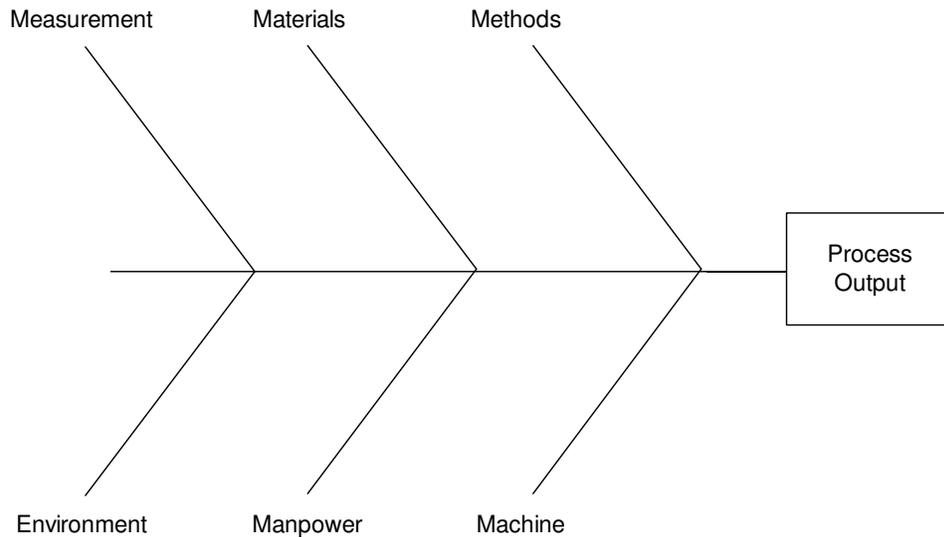
The above quality tools were only a sample of the tools that can be used to analyze the data collected. More tools are introduced in several textbooks that discuss data and risk analysis.

## 8.6 Improvement

Process improvement and customer satisfaction procedure discussed in this section will comply with ISO 9000: 2000 section 8.5 Quality Management System Paragraphs 8.5.1, 8.5.2, and 8.5.3.

### 8.6.1 Responsibility and Authority

The plant manager will be responsible for the implementation of a continuous improvement plan. The quality manager will assign a statistical application engineer to train managers and supervisors and process engineers in the basic statistical and improvement techniques. Department managers and supervisors, with the assistance of the statistical application engineer are responsible for training the employees in their departments to the statistical techniques and the basic of process capability. Assigned employees will be responsible for maintaining and updating the statistical process control charts for their departments.



**Figure 8.6:** Fishbone Diagram

### 8.6.2 Implementation

The statistical application engineer will implement a quality function deployment for each department and meet regularly with the process engineers to discuss ways of improving their processes. The plant manager will set the goals for every department, and the department managers will be assisted by the statistical engineer to meet these goals. He/She will also set the quality objectives of the entire plant regarding cycle time, safety, yield, and production. The implementation of the quality function deployment will be in three phases. The first phase where the statistical engineer will identify the customer characteristics and demands regarding the PCB.

**Table 8.14 (1): FMEA Tabulation**

Functional or Equipment Identification	Functional or Equipment Purpose	Failure Mode	Failure mechanism	Failure Detection
Solder level Machine	Coat PCB with solder	Uneven solder	Age	Inspection, Maintenance

**Table 8.14(2): FMEA Tabulation**

Failure Detection	Failure Compensation	Failure Effects	Preventative Measures
Inspection, Maintenance	Use the backup solder level machine	Reduced Production	Schedule Routine Maintenance

The second phase is defining the process features. The third phase is developing a road map for continuous improvement of processes and PCBs.

The Statistical application engineer will set goals for the implementation of the control charts such as the minimization of production cost, consistency of the processes and PCBs' functions, fewer defective products, increase output, less wasted production hours, and less machine downtime. He/She will also use design of experiments and Taguchis' methods to assist the processes engineers in finding the optimum variable settings for their process and to minimize the loss to society.

Design of experiments is approached by implementing two phases. In phase one, the statistical engineer will set objectives to determine if the current levels or settings of the independent variables result in a value of the response that is near optimum such as shown in Figure 8.7, or if the process is operating in some other regions that is possibly remote from the optimum.

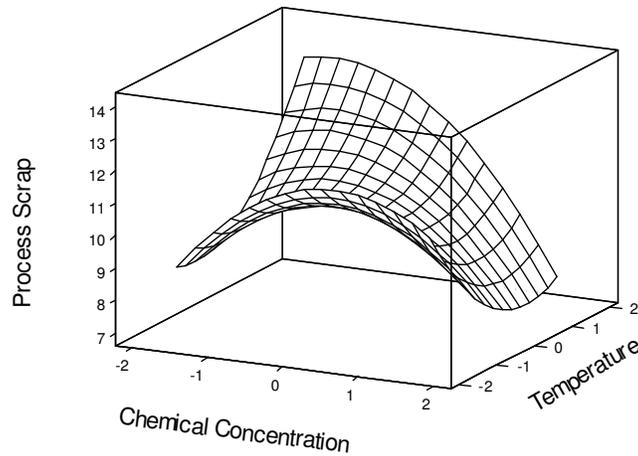
If the current setting or levels of the independent variables are not consistent with the optimum performance, then the application engineer must determine a set of adjustment to the process variables that will move the process towards the optimum. This phase of the design of experiments uses the first –order model and the method of steepest ascent /or steepest descent.

The second phase of design of experiments utilizes the second –order model to accurately approximate the true response function within a relatively small region around the optimum. Most of these methods are described in details in (Myers Raymond and Montgomery Douglas, Response Surface Methodology, 1995). The statistical application engineer must have knowledge of these techniques to implement it successfully. The process engineer will identify all the variables that have an affect on the process performance and concurrently work with the statistical application engineer to find the optimum settings for these variables.

A screening process will be implemented to determine the variables that have the most effect on the processes. Using a normal probability plot as described before in the earlier chapters will identify these variables.

The statistical application engineer will use the main variables to model the processes.

In many cases, either a first-order or a second-order model is used. The first and second order for the two main effects and their interactions are in the following formulas:



**Figure 8.7:** Surface Plot Showing the Relation Between Process Scrap and the Process Variables

**First-order equation for two main effects and their interaction:**

$$\eta = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_1 x_2 \quad (8.13)$$

**Second-order equation for two main effects and their interaction:**

$$\eta = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_1 x_2 + \beta_4 x_1^2 + \beta_5 x_2^2 \quad (8.14)$$

Where  $X_1$ , and  $X_2$  are the independent variables and  $\beta_0, \beta_1, \beta_2, \beta_3$ , and  $\beta_4$ , are set's of unknown parameters.

$X_1, X_2$ , and  $X_3$  can be calculated by transforming the natural units to coded variables.

The following equation (8.15), (8.16), and (8.17) are widely used in fitting linear regression models, and it results in all the values of  $X_1, X_2$ , and  $X_3$  falling between  $-1$  and  $+1$ .

$$x_{i1} = \frac{\xi_{i1} - [\max(\xi_{i1}) + \min(\xi_{i1})] / 2}{[\max(\xi_{i1})] / 2} \quad (8.15)$$

$$x_{i2} = \frac{\xi_{i2} - [\max(\xi_{i2}) + \min(\xi_{i2})] / 2}{[\max(\xi_{i2})] / 2} \quad (8.16)$$

$$x_{i3} = \frac{\xi_{i3} - [\max(\xi_{i3}) + \min(\xi_{i3})] / 2}{[\max(\xi_{i3})] / 2} \quad (8.17)$$

Where  $\xi_1, \xi_2$ , and  $\xi_3$  are the natural units of the collected data.

Regression analysis and the method of least squares use the collected data to estimate these coefficients. Once the data is fitted in a model we can then estimate all the coefficients. Methods such as full factorial or fractional factorial can be used in experiments involving several factors where it is necessary to investigate the joint

effects of the factors on a response variable. A limitation in the fractional factorial and full factorial methods is that the variables have to have only two levels either high or low. The following steps are needed to determine the optimum settings of the variables to obtain optimum response in any process.

- 1) Fit a first order model using orthogonal designs such as two level factorial designs.
- 2) Compute a path of steepest ascent if maximum response is required. If minimum response is required, it is recommended to compute the path of the steepest descent. The path of the steepest ascent is computed so that a maximum response is achieved. Steepest descent is computed so that a minimum response is achieved. Basic differentiation of the first order model equation will take place in this step to achieve maximum response.
- 3) Conduct experimental runs along the calculated path. Do single or replicated runs and observe the output of the response. At some point region along the path the improvement will decline and eventually disappear.
- 4) At the point of maximum or (minimum) response that is reached a base of second experiments is chosen, the designs should still be a first order design. It is quite likely to add center runs for the testing of curvature, and degrees of freedom for interaction type lack of fit.
- 5) A second experiment is conducted and another first order model is fitted. A test of lack of fit is made. If lack of fit is not significant, a second path

based on the new model is computed. Single or replicated experiments are conducted along this path are conducted.

These were only guidelines to reach the point of maximum (minimum) response for any process. It is quite possible that only one stage is calculated and hence only one path is used. If interaction or quadratic lack of fit contribution appears prominent at the second stage, the statistical application engineer will not conduct more experiments on the first order model but will fit a higher order model and then run the second stage. Some of the designs that are commonly used for the second order models are Central Composite and Box Behnken designs.

Another method to optimize the process response is by applying Taguchi's approaches to robust processes and products. Although Taguchi's philosophy is an excellent approach to quality engineering but his methods of analyzing the collected data is in doubt of its accuracy, (Montgomery, 1996).

The Taguchi notion of quality improvement places emphasis on variance reduction. His approach is based on determining the settings on that control variables that produce a robust product or process. Hence, the Taguchi analysis does reduce to process optimization, where the performance criterion is the signal to noise ratio.

Taguchi analysis is very simple to crossed array concepts in which separate designs are used for control and noise variables, and the final design is a crossing of the inner array (control variables) and the outer array(noise array). Taguchi's approach to robust parameter design takes into account both the process mean and its variance.

The problems with Taguchi's approaches to analyzing the data is that Taguchi does not consider the interaction of the noise and the control variables and many of his designs have very messy alias structure. The lack of provisions for adequately dealing with potential interactions between the controllable process factors is a major weakness in Taguchi approach to parameter design. Inner and outer array structure usually leads to very large experiments which makes it not economically wise unless there are very few variables that needs to be investigated. All of these problems with Taguchi approach lead us to believe that there must be alternatives to analyze the data collected such as the dual response method. The statistical application engineer must be knowledgeable with all the information represented in this section for process optimization.

### 8.6.3 Preventive Action

This last section of the Quality System complies with ISO 9000:2000 Quality Management System Section 8 paragraph 8.5.3.

### 8.6.4 Implementation

The plant manager will be responsible for implementing a vigorous preventative action program and will appoint an assignee to oversee its implementation. Preventative action is one of the most critical stages in manufacturing. It is better to prevent an action that will cause scrap or rework than wait until this action occurs and then fix the

problems. The department managers are going to work continuously on the elimination of all potential causes that produces nonconformities in order to prevent their occurrences. The statistic application engineer with the assistance of the process engineers and the department managers are going to list all potential problems that occur for every department. A preventative action program is going to be implemented to eliminate or economically reduce the causes that affect the yield for every process.

Weekly, the plant manager will analyze work operations with the statistical application engineer related to quality records, overall yields, major scrap items, yield improvement programs, departmental scrap, rework, and delivery schedules. The statistical application engineer will recommend the appropriate action and improvement programs to the plant manager. Resources will be allocated first to the programs that have a direct influence on yield and material cost. Departments that are statistically controlled by control charts will post all preventative actions done to eliminate the out of control points that occurred.

Customer's returned PCB will be reviewed by the quality engineer. If the assigned quality engineer determines that the company is in fault, a corrective action will be written to the department manager responsible for the returns as described before in the corrective action procedure. The department manager has to demonstrate a planned preventative action that will eliminate once for all the problems that caused the returned PCB.

Any PCB manufacturer that implements a successful quality management system as described in this thesis is going to increase its competitive edge against other PCBs manufacturers. Plant managers must not look at quality as an added feature to manufacturing; they should look at it as an indispensable part of manufacturing.

## 8.7 Conclusions and Further Studies

### 8.7.1 Conclusion

In general, organizations needs to devote resources specifically to the implementation of planned improvement programs. Top management has to encourage the employees to work towards zero defects. The implementation of ISO 9000:2000 is going to increase profitability and customer satisfaction. Profitability is achieved through the implementation of the improvement quality tools introduced. Reduction is variation is the first symptoms of improvement, scrap and rework is going to be minimized. Objectives are met when the customer is completely satisfied with the quality of the product delivered. The first objective, to provide a generic guideline for certification for PCB manufacturer, based on the ISO 9000 standard is accomplished by documenting a process to achieve the certification. The second objective, introducing the various methods and tools to improve quality is met by introducing a measuring technique to enhance productivity and assist managers in improving their processes. Some of the tools introduced were control charts, design of experiments, benchmarking, quality

function deployment, failure mode and analysis, reliability of the equipment and products, pareto charts, histograms, scatter diagrams, and box plots.

### 8.7.2 Areas for Future Research

Information on how to improve each individual process has not been introduced. A further study would be investigating individually the processes of manufacturing the printed wiring boards and to use the quality tools introduced in this paper to accomplish this task. Also one might look at how to implement design of experiments on the individual processes.

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