CHAPTER 5. OVERVIEW OF THE MANUFACTURING PROCESS

5.1 INTRODUCTION

The manufacturing plant considered for analysis, manufactures Printed Circuit Boards (PCB), also called Printed Wiring Boards (PWB), using subtractive processing, in which copper is selectively removed from a printed circuit board to form a circuit. Within this process, however, copper and other metals are also added during plating steps. The primary production steps are represented in Figure 5.1. Refer to the glossary of terms attached in the appendix for an explanation of the terminology involved.

The subtractive process begins with copper-clad laminate[7], composed of a thin copper foil covering both sides of the epoxy-glass core material. The laminate is coated with a sacrificial photopolymer material that acts as a resist in subsequent steps. The resist is photoimaged (exposed/developed) to expose the copper to be removed. The board is then etched[8], after which the resist material is stripped and disposed in a fabrication waste stream, leaving the desired interconnect pattern in copper on the exposed laminate. In a multilayer structure, each of the inner layers is constructed independently, then laminated together using a B-state epoxy[9] in between each inner layer core to form the overall structure. This process of building multilayers is essentially independent of the number of inner layers laminated together and is used to build PWB structures with any number of layers.

[7] 7, 8, …15: All the terms are explained in Appendix B

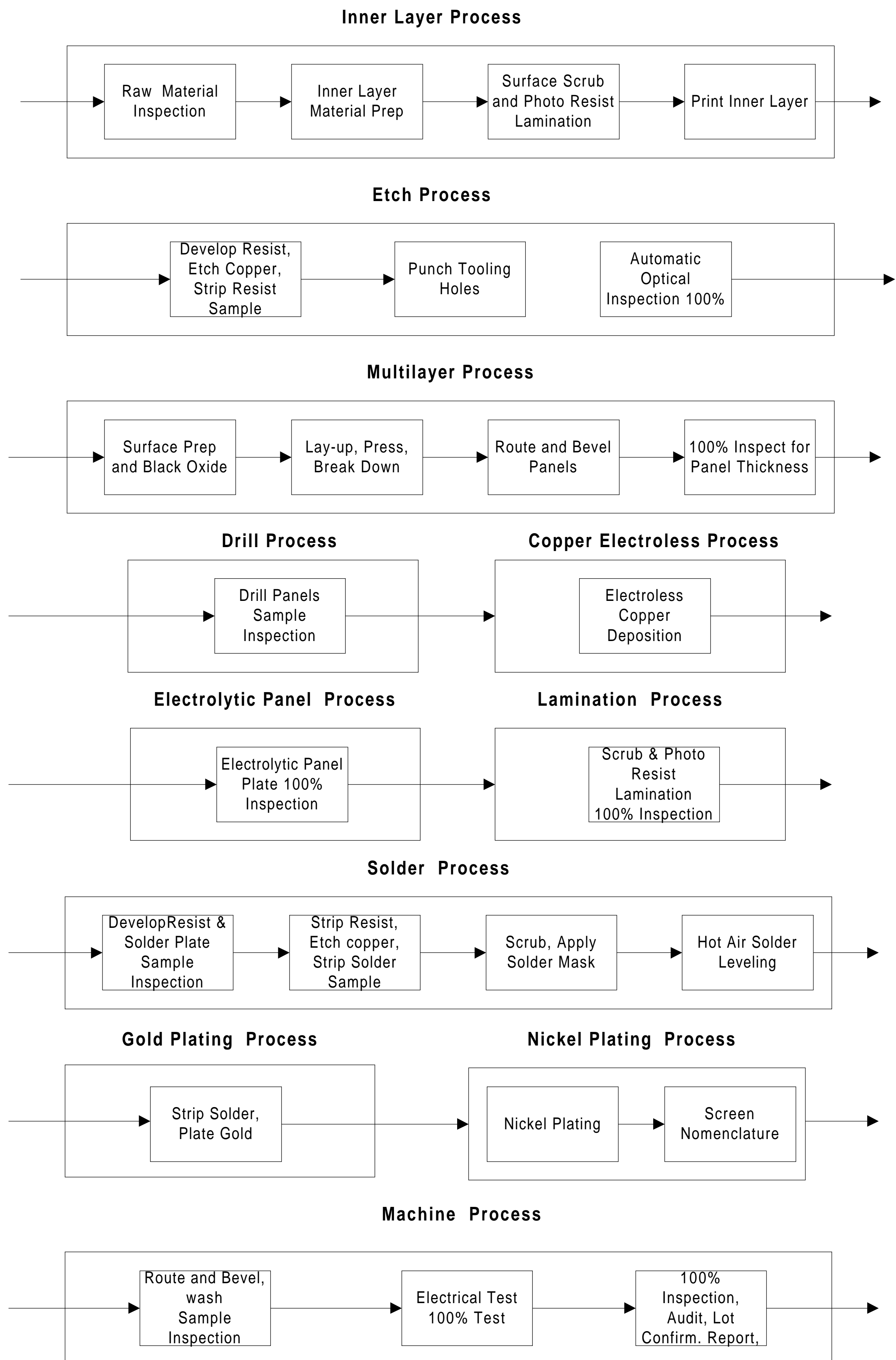

Figure 5.1 Printed Circuit Board Production Process

Each of the major processing steps in the manufacturing technology are described below:

5.2 INNER LAYER PROCESS

5.2.1 Inner Layer Material Prep: The Inner Layer Department starts the manufacturing process. The core material is typically either half ounce or one ounce of copper foil on a fiberglass and epoxy resin base laminate.

5.2.2 Surface Scrub and Photo Resist Lamination: After passing incoming inspection and being approved for use by the firm, the laminate is processed through a cleaning process after which a dry or photo film is applied to the outside of the cores.

5.2.3 Print Inner Layer: These cores are then sent into the print units for light exposure using the photo department's inner layer tool. This process places the inner layer image onto the core. During the "print" step, photoresist is applied to the surface copper of PWB material. Photoresist is a light sensitive organic coating that can be imaged with a photo-tool and a light source.

5.3 ETCH PROCESS

5.3.1 Develop Resist, Etch Copper, Strip Resist (Sample Inspection): This material is then processed through the develop-etch-strip line which develops the film, etches or removes the copper from the non-circuit area and then strips the film off the core. During the etch step, copper that is not protected by the photoresist (which now becomes the etch-resist), is etched away and only the image of the circuit remains. The photoresist is then stripped, revealing the copper circuit remaining beneath it.

5.3.2 Automated Optical Inspection 100%: The cores are transported to the inner layer inspection equipment which is comprised of three Visual Inspection Machines and one Inter Trace Electrical Tester. Depending on the complexity of the work, line width and spacing, etc., the cores are either optically or electrically inspected. At this point the cores are staged in the books needed to make up a panel.

5.4 MULTILAYER PROCESS

5.4.1 Surface Prep and Black Oxide: These cores are racked and processed through the black oxide chemistry[10], which increases copper area and provides better laminate bond strength. This process promotes copper-to-epoxy adhesion in multilayer manufacture.

5.4.2 Lay-up, Press, Break Down: The cores go into the lay up room where fiberglass pre-preg is added between the cores. Pre-preg is used to separate the circuits on the cores for dielectric reasons and to provide a medium to bond the circuit layers together. Copper foil is added to provide a circuit medium for the panel, top and bottom. The stack-up is then moved into a vacuum-assisted press. Pressing applies pressure and heat under vacuum to bond the multiple layers together creating a panel.

5.4.3 Route and Bevel Panels: After pressing, the material is moved into the finished area where the flashing is removed, the edges are beveled. After 100% inspection for panel thickness the panels move on to the drill department.

5.5 DRILL PROCESS

5.5.1 Drill Panels (Sample Inspection): Computerized Numerical Control (CNC) machines are used for drilling both component and via holes. Vias, holes drilled through a PWB for the purposes of layer-to-layer interconnection, are drilled into the PWB to connect the inner and output layers. After drilling, the inner layer foil extends to the barrel of the hole and is available for interconnections when the hole barrel is metallized. These drills are selected for accuracy of small hole, high aspect ratio drilling. The CNC drill machines all have the drill programs automatically downloaded from the Product Engineering Department. One of the keys to this area is the tool management system that ensures that the proper drill bits are used, that all drill bits are fully inspected before use. The quality of the drilled hole is the key to being able to produce the type of technology demanded by the customer base. Panels are transformed into boards.

5.6 COPPER ELECTROLESS PROCESS

5.6.1 Electroless Copper Deposition: After the drilling process, the panels are processed through a desmear[11] (i.e., hole cleaning) and electroless[12] bath. The desmear process removes resin from the interconnect holes and prepares it for electroless copper. The electroless bath places a small amount of copper on all surfaces of the boards and more importantly, inside of the holes. This thin layer of electroless copper acts as a conductor for the electrolytic copper plating process. Once this seed layer of copper is in place copper plating can occur. The electroless copper line typically contributes a significant portion of a PWB shop's overall waste. Water use is high due to the critical rinsing required between nearly all of the process steps. Copper is introduced into the wastewater stream due to drag-out from the cleaner conditioner, micro-etch, sulfuric, accelerator, and deposition baths.

5.7 ELECTROLYTIC PANEL PROCESS

5.7.1 Electrolytic Panel Plate (100% Inspection): After the boards come out of the electroless bath, they immediately go into the electrolytic copper plate bath where 1 mil of copper is plated in the holes, typically 1.2 mils of copper on the surface.

5.8 LAMINATION PROCESS

5.8.1 Scrub and Photo Resist Lamination: Lamination is the process of putting together the various layers. Lamination may be divided into several steps. First, the multilayer inner layers and ancillary materials are assembled in a stack in preparation for lamination. At this point, the circuit patterns have been generated on each layer of copper/dielectric laminate. The stack is held in registration by tooling pins. A typical circuit stack will include copper foil, B-stage[13] (substrate material with semi-cure epoxy, also referred to as prepeg) and the etched inner layers. B-stage styles are selected to provide the multilayer circuit with the specified overall thickness, and several sheets may be placed between successive inner layers. Several circuit boards may be pressed in one stack or "book" and they are separated by coated aluminum sheets or other release materials.

5.9 SOLDER PROCESS

5.9.1 Develop Resist & Solder Plate (Sample Inspection): The circuitry image is placed on the outer layer of the panel. The initial step is to place dry film on the panel, a method that is very similar to what is performed in the inner layer area. This film is then exposed using the artwork generated from the CAD data. The negative of the film is exposed to the artwork. The panel moves through the developer, which defines the area to be circuitized. The panel is then solder plated. This process places a thin coating of tin/lead over the exposed circuits, which acts as a resistant to the etchant of the next process.

5.9.2 Strip Resist, Etch Copper, Strip Solder (Sample Inspection): The panels are next processed through the strip-etch-strip (SES) line. This machine strips the dry film off of the panel thereby leaving the base copper and the solder plated circuits and holes. The next section of the machine will then etch the copper off of all but the circuits and holes. The final chamber strips off the solder, leaving a finished product that will have copper circuits over the bare fiberglass laminate. The panels are then moved to the solder mask department.

5.9.3 Scrub, Apply Solder Mask (100% Inspection): The majority of Manufacture Inc., product is solder mask over bare copper (SMOBC). When these boards come out of the SES operation, the copper traces and hole walls are exposed. The panels are processed through a quick pumice scrub, a cleaning action to make sure there is no oxidation of the copper. A solder mask which is usually either a liquid photoimageable (LPI) or a dry film solder mask is applied. The mask, typically green, is coated over the panel. The LPI solder mask is exposed through artwork received from the photo department. After print, the panel is processed through a developer and then baked. This department also applies the component marking which is applied after the surface finish has been completed. Component marking includes all printing required by the customer to identify board features and component placement.

5.9.4 Hot Air Solder Leveling - HASL (100% Inspection): After the solder is applied, hot air knives blow off the residual solder, clean out the holes and level the solder down to the required height. The purpose of the soldermask is to mask off and insulate

physically and electrically those portions of the circuit to which no solder or soldering is required. Boards are then inspected and passed on to the next station. They are now ready for the application of gold on the fingers, if required. There are three alternatives to this process offered. One is to apply a nickel-gold immersion process, which applies a nickel barrier over with the copper and then a very thin, i.e., five microinch, immersion flash gold over the nickel. This process provides excellent solderability and can be assembled in line with a process very similar to the solder product. Most PCBs produced have a tin-lead or solder finish on the pads and in the holes. In this case a horizontal conveyorized hot air solder level machine is used. The boards are run through a pre-clean process. Oil and flux are applied and the boards processed through a solder wave.

5.10 GOLD-NICKEL PLATING PROCESS

5.10.1 Strip Solder, Plate Gold (Sample Inspection): The gold is tab plated on a Microplate line[14]. The gold plate process is an in-line conveyorized system that will strip off the solder from hot air solder leveler to expose the copper on the tabs, plate nickel over the copper, and then plate the gold over the nickel to the thickness specified by the customer. After the gold plating, the boards are then sent to the rout department for final board profiling. Nickel-gold is a significant alternative finish. Nickel-gold coatings may be electrolytically plated as an etch-resist.

5.11 MACHINE PROCESS

5.11.1 Route and Bevel, Wash (Sample Inspection): In the Route Department, the tool program is brought in from the product engineering team. The program is automatically loaded into the rout controllers. These machines rout the panels out to the required dimensions, at the same time putting in any type of slots, shapes, palletizing, or other shaping that is required. This is also the department where scoring[15], if required, is performed. Other required profiling, whether it is beveling, slotting, etc., is performed before the boards are passed on to the electrical test section. For most parts, the functions of the surface finish are to prevent copper oxidation, facilitate solderability, and prevent defects during the assembly process.

5.11.2 Electrical Test (100%): This ensures continuity around the holes and surface mount pads. In the ET area the testing is performed in two different ways. For those jobs that are quick turns, or jobs with small quantities, the boards are put on one of the two Probots, which are fixtureless testers. The Probots use flying heads to test out the circuits and to ensure continuity between all test points. The advantage of using the Probot is to eliminate the time and expense of making a test fixture.

5.11.3 100% Inspection, Audit, Lot Conformation, Report, Ship: Final Inspection visually inspects the boards but, more importantly, insures that the product meets all of the customer's specifications. The board is dimensionally checked, visually inspected, and reviewed for cosmetic purposes, and double-checked to make sure that the boards meet the requirements of the customer. The boards are then bagged in the final inspection area and forwarded to shipping, which will box them according to customer requirements, and ship them by the method specified.

5.12 DEFINITION OF VARIABLES

The validity of a performance measure approach is reflected by the ability to select the critical input and output variables which affect the performance of the processes and it is also important that there is an opportunity for improvement of those inputs and outputs. The following are the input and output variables identified for the research. The data had been collected for a two-year period (23 months). The first year has been divided into twelve months and the second year into eleven.

5.12.1 Input Variables

Two input variables were defined for the model; direct labor hours and raw materials costs. They are discussed in detail in the following sections.

5.12.1.1 Direct Labor Hours

Direct labor hours was obtained from an excel spreadsheet maintained by the firms safety department to track accident rates as part of the occupational safety and health administration requirements (OSHA reporting system). Direct labor is monthly for a period from September 94 through July 96 for all the processes. All the labor hours are

converted into cost inputs (labor hours converted into costs at approximately $10/hour). The data are expressed in fiscal months.

5.12.1.2. Material Inputs Costs

The material inputs are from the accounting system. The materials management systems data was not used. The materials management system is primarily designed as an order point inventory system. Materials are tracked as they are transferred to production units and as they are received. For monthly materials the cost accounting system provides the best and most accessible data.

The inputs include the cost of all the materials required for processing at a particular process. The materials common to most of the processes are the panels, plates, acids and other chemicals.

There are other inputs for which data was available, but were excluded from the analysis. These are the overhead costs which include equipment costs, quality costs, engineering costs, maintenance costs. Since the time period considered was only for two years, these costs are assumed to be constant over this period.

In any efficiency analysis, there is always the issue of defining the inputs and outputs, which correctly define the system under study. Only those input and output variables are considered which have a scope for improvement and yet adequately represent the system. In the present analysis, the inputs like equipment costs, engineering costs and quality costs were assumed to be fixed and there is very little scope of improvement. Also since the time period of the analysis is only for a period of two years, these costs can be safely excluded from the analysis. Including the overhead costs and other related costs would be much beyond the scope of this research.

5.12.2 Output Variable

Only one output variable exists for the model and it is the number of boards coming out of each of the processes. The output variable is discussed in the following section.

5.12.2.1 Number of Boards

Data was available on the number of boards which were run, the number of boards reworked and the number of boards scrapped. For this analysis, the output

variable, which is the total number of boards is the total quantity of boards run minus the total quantity scrapped (includes the total quantity of boards reworked). This was obtained from the Quality Control Department. Data related to the production targets of the plant and the individual processes were also obtained from the production-planning department. These targets are used in determining the performance of the individual processes and also to assess the contribution of the individual processes to the overall plant targets. The weekly targets have been aggregated to monthly targets for the two-year period.