Applying Intel's Copy Exactly Methodology to Standardize Ford Electronics SMD Board Assembly Processes

by

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Ford Electronic Operations has currently transitioned only about 40% of their electronics packaging technology from through-hole technology to surface mount device technology. Unfortunately, as each of Ford's seven Electronics plants have deployed SMD equipment at different times there tend to be many different line designs and equipment platforms installed at Ford. The resulting proliferation of processes has made it extremely difficult to re-source product from plant to plant because each plant is either using different equipment or two plants are running the same equipment in radically different manners. Little knowledge-sharing is occurring among the plants. Furthermore, much of the SMD equipment installed has quickly become obsolete only to be replaced with each new product program. Over the next few years Ford plans to add capacity for much of its remaining through-hole technology. Senior Management has commissioned a team to investigate how to obtain better process standardization throughout Ford SMD assembly operations.

This thesis reviews the progress the SMD Process Commonization team has made towards increasing the level of standardization within Ford Electronics Operations. Specifically, it discusses the results of a study of 6 of the 7 plants, the initiation of a technical forum, and a benchmarking study of Intel. The thesis outlines how Ford — upon recommendation of the SMD Process Commonization Team — adopted a new approach to managing its process technology based on Intel's Copy Exactly process. It also reviews the preliminary results of this new process. In the first three months of implementation the new Copy Exactly Teams have identified over $4.5 million in savings opportunities within Ford Electronics. Finally, the thesis offers recommendations on how to make sure that this implementation continues smoothly.

Thesis Advisors:
Professor John Kassakian, Electrical Engineering and Computer Science
Professor Charlie Fine, Sloan School of Management

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1. Introduction and Overview

1.1 Introduction

Ford Electronic Operations (ELO) has currently transitioned only about 40% of their electronics packaging technology from through-hole technology to surface mount device technology (SMD). Unfortunately, as each of Ford's seven Electronics plants have deployed SMD equipment at different times there tend to be many different line designs and equipment platforms installed at Ford. The resulting proliferation of processes has made it extremely difficult to re-source product from plant to plant because each plant is either using different equipment or two plants are running the same equipment in radically different manners. Little knowledge-sharing is occurring among the plants. Furthermore, much of the SMD equipment installed has quickly become obsolete only to be replaced with each new product program. Over the next few years Ford plans to add capacity for much of its remaining through-hole technology. Senior Management has commissioned a team to investigate how to obtain better process standardization throughout Ford SMD assembly operations. This team is known as the SMD Process Commonization Team.

Past efforts to increase the level of process commonality between Ford's plants have resulted in struggles between plants and central manufacturing engineering. Each plant currently operates relatively independently as they select equipment to install in their plants. Few mechanisms are in place to allow different plant engineers to share ideas about new equipment. A reorganization of advanced manufacturing engineering and significant staff turnover have helped foster this situation — since plants often do not know whom to call in the central organization. Furthermore, different manufacturing engineering structures in each of the plants inhibits central manufacturing engineering's ability to be more proactive in contacting the plants.

Short term actions to increase communication among all SMD organizations will help remedy some of these impediments while longer-term strategies for evolving more common processes must be enacted. In the short-term, technical forums, video and audio conferences, and personnel movement across plants may help facilitate more common solutions to technical problems confronted by each plant. In the long-term Ford must reexamine the manner in which it manages process technology across its seven plants.

This thesis will review the progress the SMD Process Commonization team has made towards increasing the level of standardization within Ford Electronics Operations. It will review how Ford — upon recommendation of the SMD Process Commonization Team — adopted a new approach to managing its process technology based on Intel's Copy Exactly process. It will also review the preliminary results of this new process which to-date has identified over $4.5 million in savings opportunities within Ford Electronics. Finally, the thesis will offer recommendations on how to make sure that this implementation continues smoothly.

1.2 Data Collection

The author served full-time on the Process Commonization Team during his internship June to December 1996. The author participated in all of the team meetings held during this time. As part of his work on this team, the author conducted site visits to six of the seven plants as well as met with representatives from Ford's three major equipment vendors. During these visits, interviews were conducted with the plant engineers and management as well as floor operators. All visits also included a videoconference with other members of the Process Commonization Team in order to assure that all perspectives were covered. In total over 50 interviews of staff, plant engineers and management served as the basis for much of the conclusions.

1.3 Overview of Thesis

Chapter 2 begins by providing relevant background material on the automotive electronics industry in general. Next an overview is provided of the key technologies involved in SMD board assembly.

Chapter 3 begins by providing an overview of the advanced manufacturing organizations which directly support Ford Electronics Operations. Next, an overview is provided of the seven plants and their advanced manufacturing engineering organizations. Finally, Ford's preferred SMD placement equipment vendors are profiled.

Chapter 4 reviews the process which the commonization team followed in its efforts to increase SMD assembly commonality within Ford Electronics. It provides backgrounds and objectives for the major groups which formed as a result of these efforts including the process commonization team itself. It also describes an SMD Technical Forum which was formed to help begin to build commonality.

Chapter 5 describes the current state of process commonization within Ford Electronics. It outlines the diversity of processes within Ford both in terms of the different equipment they use and the different line configurations. The chapter then describes the different factors which helped contribute to the current proliferation of processes.

Chapter 6 provides an overview of the Copy Exactly program at Intel as well as provides an overview of the Copy Exactly organization which the team recommended Ford put in place. It describes the benefits/risks of these systems and the organization structure required to support them. The chapter concludes by giving an overview of where Ford's implementation of Copy Exactly currently stands.

Chapter 7 offers recommendations on the implementation of Copy Exactly at Ford Electronics.

2. Automotive Electronics & Surface Mount Technology

2.1 Automotive Electronics Industry

Before investigating Ford's specific problem, it is instructive to take a step back and examine the automotive electronics industry in general. As Fig. 1 shows, automotive electronics is a rapidly growing industry. Dataquest estimates that by the year 2000 the global market for automotive electronics will have reached $57 billion up from $36 billion in 1994. As electronic technology becomes increasingly powerful and affordable it is likely that an endless variety of products will be added to cars. Examples of electronics abound: keyless entry systems, passive anti-theft systems, anti-lock brake systems, airbags, navigation systems, sophisticated engine control modules, sensors to improve environmental performance, etc. In short, increasingly electronics are being used to strategically differentiate automobiles.

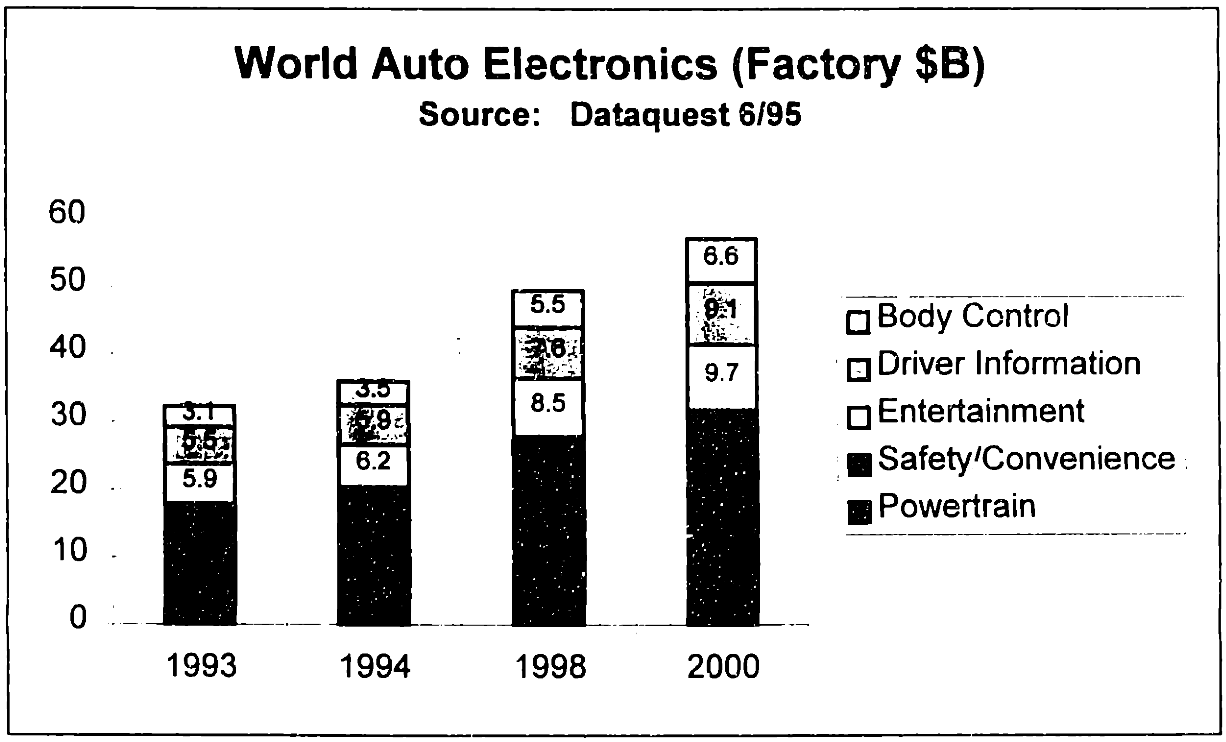

Figure 1--Projected Worldwide Automotive Electronics Market

Figure 2 illustrates the typical breakdown by application of automotive electronics costs in a mid-range sedan sold in North America. It is interesting to see that these total costs will likely begin to drop over the coming years. Though new electronic features will continue to be added to vehicles, many of these will come about as the prices for the other electronics components fall. Nonetheless, as we saw above, the automotive electronics industry as a whole is expected to continue to grow. This growth will be driven both by the growth of the world automotive market (projected to grow at about 2.9% for the rest of the decade) (Prismark Partners LLC, 1996) and the spread of electronics from high-end American cars to all segments of cars throughout the world.

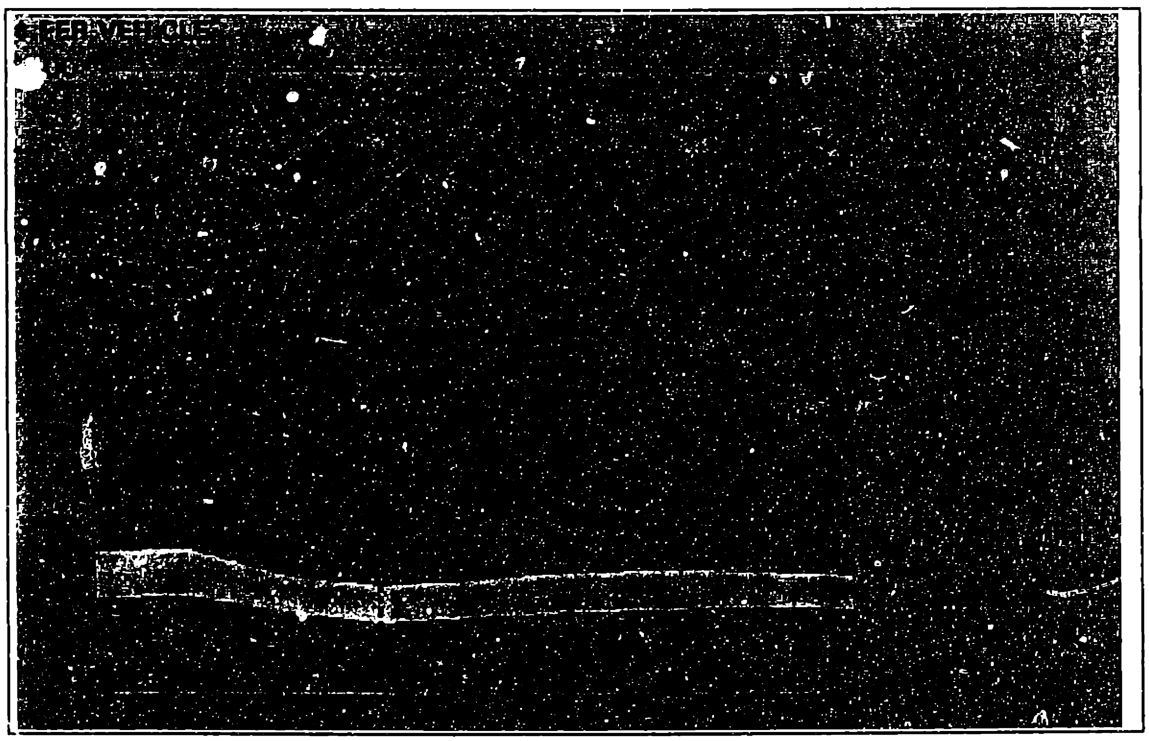

Figure 2—Forecasted Mid-Range North American Sedan (e.g. Taurus) Electronic Content by Application (from "Automotive Electronics: Is It Really a Growth Market?", Prismark Partners LLC, 1996)

In general the themes affecting the evolution of the automotive electronics industry are the same as those affecting the entire electronics industry: miniaturization, increased functionality, integration, customization and reduced cost. As more and more transistors are etched into silicon, electronic packages are becoming increasingly small. This smaller size not only makes it possible to add electronics in places never before considered (in the driver and passenger seats, for example) but also reduces the weight of these packages. More transistors (and the availability of low-cost, sophisticated processors developed for the computer industry) greatly increases the functionality of any given processor. Increasingly functions which were distributed throughout a vehicle are being integrated into a single module. Electronics are being customized to each individual's unique tastes (either through increased product variety or software). All these factors — as well as the economies of scale driven by the size of the electronics industry — result in lower cost electronics.

It is important to keep in mind that automotive electronics is still a relatively small segment of the global electronic industry. As Fig. 3 shows, the total amount of electronics consumed by automotive applications was just 2% of all electronics in 1993.

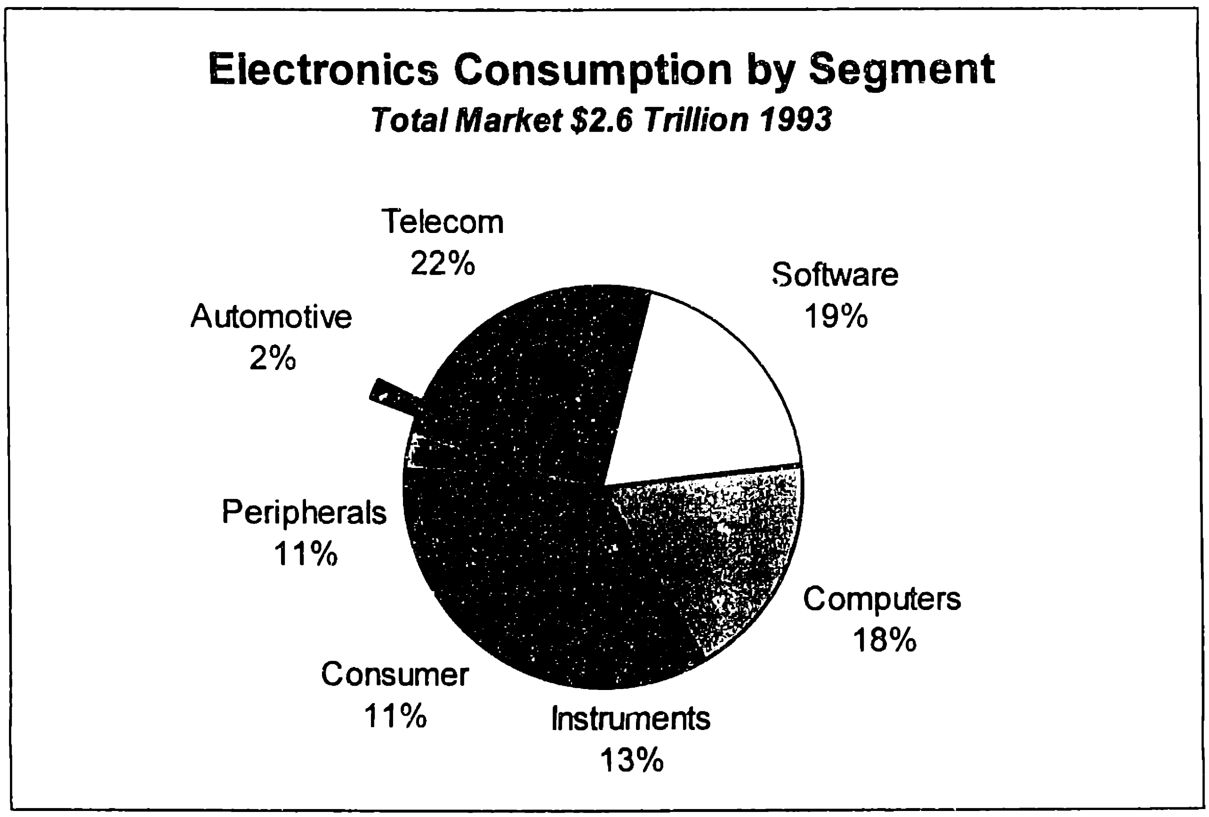

Figure 3--Automotive Electronics as Percentage of Electronics Industry (from Forbes, April 11, 1994, p.41 from American Electronics Association)

As Fig. 4 shows, in 1995 just 3% of all semiconductors made it into automotive electronics applications (Hansen Report, October 1996) down from 5% in 1993 (USA Today, October 20, 1993). These percentages change when considering just the US market; for example, 12% of all PWBs produced in the US go into automotive applications (1995 Electronic Market Data Book). Furthermore, since the automotive industry is significantly more concentrated than the other industry segments, individual automotive electronic suppliers still can exert some leverage over the rest of the electronics industry.

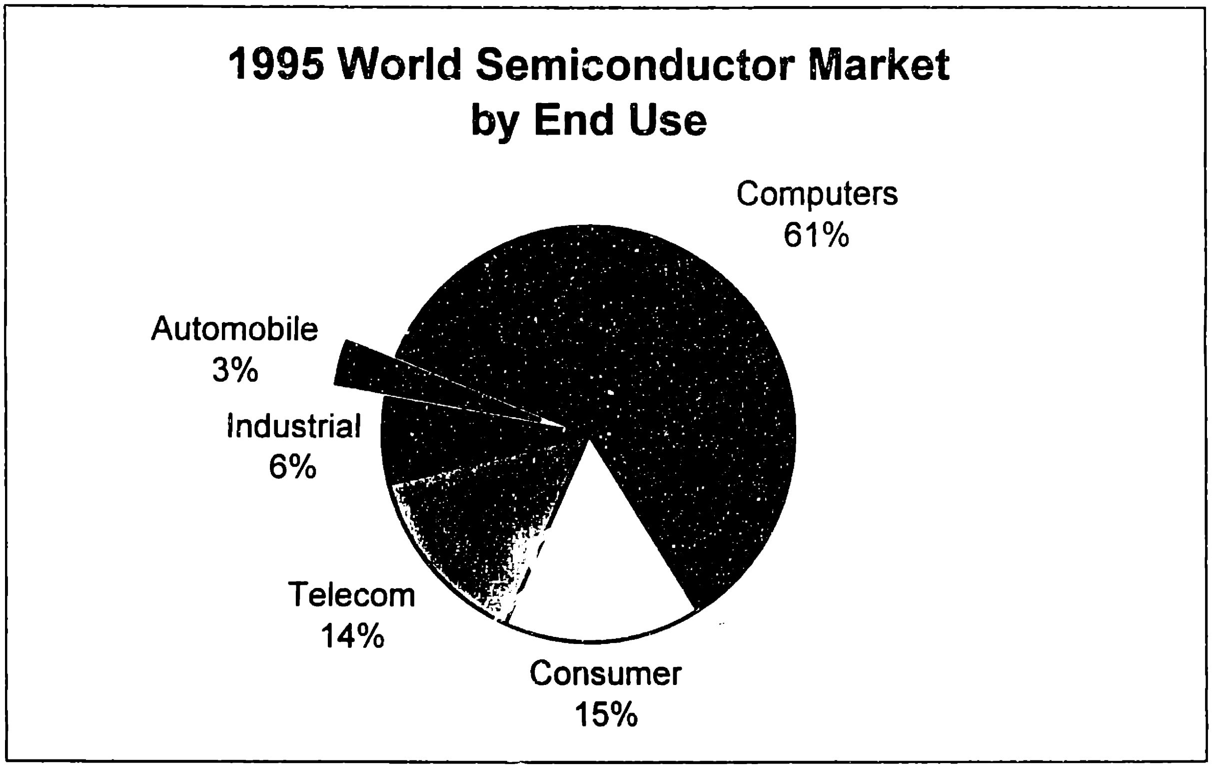

Figure 4—World Semiconductor Usage (Hansen Report on Automotive Electronics, October 1996 from Semico Research of Phoenix, Arizona)

2.2 Surface Mount Technology

Smaller, more powerful components, combined with demands for increasingly shorter connections have driven substantial changes in the electronics packaging industry. The insertion of wire terminated components into holes in printed boards (through-hole) is giving way to the attachment of components directly onto the surface of the board (surface-mount technology). Surface mount technology results in packages which not only weigh less and run faster but are more reliable and have lower cost than through-hole applications. (Wassink et. al. 1995)

According to a recent survey of 20 large electronics OEMs (with annual revenue of $500 million to $8 billion) there will be a significant transition to SMD throughout the decade. (SMTA Newsletter July 1996). The computer/communications industry segment has led the transition to surface mount technology with approximately 85% of all their boards using SMD components in 1995. Other industries such as instrumentation/controls have lagged in the implementation of surface mount technology (only approximately 45% of all instrumentation/controls board assembled in 1995 use surface mount) but these segments are expected to transition to surface mount by the year 2000 (e.g. instrumentation/controls is expected to have over 63% of the boards using surface mount in the year 2000) (SMTA Newsletter July 1996). Ford Electronics will experience a similar transition to surface mount technology by the year 2000.

2.2.1 Typical SMD Board Assembly Process

Though the concept of attaching active (e.g. integrated circuits) and passive (e.g. capacitors and resistors) components directly onto a board is quite easy to grasp, there are a bewildering number of technologies which make this possible. Figure 5 illustrates the main process steps in a "traditional" double-sided surface mount packaging line (Rua, 1996). Boards are automatically loaded onto a line and fed into a stencil printer where solder paste is applied to contact pads on the top of the board. The boards are then transferred into a component placement machine where components are placed onto the solder paste. The solder is then reflowed after which the board is flipped in order to place components onto the bottom of the board. Adhesive is dispensed onto bottom portions of the board in order to hold the SMD components in place as they are wave-soldered. Components are placed onto the adhesive which is then cured. With the components firmly in place, the boards are then flipped again and flux is applied in order to clean the board. The board is then sent through a wave-solder machine to finish the attachment of the now-upside-down bottom components. The boards are then inspected and tested and finally unloaded from the line. Each of these process steps are outlined in greater detail below.

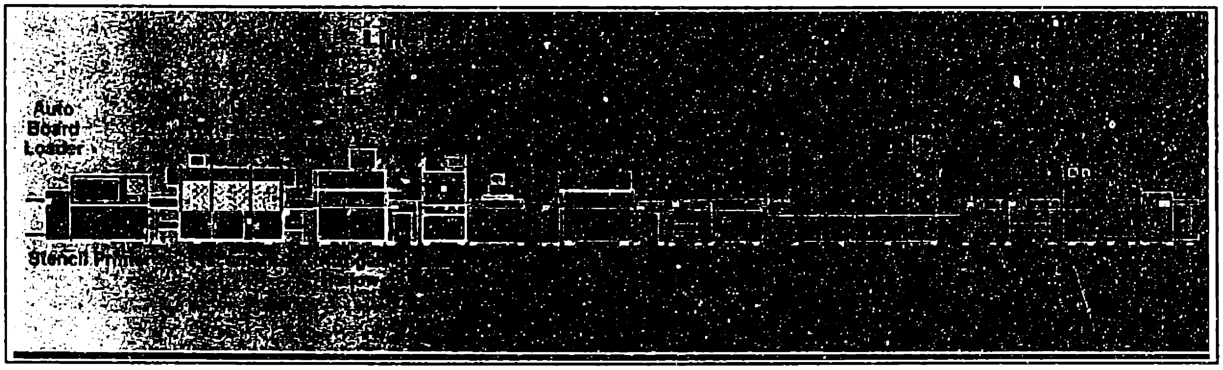

Figure 5--Typical Process Steps in a double-sided SMD assembly line (from Rua in Electronic Packaging and Production, February 1996)

2.2.1.1 Automatic Board Unloading (Board Technology)

The first step in the surface mount process is the unloading of the bare boards from a stack of boards in a board loading magazine generally using an automatic board unloader. Though the example illustrated in Fig. 5 uses a .062 in thick double-sided FR-4 glass epoxy board (substrate), there are two other main types of boards which can be used: FR-2 (phenolic paper) and FR-3 (epoxy paper). By the year 2000 most applications are expected to use FR-4 boards or other new specialized board materials, though currently FR2 and FR3 boards are still commonly used. The primary advantage of FR4 boards are that they allow for finer lines (the paths in the board which define the circuit by connecting the components—these lines can be etched in several different layers of the board) and can be used with a greater variety of soldering processes. Boards also vary based on the number of layers in which the paths reside.

In addition to the thickness and composition of the board, the length and width of the board also varies according to the application needs. By using an adjustable conveyance system along with bar code labeling of boards, boards of differing dimensions can be loaded and run on the same line with minimal change over time required. This, of course, can lead to greater production flexibility and thus greater product variety. Conveyance systems can impose constraints on the design of boards. For example, a certain clearance must be left between where components are placed and the edge of the board so as to assure that components are not in contact with the conveyor rail during transport.

2.2.1.2 Application of Solder Paste (Stencil Printing) and Laser Inspection

After the board is loaded onto the line it is transferred into a stencil printer where solder paste is applied. Solder paste is required to attach components to a board when the attachment technique is reflow soldering (an alternative attachment technique, wave soldering, will be illustrated later). Alternative methods of applying pastes besides stencil printing are dispensing and screen-printing. Stencil printing has advantages over dispensing and screen-printing in that it can apply much finer lines of solder paste. In fact stencil printing has replaced screen-printing in most applications. In applications where fine lines are not required dispensing is often used since it is highly flexible (the application pattern can be changed without incurring much change over costs).

In stencil printing, a stencil (a piece of metal manufactured by either etching, laser cutting or electroforming) with holes outlining the areas where solder is to be applied is laid over the board. Solder paste is then applied by moving a squeegee across the surface of the stencil forcing solder paste into the holes and thus onto the board. The stencil is then removed from the board, leaving paste on the board where the holes in the stencil were.

Solder application is a critical process: over half of all total failures can be attributed to this step. In order to reduce the level of defects introduced through soldering, in our example, an automatic laser inspection station measures the height of solder immediately after solder application. The measured height is compared to the height limits specified by the user and appropriate alarms are tripped if the solder is shown to be out-of-specification.

2.2.1.3 Component Placement

After the solder is placed onto the board, the board is transferred into the component placement operation where various components are placed onto the solder. There are currently two main categories of components which are placed on the board: passive components and active components. The dimensions of the passive components continue to decrease (currently the most popular passive component package is the 0805 which is 2mm by 1.25mm, though this is quickly giving way to the 0603 package which is 1.6mm by 0.8mm). In addition to the decreasing size of passive components, active components are increasing the number and density of pins (leads) which are used to connect to the printed board. In general the speed of the placement varies based on the size/pitch of the component. The finer the pitch (the distance between the leads of an active component) the longer it generally takes to place the component (the most accurate placements require vision alignment systems to assure accurate placement). Wassink et. al. identified five major categories of placement machines as outlined in Fig. 6.

Type	Output (SMDs / hour)	Smallest Lead Pitch (mm)
Entry Level Placers	< 4,000	.65
Medium Speed Placers	< 8,000	.5
High Speed Placers	< 16,000	.5
Very High Speed Placers	< 60,000	.5
High Performance Placers	< 4,000	.3

Figure 6--Categories of SMD Placement Equipment (from Wassink et. al., 1995)

In each of these machine categories, boards are fed into the placement machine and then positioned under the component placement head using either position pins (pins beneath the board locate the board), edge clamps (clamps locate the board), or global fiducial alignment (visioning systems look for markers on the board in order to precisely align the board beneath the heads). Components are fed to the placement heads using one of five types of feeding mechanisms: tape feeder, bulk feeder, stick feeder, tray feeder, and bare die feeder. (Wassink et. al. 1995) The placement equipment vendors use various feeder/position mechanisms. Many companies (Ford included) then try to optimize the component placement rates by improving the machine's positioning or feeding methods or both. There are several different optimization software packages available and some companies have realized significant productivity gains by optimizing the placement programs.

2.2.1.4 Nitrogen Reflow Soldering

Once the components have been placed on the board, the board is moved to the nitrogen reflow operation. There are three alternative soldering techniques currently used to attach components: reflow, wave, and laser. Each of these have distinct process sequences. The process illustrated in Fig. 5 outlines the reflow and wave techniques which we describe in detail. Reflow soldering entails moving the board through a hot-air convection soldering oven which has different temperature zones. As the solder paste is heated it melts and surface tension causes it to spread around the component. Once the board is cooled the component is soldered to the board. Specific defects which might occur when reflow soldering include: bridges (solder connects two separate component lands), solder balls, dislocation (component is rotated around its two lands), and tombstoning (component rests on only one land, the other end is elevated).

Recently ovens have been equipped so that the heating process takes place in the presence of an inert-gas such as nitrogen (as is the case in our example). This prevents oxidation from taking place during the soldering process. Debate currently exists as to whether reflowing in the presence of inert-gases truly shows substantial quality improvements over reflowing in air, however. (Wassink et. al. 1995)

2.2.1.5 Flipping, Dispensing, Component Placement & Curing

Once the components on the top-side of the board have been reflow-soldered, the board is flipped so the bottom-side components can be placed. In our example, the bottom side components will be wave-soldered (this is because the board also contains through-hole components) so an adhesive will first be dispensed. This adhesive is necessary to keep the components from falling off during wave soldering. Once the adhesive is applied the components are placed using a placement machine as described above. The board (with the components placed on the adhesive pads) is then transported to the cure oven where the adhesive is cured.

2.2.1.6 Flipping and Spray Fluxing

With the components now firmly attached, the boards are then flipped over again (wave soldering takes place with the components upside down). Flux is then sprayed onto the board to remove contaminants. In our example, the components are wave soldered in a nitrogen atmosphere so significantly less flux will be required than would be required in open-air wave soldering. Reducing the level of flux required is desirable. The residue which a flux leaves can contaminate the assembly; however, the traditional options of cleaning the boards using CFC based solvents are no longer allowed. Though HFC cleaning agents and water are still used in lieu of CFC-based, increasingly, cleaning of flux from the boards is eliminated all-together by using cleanliness tests or "no-clean" fluxes. Unclean boards are identified and scrapped or avoided altogether.

2.2.1.7 Wave Soldering

After flux is applied to the board, it is transferred to the nitrogen covered wave-solder oven where it is heated to about 250 degrees Celsius. Wave-soldering is used primarily for boards that have a relatively low component density and a coarse conductor pattern, however for fine-line assemblies reflow is preferred. (Wassink et. al., 1995) In general, wave soldering is become less and less prevalent. In our example, the nitrogen atmosphere significantly reduces the level of flux required and hence the level of potential contaminants. Typical defects which need to be avoided when wave soldering include: nonwetting (solder missing where needed), bridging (adjacent components connected), and excess solder.

2.2.1.8 Optical Inspection and In-line Testing and Magazine Unloading

After the board is wave-soldered it is passed to the automatic optical inspection station. Using sophisticated feature recognition software it scans the board for placement and solder joint defects. Defects are highlighted and if necessary the board is repaired or scrapped. Furthermore, quality information is fedback to the process (via a CIM system) so that the proper process adjustments can be made. After inspection, the board is put through electrical and functional tests with defects appropriately alarmed. Good boards are then passed onto the automatic board unloader where they are placed into magazines of 50 boards each.

2.3 Emerging Component Technologies

As the pitch between component leads become finer and finer (as a result of increased integrated circuit functionality) and as the need for faster boards increases, the need to find alternative connection techniques becomes apparent. Much work has been done in identifying different means of attaching bare IC dies (the IC without either its package or leads) directly to the substrate. *Chip on Board, Tape Automated Bonding*, and *Flip Chip* are different techniques of attaching a bare IC die directly to a substrate by utilizing wires, foils and/or bumps on the IC and board. Though *Ball Grid Arrays* do not attach a bare die directly to a substrate, they do have similarities to Flip Chips and hold promise for improved performance.

2.3.1 Wire Bonding/Chip on Board

The most popular technique used to connect a bare IC (die) to its package is wire-bonding. There are two main techniques used for wire-bonding: ball/wedge (Thermosonic/Metallurgy) and wedge/wedge (Ultrasonic). Ball/wedge bonds can generally be completed at a rate of about 7 bonds per second and utilize gold wires. Wedge/wedge bonds take about 3 bonds per second but can be done with silver wires at lower temperatures. (Wassink et. al., 1995)

Chip on board (COB) describes the process whereby a bare die is wire bonded directly to a board and then coated with a passivation resin. This leads to thinner/faster boards. Ultrasonic bonds of silver wires are generally used since gold wires would require high temperatures which current boards cannot accommodate. 3 bonds per second are generally possible. A major limitation on this technique is the availability of inexpensive, known-good-die (e.g. bare die which have been tested and proven good). (Wassink et. al., 1995)

2.3.2 Tape Automated Bonding, Flip-Chips and Ball Grid Arrays

In Tape Automated Bonding (TAB) an IC die with bumps on it is connected to a foil with conductive tracks on it which connect to the bumps on the IC. This IC/foil package is then connected to the printed board by "soft-soldering" the conductive tracks to the conductive pads on the board. TAB can accommodate pitches of about 75 μm. Flip-chip bonding eliminates the foil and attaches the bare, bumped IC die directly to the printed board via adhesives. Though flip-chip's elimination of the foil presents it with an advantage over the TAB technique, it also makes it difficult to test the IC prior to installing it on the board (the TAB die can be tested via the conductive tracks on the foil). Thus without known-good-die, Flip-Chips can result in significant scrap expense.

In a similar spirit of flip-chips, ball grid arrays (BGAs) are packaged ICs which have solder balls instead of leads as connections to the substrates. These solder balls allow for significantly lower pitches than traditional IC packages and also have the advantage of being able to be tested before being attached to the board. BGAs can be used with existing SMD equipment as well. There is, however, still questions concerning the reliability of the BGA package and, the BGA is still more limited than the flip-chip in terms of switching speed and electrical performance (inductance) since within the BGA package the IC is connected with wires. BGAs will likely represent an intermediate step between COB and Flip-Chip technology.

3. Ford Electronic Operations SMD Assembly Operations Overview

3.1 Organization of Advanced Manufacturing Engineering, Dearborn MI

Several engineering organizations are involved in the management of process technology at Ford. There are two main groups involved in developing and managing manufacturing technology within Ford Automotive Components Division. Advanced Components and Subsystem Integration (ACSIM, about 54 people) and Manufacturing Engineering and Process Support (MEPS, about 86 people). The parts which most directly support Electronics Board assembly are roughly organized as depicted in Fig. 7, representing about 20 and 60 engineers respectively. Both of these organizations are located centrally within Dearborn, MI; though they are in separate buildings.

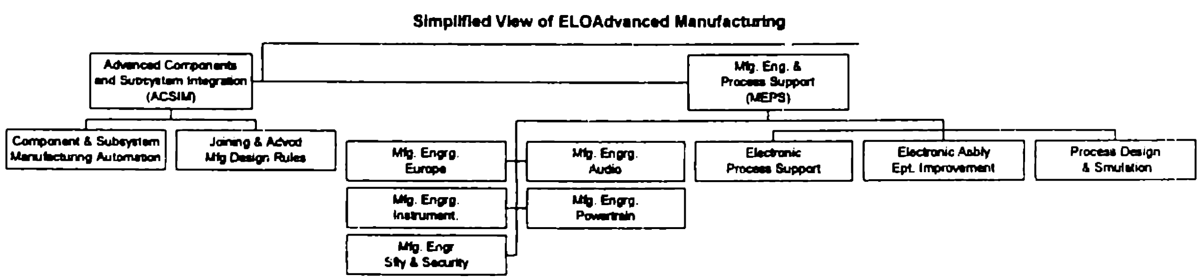

Figure 7 -- Advanced Manufacturing in ELO, Dearborn, MI

3.1.1 Advanced Components and Subsystem Integration and Manufacturing

The charters of these two organizations, ACSIM and MEPS, is subject to much debate but roughly broke down as follows. ACSIM is in charge of developing manufacturing technologies to support advanced (yet to be designed) products. Such products are expected to be launched within the next 5-10 years. ACSIM thus tends to interface with the equipment vendors on ideas that might be incorporated into future equipment designs (oftentimes working at the outer limits of the vendors' technology plans). ACSIM receives much of its funding through central "Factory of the Future"-type funding which allows it a degree of independence from Electronic Operations short-term needs.

3.1.2 Manufacturing Engineering and Process Support

MEPS is in charge of providing manufacturing input on new (but not as radically different as those supported by ACSIM—e.g., 1 to 2 years out) product designs, supporting manufacturing operations as needed, and helping develop standard manufacturing processes. In general, however, most continuous improvement activities are to be led by the individual plants. In addition to its support roles, MEPS plays a role in helping to evaluate significant investments. MEPS also attempts to help serve as a single Ford voice to the individual equipment vendors. By coordinating regular video conferences with the plants, MEPS equipment improvement section attempts to gather all of the plants' vendor concerns. In many cases, however, most vendors bypass MEPS entirely and interface directly with the individual plants.

3.1.3 Manufacturing Technology Development

MEPS and ACSIM were put in place as a result of the Ford 2000 initiatives launched in 1995 and thus are both relatively new. They represent a significant departure from the previous manufacturing engineering organization which was entitled Manufacturing Technology Development (MTD). The former MTD tended to be much more involved in the day-to-day activities of the plants; though it did do much advanced work as well. MTD also tended to have a greater influence on the directions the individual plants took in terms of equipment selection and design. MTD — augmented with some new simultaneous engineers — was basically split into ACSIM and MEPS with the former manager of MTD being named to head ACSIM.

3.2 Ford ELO Plants

Ford has 7 plants located in 7 countries. Figure 8 provides an overview of these facilities. The different assembly processes will be discussed later in the thesis.

Plant	**Floor Space** (sq. Ft.)	**Employees** (hourly and salary)	**Products** (representative)
Altec, Mexico	214,900	3843	Audio, Clusters, and Speed Controls
Cadiz, Spain	77,290	450	Engine Controls and ABS
Enfield, England	119,000	975	Clusters
Markham, Canada	224,370	1844	Clusters, Airbags, PATS
North Penn, PA, USA	404,000	1966	Engine Controls, ABS, and Sensors,
Palmela, Portugal	153,000	1543	Clusters, PATS, Audio, and Airbags
SAEO, Brazil	209,000	3316	Audio, and old engine controls

Figure 8--Ford ELO Plants with SMD Capability

3.3 Plant Advanced Manufacturing Engineering Organizations

The advanced manufacturing engineering organizations in the plants vary significantly in terms of size, organization structure, and skills. Advanced Manufacturing Engineering in some plants such as Cadiz is very decentralized. In Cadiz, there are manufacturing engineers assigned to a specific process within the plant. Not only are these manufacturing engineers responsible for supporting daily production requirements, they are also heavily involved in selecting and installing all new SMD equipment, making visits to the vendors as required.

In other plants, such as North Penn, Advanced Manufacturing Engineering tends to be centralized under one manager. The centralization of Advanced Manufacturing Engineering at North Penn, in fact, represented a conscious attempt to increase the level of common processes within the plant. Before centralization each area had its own group of advanced SMD engineers. This soon resulted in many different line configurations, however and thus a central SMD group was formed.

In addition to the organizational structural differences in plant Advanced Manufacturing Engineering, the different plant groups also have different philosophies in terms of specialization versus generalization of the engineers. At Markham, the advanced manufacturing engineering manager emphasized that his organization was staffed with technology generalists. He stated that this allowed him greater flexibility when designing and installing lines. He contrasted this with the North Penn philosophy of having specialists in a given technology (e.g. Fine Pitch, Vision, etc.).

As hinted above, the plants tend to draw distinctions between current manufacturing engineering and advanced manufacturing engineering. Current manufacturing engineers are concerned with supporting and helping to optimize production. Advanced Manufacturing Engineers help design, integrate and install new lines. In practice this line is extremely blurred, however. This blurring, while at times frustrating to the manufacturing engineers, is in general viewed as good as it helps assure that the new lines are designed with consideration of lessons learned from current production. Some of the functions of an advanced manufacturing engineer include: selecting equipment, accepting equipment, designing lines, launching new products, optimizing production, improving operations, etc.

3.4 Interfaces Between Advanced Manufacturing Engineering Groups

There were several factors which impeded the ability of the various ELO Advanced Manufacturing Engineering groups to communicate effectively with each other. This section briefly describes these impediments. The SMD assembly areas of both ACSIM and MEPS have experienced significant personnel turnover during their relatively short lives. Most of ACSIM's manufacturing and automation staff have been in the group for less than a year. Both the manager of MEPS and the MEPS process development supervisor have changed within the last year. Most of the SMD assembly related positions within MEPS electronics process support are still in the process of being filled. Some members of the ACSIM staff complained that they were being asked to stretch too far technologically. Others stated that although they greatly value the opportunity to push the technology (ACSIM staff earned numerous patents each year) they wish they could spend more time seeing their work actually implemented.

Partially as a result of the turnover and their new charters, MEPS and ACSIM have very loose communication links with the plant advanced manufacturing engineering staffs. Indeed many plant representatives expressed concern that they did not know whom to call in either of these two organizations nor did they understand the role of these organizations (except for MEPS which many of them claimed simply was there to serve as a roadblock to their efforts). Some of the plants said they missed the support they used to receive from the old MTD organization, though, others tempered this by saying that at least now they have a bit more freedom to innovate.

3.5 Preferred SMD Placement Equipment Vendors

Ford has selected three main vendors for SMD placement machines. All new equipment is purchased from these three vendors, though both Ford central staff and the individual plants continue to scan other vendors to make sure that no innovation calls for a revision of this strategy. These vendors are based out of Europe, Japan and the USA. All offer both top and bottom side placement equipment; though they do tend to have a core competence in one of the following: fine pitch, wide-range, or chip shooting. Ford interfaces with these vendors through both its central staff and directly through the individual plants. Though conscious efforts have been made to try to assure common world-wide pricing and service, significant discrepancies do exist. It is not uncommon for the different plants to make different demands on these vendors, nor is it uncommon for the vendors to offer different prices/services to the different plants.

Vendor A
Ford had previously had a very close-knit relationship with this Japanese-based vendor, though various factors have degraded this relationship. Among these factors are a move on Ford's part to develop domestic vendors, a bad relationship between Vendor A and North Penn due to a difficult equipment launch, as well as a perception of Vendor A charging higher prices. In general though, Vendor A provides the best global support and has a very cost-competitive wide-range placement machine.

Vendor B
Ford had originally made an effort to name European-based, Vendor B as its sole SMD placement equipment supplier. However, major problems with its early generation of placement equipment resulted in a quick diversification away from Vendor B. Later generations of the placement equipment repaired this problem, though Vendor B still has a reputation for releasing equipment before it is ready to be marketed. Vendor B is recognized as providing the highest speed chip shooting equipment on the market, though the equipment is often criticized for being difficult to change over and relatively expensive. Vendor B also offers fine-pitch and wide-range placement machines, though Ford evaluations have not shown these to provide any substantial advantages over other vendors' offerings. Vendor B receives mixed reviews for its service.

Vendor C
Vendor C is a US based vendor with a tight relationship with the Markham plant. Vendor C offers what most tests have shown to be the best fine-pitch placement machines on the market, though some of vendor A's equipment has matched Vendor C's equipment in recent evaluations. Vendor C has the weaker international support than the other three, though, most plants use their equipment. Vendor C also supplies wide-range placement equipment mostly through technology it gained from a Japanese partner.

3.6 Installed SMD Placement Equipment

Most of the plants have equipment from all of the vendors, though they each have relatively clear preferences towards a given vendor. For example, as can be seen in Fig. 9, Markham has none of Vendor A's equipment installed in its plant, while neither Cadiz nor Palmela have any of Vendor C's equipment. The reasons for these variations (and the degree to which a new organizational process can help eliminate) will be examined throughout this thesis.

	Vendor A	Vendor B	Vendor C	Other
Altec	25.53%	70.28%	4.19%	0.00%
SAEO	17.61%	74.06%	8.33%	0.00%
NPEF	32.38%	67.26%	0.36%	0.00%
Markham	0.00%	54.49%	19.95%	25.56%
Cadiz	40.22%	59.78%	0.00%	0.00%
Palmela	52.83%	47.17%	0.00%	0.00%
Enfield	0.00%	0.00%	100.00%	0.00%

Figure 9 -- SMD placement equipment in use in ELO Plants

4. Methodology

In early 1996 senior management had expressed concern that there was an increasing lack of commonality in ELO assembly operations. A lack of equipment commonality had been cited as a cause of redundant product engineering and manufacturing engineering. It also reduced ELO's ability to move product from plant to plant. Furthermore, recent investments in SMD capacity had resulted in significant struggles between ELO staff and plant staff. As a result of these concerns, a team was formed to look into different opportunities to standardize ELO assembly operations. This chapter describes the approach used by this team.

Shiba et. al. describe a 7-Step improvement process which organizations can use to improve a weak process such as that encountered by this team. Though adapted to Ford's specific environment, the team used an approach that corresponded very closely to this 7-Step Process. The 7-steps of this improvement process are: "(1) Select theme; (2) collect and analyze data; (3) analyze causes; (4) plan and implement solution; (5) evaluate effects; (6) standardize solution; and (7) reflect on process and the next problem." (Shiba et. al. 1993) This chapter will use these 7-steps to frame the main activities of the team.

4.1 Select Theme: SMD Identified as a Core Process Technology to Commonize

The first step in the improvement process is to identify the theme around which the improvement effort is to be focused. For Ford this theme came about as a result of discussions in the spring 1996 plant managers meetings. This section describes this theme selection.

The plant managers meetings are quarterly gatherings of all of ELO's plant managers held to review strategy as well as progress towards goals. In the spring 1996 meeting several staff representatives reported on the potential benefits which could be achieved by commonizing manufacturing processes throughout ELO. Specific benefits listed included: increased product sourcing flexibility, improved product and manufacturing engineering efficiencies, greater supplier leverage, faster product launches, improved product quality, and greater sharing of best practices.

All plant managers agreed that an initiative should be launched to identify possible areas where commonization could be achieved. In order to make this task more manageable they identified several core process technologies which should be investigated. They then designated a lead plant for each. These technologies and the lead plants are listed in Fig. 10.

Technology	**Lead Plant**
SMD/Screen Printing/Reflow	North Penn
Wave Solder	Plant A
Wirebonding	Plant B
Plastic Molding	Plant C
Gauge Winding	Plant D
Lamination	Plant B
Tuner Alignment	Plant F
Testing	Plant A
Dispense/Sealant	Plant B
Automated Assembly/Integration	Plant E
Vision	Plant G
Low-cost Assembly	Plant A
CIM	Plant E
Barcode	Plant F

Figure 10--Core ELO process technologies to be investigated and lead plant as identified in spring 1996

Although this list of core technologies was quite long, many believed that of all the items, SMD placement was one of the most absolutely critical because it both represented a substantial portion of the division's total capital expenditures and it had a significant impact on final product quality. The reasons why North Penn was chosen as the lead plant were not explicitly stated at the meeting. However, the North Penn plant had by far the greatest investment in SMD technology and was therefore very anxious to influence the direction the division took. It also had a strong advanced manufacturing engineering organization which was extremely experienced in working with SMD technology. The following subsection describes the SMD Commonization Team which was formed as a result of the spring plant manager's meeting.

4.1.1 SMD Commonization Team

As a result of the findings in the spring plant manager's meeting, a team of staff and plant management and engineers from North Penn (lead plant for SMD) was formed. This team met in early summer in order to develop a work-plan and begin sketching opportunities for improvement. Since SMD technology was so critical, this team was expected to proceed ahead of the other teams which were formed to address the other core technologies. It was hoped that the other teams would benefit from the process which the SMD team would develop in its attempt to increase process commonization within SMD.

The team's draft roles and responsibilities were: to develop a technology application strategy; define a roadmap for technology development; pilot and deploy new technology (if new technology is required); develop equipment rules (to guide financial approval and purchasing); and work with co-champion and plants to achieve buy-in/consensus, while refining (but not diluting) strategy and rules.

The team's first meeting was held at North Penn. The core members of the team included: the manager of advanced manufacturing engineering at North Penn; the supervisor of the electronic process support section within MEPS; the supervisor of process design and simulation section within MEPS; as well as several supporting engineers as required. The author was also a supporting member of this team. The team had the full support of the North Penn plant manager who asked to be updated at the end of the 2 day meeting. The team established several objectives which it referred to as its roadmap. These objectives are outlined in Fig. 11.

- Develop a best in class equipment supplier matrix and refine with all plants giving input.
- Characterize current processes in use throughout the division....determine best practices for each process and commonize throughout the division. Create a common SMD process and design guideline between all plants
- Perform a benchmarking analysis to determine Best in World processes and practices.
- Establish an SMD Process Forum and meet semi-annually to improve communication and lead strategic decision-making tasks. Key engineers from each plant must attend and create a unified voice to suppliers.
- Influence purchasing to negotiate volume purchasing agreements, blanket-orders and consignment spare parts.
- Develop a Ford-internal SMD Assembly WWW home page
- Develop process to evaluate new equipment and share this information with the other plant SMD process leaders. Adopt new equipment when appropriate.
- Revise design rule team process to keep product design rules up-to-date.
- Track future component trends
- Develop high speed/medium flexibility and medium speed/high flexibility line configurations with SMD Forum input
- Develop a board optimization programming system that will allow different machine vendors to be integrated and programmed in the same line with a single SMD optimization software package.

Figure 11--SMD Core Team Objectives

It was clear that these objectives were quite encompassing and therefore would take some time to implement. However, the team established some near-term priorities:

- to evaluate the current state of the SMD assembly processes within the division
- to form an SMD Technical Forum
- to benchmark best in world approaches to standardization and
- to recommend a new process for the management of SMD process technology.

The team would then report progress on these goals at the Fall 1996 plant manager's meeting.

4.2 Collect and Analyze Data and Analyze Causes: Analysis of ELO SMD Assembly

One of the first objectives of the team was to assess the level of process commonality in SMD placement as well as identify some of the relevant factors which led to any lack of commonality. It was agreed that each site would be visited. An inventory would be taken of all processes within the division and comparisons would be made. Also, relevant plant manufacturing engineering management would be interviewed in order to determine what type of equipment they would likely purchase if a new investment were made and why. These results would be summarized at a technical forum which was to be held in early fall. The results of these interviews are reviewed in Chapter 5, Current State Analysis. These visits would also serve as an opportunity for the plants to become more acquainted with the commonization team and their objectives. It was additionally agreed that it was important to benchmark a company which was consider to have a 'best in class' process to achieve process standardization.

The next two subsections will describe the SMD Technical Forum as well as preview the Intel Benchmarking Visits (some of the findings of which are summarized in Chapter 6). These two events occurred during the "collect and analyze data and analyze cause" phase of the SMD Commonization Team's efforts.

4.2.1 SMD Technical Forum

There was much debate as to the purpose of the SMD Technical Forum. Some team members wished this to be an opportunity to share best practices and develop an SMD community. Other members of the team thought that it would be best to drive this team towards immediate consensus on a standard equipment platform. It was agreed that the first meeting of the forum would focus on team-building and technical sharing. The team would then establish a work plan to move towards consensus on commonality; but it was agreed that little consensus would be achieved without the full support of each of the plants' local management.

The forum was held at the North Penn plant in early Fall 1996. About 2-5 representatives (principally advanced engineering supervisors and engineers) attended from each ELO plant as well as several experts from ELO staff. Each plant presented an overview of their operations and hosted a technical session to provide an overview of their work in areas which may be of interest to other plants. Additionally, purchasing was involved in this forum and a strategy was drafted to help provide a unified voice to each of the equipment vendors.

At the end of the meeting the team had reached consensus on objectives for the SMD Technical Forum. These objectives are listed in Fig. 12. They will serve as a guide for all future Forums.

- Develop a strategy to implement common SMD processes to reduce manufacturing design and product development efforts. Develop 5 year roadmap to reflect component, product design and equipment trends.
- Share SMD knowledge, best practices, and technology among ELO plants/staff. Define Best in Class processes and operating practices.
- Define process for best line configurations/rules and simulation packages.
- Define common design rules (images & motherboards) across plants/staff.
- Serve as a unified Ford voice to vendors.
- Define roles and responsibilities of plants, champion and all staff organizations
- Define a process for new products & technology (equipment, components, and material) validation and share with/transfer to other plants.
- Identify Best in Class Equipment/Suppliers
  - ◊ Define a process for new technology/equipment validation
  - ◊ Consider local service and issues
- Share training & implementation plans.
- Investigate opportunities for better data management & optimization.
- Enhance communication between manufacturing and Dearborn (design, manufacturing staff, component engineering.)

Figure 12--Objectives Defined for SMD Technical Forum

Action items were assigned for each of these objectives. The action items were reviewed with the team members and buy-in was received. The next Forum was scheduled for the first half of 1997.

4.2.2 Intel Benchmarking

A benchmarking trip was undertaken to Intel which was considered best in the world in terms of process standardization. This visit was conducted by senior members of the commonization team as well as the North Penn plant manager. The visit suggested not only that ELO was significantly less common than the best in the world, but also outlined an approach ELO could adopt for its own use as it attempted to standardize. An overview of some of the conclusions from these visits is included in Chapter 6.

4.3 Plan and Implement Solution: Summarize Results and Develop New Organization Structure

After the plant visits, benchmarking trip, and technical forum the leaders of the SMD commonization team reported the results to senior management at the fall 1996 Plant Managers meeting. During this meeting they outlined a new approach which would help lead to increased standardization of SMD technology. Commitment was obtained by all present (including all plant managers) to implement these recommendations. Consistent with the approach observed during the benchmarking trip a team of SMD advanced manufacturing engineers was formed to institutionalize commonality throughout the division. These new organizational structures are discussed in detail in Chapter 6.

4.4 Standardize Solutions and Reflect on Process: Evaluate Success of Teams and Replicate

The progress of these teams will be monitored throughout 1997. If successful it is expected that this new approach will be extended to all other core technologies with Final Assembly and Test targeted for 4^{th} Quarter 1997. As is discussed in Chapter 7, to-date the new process has led to the identification of $4.5 million worth of savings opportunities.

5. Current State Analysis

5.1 ELO SMD Assembly Process Description

There are three basic means by which processes can differ: different equipment, different line configurations, and different operations. Figure 9 shows the degree to which the placement equipment preferences vary within ELO. Clearly, the same equipment was not being used by all ELO SMD processes. However, even in those situations where similar equipment is used, there is still a substantial variation in the way these processes are designed and operated.

There are many different SMD assembly line designs in use throughout the Ford ELO plants. These range from continuous-flow processes as described in chapter 2 to extremely discontinuous batch operations.

Such diversity in line designs as well as equipment vendor types has led to a wide diversity of assembly processes within ELO. These processes vary both in terms of the range of component packages which can be placed (e.g. 0805 to 1206) and the rate at which these components are placed per hour. Figure 13 captures this great diversity. Each of these data points represents a manufacturing process within Ford ELO operations. For purposes of this figure a manufacturing process is defined as a set of equipment which can screen print (or place adhesive), populate and solder (or cure) either the top or bottom-side of a board. The capacities of these processes are defined as maximum number of components which can be placed in an hour by all the placement machines in this process.

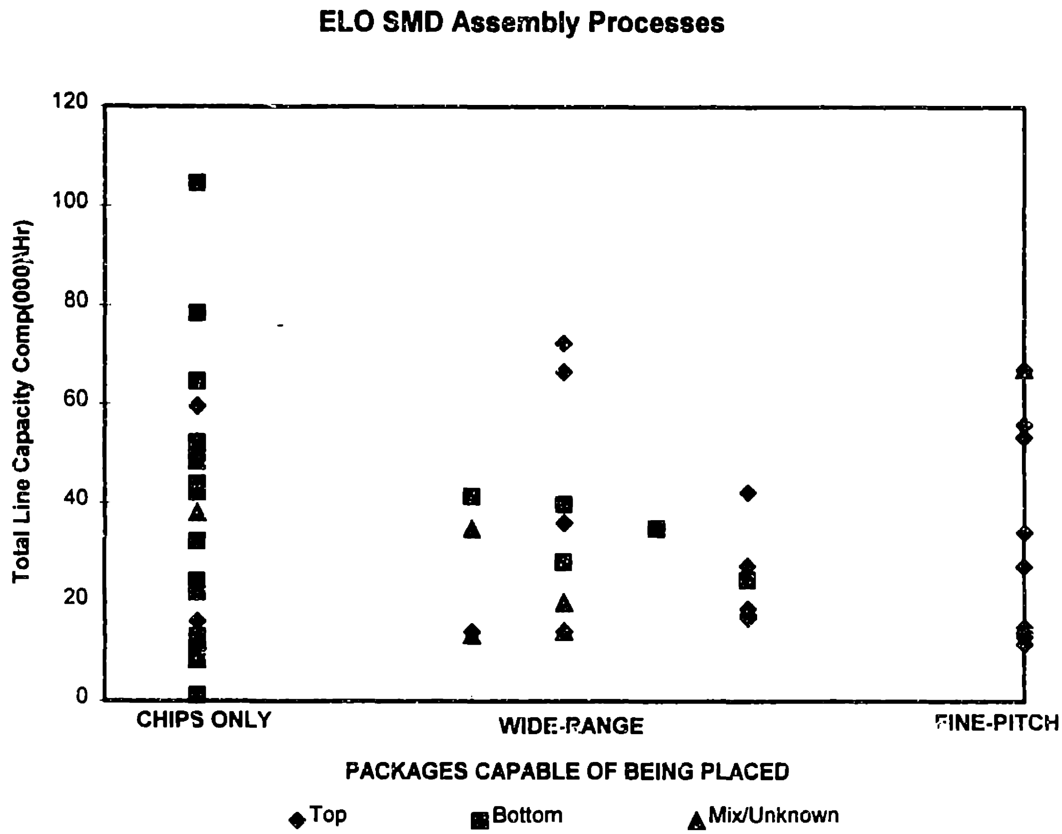

Figure 13--ELO SMD Assembly Processes

5.2 Local Factors Influencing Equipment Decisions

There are many factors which influence the design of an electronics assembly line. This section will briefly describe some of these factors which have led to the great diversity of processes within Ford Electronics Operations. It will also illustrate how these factors are interrelated.

<u>Installed Equipment Base</u>

The installed equipment base significantly influences future purchases. Moving to a new vendor may obsolete investments in spare parts, software, and training as well as introduce more uncertainty into a new equipment investment. Thus a plant may be extremely reluctant to try a new vendor. As Fig. 9 illustrates different plants have installed different equipment platforms. Though the desire to stick with a given vendor was displayed in many plants, as we will see below, having a significant vendor presence in a plant does not *necessarily* mean that this plant will prefer that vendor. If the plant had significant problems with this vendor, they might not want this vendor in their plant again. For example, though SAEO has almost 74% of their current installed capacity with Vendor B, in their most recent equipment investment they strongly preferred Vendor A over Vendor B.

Layout

Each plant varies considerably in terms of its layout philosophy. Some plants are organized according to product while others are organized in terms of technology. At Palmela for example, the SMD assembly areas are fully integrated with the rest of the through-hole component placement areas as well as final assembly areas. In Brazil, on the other hand, they are organized according to technology. There is a central SMD assembly area in Brazil where SMD components are placed on the top side of the board. The boards then are shipped to the through-hole component placement area, back into SMD assembly for bottom-side SMD component placement, into storage and then to the final assembly area. These different layout philosophies had significant impacts on the way each area was operated and also constrained the range of equipment which could be selected. In some cases, certain line configurations could simply not fit within the existing placement rooms due to prior decisions made related to plant layout.

Product Layout

As expected, organizing by product tends to result in lower work in process inventory because there are no buffers between process steps. On the other hand, equipment utilization tends to be lower in a product layout because buffers are not there to absorb variability. Furthermore, maintaining a steady proportion of top and bottom components is extremely critical when organized by product as opposed to technology. Any change in mix would result in an unbalanced line and thus cause under-utilization of either top or bottom placement capacity. Rather than continuously redesigning the lines some plants with product layouts simply shift partly populated boards between lines to try and balance across all the processes in their plant. This practice, however, is discouraged because of the threat it presents to quality as well as the increased amount of material handling required. Some plants with product layouts, therefore accept lower equipment utilization when the mix of top and bottom side components change.

Process/Technology Line Layout

As expected, those plants which have a centralized SMD area tend to have higher equipment utilization and increased flexibility. On the other hand, production scheduling (coordination between board assembly, through-hole component placement and final assembly) tends to be more complicated, inventory levels tend to be somewhat elevated and there tends to be more material handling demands when process/technology line layouts are used. Plants with central SMD areas (such as Brazil and Mexico) tend to prefer flexible equipment with shorter setup times. Integration with automation is not as critical.

Hybrid Layouts

Even in those plants which are organized by process technology, there is still some element of product orientation. Since volumes on some products are so high, some board assembly lines are de facto dedicated to a specific product. Markham tends to exploit these opportunities most dramatically, by having a central SMD area for some boards, while having SMD board assembly integrated with lines when volumes suggest it makes the most sense.

<u>Volume/Mix</u>

As expected, those plants with higher volume/lower mix tend to prefer equipment which has a higher placement rate, even at the expense of more difficult change overs. Those plants with a greater number of products, tend to prefer placement equipment with great flexibility. Furthermore, some plants which seem to be concerned about gaining future product, tend to prefer having flexible equipment installed in their plant so that they can be assured that they are able to build whatever new products might be introduced. In some cases, though, even if a plant has a couple of very high-volume products, they still prefer flexible equipment depending on their ability to perform change overs.

Varying Strategies when Plant was Launched

In some cases, there were different strategic influences when a plant was launched which affected the type of equipment selected. In some cases it was noted that plants were encouraged to use US vendors in order to help diversify the vendor base. In other cases, other vendors were temporarily "black-listed" due to significant quality/design flaws with their equipment. Vendor variety was also used as a hedging strategy to prevent a catastrophic equipment design flaw from crippling all plants. Other plants were encouraged to 'pilot' new technology to see whether it was production ready. Some plants were launched when having short manufacturing cycle times was viewed as most critical, others were launched when utilization of equipment was considered most critical.

Vendor Penetration into Region/Local Support

Vendors are perceived to support different regions differently. A given vendor might, because they have a heavy presence in a given region, be able to provide outstanding service to a plant while providing terrible service in other regions. Cadiz, for example, said that one of its equipment vendors frequently complained about the time it took for them to get to Cadiz to provide them with service. Brazil also said that all of the other electronic assembly plants in the area used Vendor A's equipment; while no one used Vendor B's equipment. As a result Vendor A's service personnel are well-trained, experienced experts. Vendor B outsources its service personnel in Brazil which tends to result in inexperienced personnel. Vendor C also has a minimal SMD placement presence in Brazil.

In addition, a vendor's geographic penetration also affects its responsiveness and its pricing. A vendor with a large presence in a region is able to provide spare parts much more quickly as well as accommodate rapid requests for new equipment purchases. In terms of pricing, examples were cited where a vendor with a dominant position might drive local prices extremely low so to completely eliminate the other vendor in this region.

A final example of a situation where a plant's location affects its vendor preferences is Markham's outstanding relationship with Vendor C due to the fact Vendor C is so nearby. Markham is in effect a test bed for Vendor C's latest technology. By having a large number of Vendor C's engineers in its plants Markham is able significantly to influence future equipment designs as well as quickly resolve any equipment issues. The relationship Markham developed with Vendor C was very consistent with that described in Hayes, Wheelwright, and Clark's book Competitive Manufacturing. At a trade-show, for example, the equipment Vendor C was demonstrating had been first used at Markham. Much of the performance data Vendor C used in its publication was collected by Markham. In turn, Vendor C was known to bend over backwards for Markham requests. Unfortunately, Vendor C does not have a strong global presence. The Mexico plant complained about the service it received from Vendor C.

Import Regulations/Incentives

Different customs regulations exist in each of the plants. Some countries for example have very generous training incentives while other countries have restrictive import regulations. If a plant is located in a country with generous training incentives, they tend to be more willing to experiment with newer, more sophisticated technology. Plants which are located in countries with very restrictive import regulations might try to avoid any equipment which had parts which needed to be imported regularly. For example, some of Vendor B's parts need to be rebuilt on a regular basis. Vendor B has not yet qualified any local repair facilities in Brazil; therefore, Brazil — which has very stringent custom regulations — has a turnaround cycle of several months on these parts. This causes Brazil to have to stock many more spare parts than would be expected and also adds greater risk to production since if the spare parts are exhausted the line could be down for a considerable amount of time waiting for new spare parts.

Local Operational Practices

In some plants the operators are multi-skilled. Preventive Maintenance is performed by the operators themselves as are change overs. Other plants have very restrictive rules or practices regarding who perform change overs, when maintenance is performed, etc. This affects the plants' preferences for the different equipment types. Some equipment requires more frequent maintenance as well as has more difficult change overs. Such equipment would tend to be avoided by those plants which do not have multi-skilled operators.

Level of Automation

Due to varying labor rates and skill sets, the plants tend to have different levels of automation. Some plants have automatic inspection systems, heavily integrated information systems, automatic adjusting conveyance systems, change over carts, and other highly automated equipment. These investments in automation affect future equipment decisions in many ways. Some investments lock a plant into a given equipment set due to software or conveyance incompatibilities. Other investments help reduce the effort required in a change over thereby reducing the value of flexibility. Highly automated inspection systems reduce the need for certain quality control systems. On the other hand, where little automation is present the plants could be less loyal to a given vendor and would certainly value equipment which is easier to change over.

6. Applying Intel's Copy Exactly in the Ford ELO SMD Environment

6.1 Introduction

In Fall of 1996 a team consisting of the senior members of the ELO SMD Process Commonization Team (North Penn Plant Manager, North Penn Manager of Advanced Manufacturing Engineering, and Supervisor Electronics Process Support) visited Intel to obtain a better understanding of their Copy Exactly (CE) process. The information gathered from this trip — as well as obtained through numerous other sources served as a framework for a new approach to commonization within Ford ELO. A brief overview of this process — including an application to the Ford environment —was provided to the ELO Plant Manager's meeting in Fall 1996. There was strong agreement amongst those present that Ford should adapt the Intel Copy Exactly approach to the Ford environment. The supervisor of MEPS Electronics Process Support — who had outlined this new approach — was tasked with putting a CE organization in place within Ford. After providing a brief introduction to the CE framework within Intel, this section describes Ford's adaptation of CE.

6.2 Intel Copy Exactly

Two LFM theses (Fears '94 and Mlynarczyk '95) provide an excellent overview of the Intel Copy Exactly (CE) process. This section will summarize some of these findings as well as suggest some possible applications to the Ford environment. The interested reader is strongly encouraged to review these theses for more depth on the CE process.

In the early 1990's Intel realized that one of their keys to competing successfully within the semiconductor industry was shortening the length of time it took them to get new product designs to market. Upon investigation of what was preventing them from getting new products to market quickly they identified the variation amongst their semiconductor fabs as a leading contributor. In order to reduce this variation, Intel management decided to build upon their existing culture of collaboration and introduce a new program called Copy Exactly.

Fears (Fears '94) describes Copy Exactly as follows:

"Once a process technology is developed and proven at the Technology Development Center it is proliferated to the chosen manufacturing sites. Due to the increasing cost and complexity of state of the art process technology, Intel believes that the quickest, most efficient, predictable and reliable method available to bring a new Fab on line is to copy the originating Fab in most every detail. This paradigm of technology transfer to establish a process (manufacturing) technology at a facility is called the Copy Exactly Program. The principle ideals of Copy Exactly are very simple and straightforward:

- Copy everything exactly from the originating site unless physically impossible to do so, impractical or there are overwhelming economic or competitive reasons not to copy.
- Every exception (item not copied exactly) requires a review and approval process (white paper and Process Change Control Board)
- All members of Fabs must work together to improve the process and systems before and after the transfer."

Mlynarczyk (Mlynarczyk '95) notes that CE can be used for more than just managing technology transfers from the development fabs to the production fabs: "The high demand for Intel's products has resulted in the need for multiple fabs that run the same process technology. As a new process technology is transferred to each site, the CE methodology is repeated, and any continuous improvements that are made at one site are proliferated to the other sites. As long as the sites stay matched over time, the result is a 'virtual factory' in which all sites run identically. Thus, CE is more than a strategy for technology transfer. It is a strategy for managing multi-site operations throughout the technology life-cycle."

6.2.1 What does Intel Copy?

Perhaps what is most striking about CE (especially compared to Ford's current state) is the level to which different lines in different plants are kept identical. The purpose of this section is to give the reader some idea of the level to which Intel maintains a truly 'virtual factory'.

Mlynarczyk (Mlynarczyk '95) describes the level to which Intel follows CE. For each piece of equipment which is to be installed in a new process, not only is the hardware matched identically across all plants, but also the software, the process recipes (machine settings), maintenance procedures/specifications, troubleshooting procedures, and purchase contracts for the equipment. This equipment is configured into identical lines as well. All lines in all sites for a given product are of identical lengths and configured identically using the same materials and instrumentation. All measurement equipment are identical. The raw materials used by the matched processes are identical (e.g. silicon wafers, gases, etc.). All SPC procedures are followed identically (same variables measured, same sampling plan, etc.). The automation is also copied as well, e.g., same station controller hardware/software. The general operations are mostly identical as well, e.g., WIP management strategy, and layout of equipment. (Mlynarczyk '95). Regular management audits of all sites ensure that this standardization continues throughout the life of the processes.

6.2.2 Organizational Structure to Support Copy Exactly

Mlynarczyk (Mlynarczyk '95) describes several groups which help to assure that Copy Exactly is being adhered to: Management Review Committee, Joint Management Teams, Change Control Board, Process Equipment and Installation Group, Technology Development Working Groups, and Process Equipment Development (Users Groups). As we will see in section 6.3 many of the Ford ELO structure can be adjusted so to correspond with these groups. First, however, this section will briefly describe these different organizational groups within Intel.

6.2.2.1 Management Review Committees

The Management Review Committee consists of all plant managers from each site. "This team is chartered with overseeing the technology transfer and subsequent synergy efforts.

It also acts as a review board for issues that cannot be resolved at the lower levels." (Mlynarczyk '95)

6.2.2.2 Joint Management Teams and Joint Engineering Teams

The Joint Management Teams consist of management level stakeholders from each site that share processes/products. "There are three Joint Management Teams: Joint Engineering Management; Joint Automation Management and Joint Operations Management". (Mlynarczyk '95) The Joint Management Teams attempt to develop consistent policies and procedures across all sites and also ensure adherence to CE by conducting audits of the different processes. The Joint Management Teams also manage several joint engineering, operations and automation teams. Joint Engineering, Operations, and Automation Teams are teams of engineers which cross all sites and which are tasked with initiating controlled continuous improvements which span all sites.

6.2.2.3 Change Control Boards

The Change Control Boards oversee all major changes which occur throughout the sites. There are several Change Control Boards which focus on such areas as facilities (e.g., building, subfab, and cleanroom), process (process and equipment), automation (e.g., hardware, software, and conveyances), and operations (e.g., inventory management).

In general, whenever a site desires to make a change to equipment, process or operations it must first be approved by the appropriate Joint Engineering Teams before even being submitted to the Change Control Boards. If approved by these Joint Engineering Teams, the reasons for the change must be documented in the form of a preliminary technical white-paper. This white-paper is then reviewed by the appropriate Change Control Board. If the Change Control Board approves the preliminary white-paper a test is run to evaluate whether the expected improvements occurred. The results of this evaluation are then summarized in a Final White-paper which is submitted to the appropriate Change Control Board for final approval. This white-paper includes the implementation plan to launch this change in all sites.

6.2.2.4 Other Groups in Support of Copy Exactly

The Process Equipment and Installation Group "is chartered with installing and qualifying equipment...[it] is a relatively new group enacted to hasten the installation/qualification process by having individuals build an expertise in this area." Technology Development Working Groups "interface with the equipment Joint Engineering Teams to review process or equipment changes and their effects on defect reduction." Process Equipment Development "acts as a liaison between and within technology generations. The group members also work with suppliers to standardize equipment sets and to facilitate equipment productivity improvement programs...PED executes its charter through a number of technical working groups and committees, which are staffed with its members and personnel from across Intel." (Mlynarczyk '95)

6.2.3 Benefits of Copy Exactly

Intel has experienced many benefits from following the CE strategy. Among the benefits most applicable to Ford are: improved time to market, greater best practices sharing, greater flexibility in product sourcing, elimination of duplication of engineering efforts, and increased supplier leverage. (Mlynarczyk '95)

<u>Improved Time to Market</u>

The benefit which first led Intel to pursue CE was the fact that new products can be transferred to a full production fab much faster under CE. By making sure that the process in the new fab site is identical with the development fab, time to market is greatly reduced. Numerous studies within Intel have shown that the ramp up time of new processes has indeed been considerably reduced thanks to CE. Within an increasingly short length of time, yield losses of the new process are reduced to the level of the development process resulting in not only quicker but also less costly production rampups.

Best Practices Sharing

Since all processes are identical, any learning which occurs at one site can be shared with all other sites. Though this learning is tightly controlled, an improvement can now be used to benefit the entire system. It is also now much easier to move engineers from plant to plant since processes are identical.

Flexibility in Product Sourcing

Since all processes are identical, products can be reallocated across multiple sites. This allows Intel to optimize across its entire production system rather than solely within one plant. Thus as demand shifts or material resources become more available in a given region the mix of products can be changed much more easily. Also, since all processes are identical, Intel does not need to requalify product when moved to a different site. Intel simply can qualify one line and know with confidence that all the other lines will produce the identical output.

Elimination of Duplication of Manufacturing Engineering Effort

Redundant Manufacturing Engineering efforts can be greatly eliminated since all processes are identical. A central group of experts can help with installation of equipment. Only one round of equipment selection and acceptance needs to take place. Manufacturing Engineers in different sites can agree to work on different problems and then proliferate the solutions to all sites rather than each site working on the same problems with different equipment.

Supplier Leverage

Since Intel now has much larger orders from a single vendor it has greater leverage in working with this vendor. This leverage can lead anywhere from bulk purchase discounts to actually being able to influence the vendors' future equipment design.

6.2.4 Costs and Risks of Copy Exactly

Intel had to overcome significant risks as well as incur some substantial costs in implementing CE. Among these were: Increased control overhead; obsolete equipment;

exposure to bad choices; substantial difficulty in implementing in existing sites; and cultural change. (Mlynarczyk '95)

<u>Increased control overhead</u>

As is evident from 6.2.2 there is a significant amount of organizational structure required to support CE. This not only requires significant management attention, but may also actually slow the pace at which innovations are implemented. In actuality, however, we will see in Ford's case much of this infrastructure exists. It simply needs to become better disciplined.

<u>Obsolete Equipment</u>

Since all equipment choices are made relatively early in a new product's life-cycle and this equipment is copied exactly within each plant, Intel may have to forego the opportunity to use the most up-to-date equipment within its fabrication plants. This cost, though at times significant, is often mitigated by the fact that by sticking with one particular equipment set for a long time, this equipment can be optimized to run much better. Often these customizations result in equipment which runs better than the next generation of a piece of equipment would run upon initial installation.

<u>Exposure to Bad Choices</u>

If a piece of equipment is selected (or operational practices implemented) which turns out to be a bad decision, this decision is no longer limited to a single plant. All plants/lines are exposed to this. As we saw in our discussion of Vendor A, Ford is particularly sensitive to this risk due to its negative experience with an early generation of Vendor A's equipment which was launched in several of Ford's plants, but proved to be very unreliable. However, this risk is mitigated by having all the division's engineers involved in the evaluation of a new piece of equipment and adhering to rigid evaluation standards.

<u>Difficulty in Implementing in Old Processes</u>

Intel has had most of its success in implementing CE in new processes. For processes which have already been launched, Intel has had difficulty enforcing CE. However, many benefits of the 'virtual factory' can still be experienced in sites which have already been launched as we will see below.

Significant Cultural Changes Required

It took several years for Intel to launch CE throughout its organization. Though Intel had a culture truly grounded on teamwork, cultural barriers still presented significant threats to the success of CE. Among these barriers were the reluctance of engineers to postpone making continuous improvements until proper signoff was obtained and a reluctance to share significant innovations with other sites.

6.3 Ford Implementation of Copy Exactly

As we saw in Chapter 5 there are many factors which have contributed to the substantial diversity of SMD assembly processes within Ford. Some of these factors are either extremely difficult if not impossible to change (e.g., government regulations), would take substantial amounts of investment to change (e.g., plant layouts) or would take a significant amount of time to change. Nonetheless, at Ford there are still substantial opportunities to reap the benefits of some level of process commonality within ELO SMD assembly operations. By increasing the amount of discipline in the organization, managing equipment vendors better, and increasing the amount of information sharing throughout the division, substantial opportunities exist. Many of the changes required will take some time to implement. However, by instituting processes and controls which are focused on common solutions, Ford can begin to reap the benefits much earlier than might be expected.

For this reason, at the fall Plant Manager's meeting, the supervisor of Electronic Process Support, along with the rest of the ELO SMD commonization team, was tasked with developing a proposal to implement CE within the Ford Electronics environment. This team not only received full support from the head of Electronics Operations but also received endorsement from each of the plant managers. The proposal to achieve commonization within Electronics would not only have to be realizable within the Ford environment but would need to show substantial results quickly. This section outlines this new organization and its objectives.

6.3.1 Overview

The supervisor of Electronic Process Support with the assistance of the ELO SMD process commonization team developed a proposal for a new organization within ELO entitled Manufacturing Improvement Engineering (MIE). This virtual group (consisting of engineers and managers in plant and staff advanced manufacturing engineering organizations) would serve as the umbrella for the CE-like organization within Ford ELO. The Mission Scope and Key Metrics for success of this organization are described in Fig. 14.

Mission:
- Resolve common customer problems with identical root cause & containment solutions across all plants.
- Establish a Common Operating System to achieve Commonization through process control and standardization.
- Join MEPS, ACSIM, Component Engineering, Product Engineering Operations, and the plants together to deploy new equipment and process capability, focusing on highest yield issues. Eliminate non-value add processes.

Scope:
- Top Customer Issues on all ELO Products
- Current Technology Issues (within next 3 years implementation)
- Process Change Control Management

Key Metrics for Success:
- 1st Pass Yield Improvement
- Customer PPM Reductions
- % Commonization Matching Status
- % Attendance at Meetings
- 100% Compliance During Line Audits to World Process Specifications
- # of Design Rule Violations on All Products
- Equipment Performance Efficiency

Figure 14--Mission, Scope, and Metrics for MIE

6.3.2 Ford's Copy Exactly Organization Structure

Ford's CE Organization is structured similarly to Intel's. Surprisingly, there were many structures in place which made an adoption of CE fairly straightforward (e.g., the quarterly plant managers meetings). What was most needed, however, was the institution of disciplines, focus and alignment of incentives. Three groups have been chartered: Management Review Committee; Manufacturing Improvement Engineering Core Team & Change Control Board; and Manufacturing Improvement Engineering Continuous Improvement Team. See Fig. 15 for an illustration of how these teams relate to each other. Each of these will be discussed in detail below.

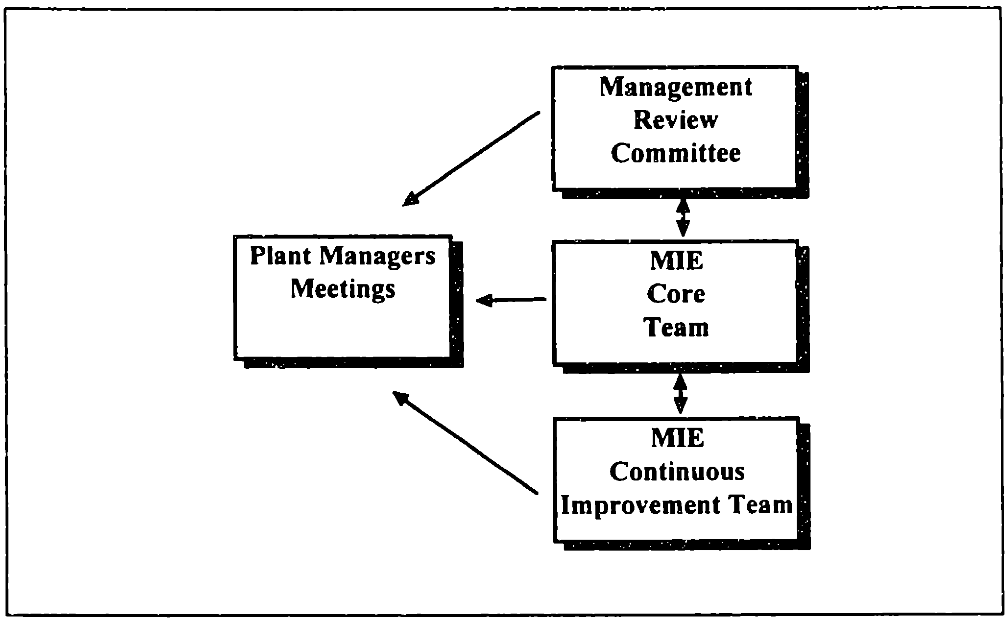

Figure 15--Manufacturing Improvement Engineering Organization Reporting Structure

6.3.2.1 Management Review Committee

The responsibilities of the Ford ELO Management Review Committee (MRC) are very similar to that of Intel's. The MRC develops and endorses the high-level technology roadmap for board assembly. They also review and signoff on new projects which were recommended by the MIE Core Team. This team meets once a quarter generally during the already scheduled Plant Manager's Meetings. The team consists of all the plant managers and Manufacturing Engineering staff managers. This team also involves component and product engineering as appropriate. In short, the management review committee is in charge of championing the CE process, evaluating progress in achieving CE objectives, lending support when major roadblocks occurred, and providing overall strategic guidance to ELO manufacturing operations.

6.3.2.2 Core Copy Exactly Team (Change Control Board)

The Ford ELO Core Copy Exactly team is very similar to Intel's Joint Management Team. Though, in addition to the Joint Management Team's tasks, Ford's Core CE team is in charge of putting the infrastructure in place to support CE. The team is composed of plant Advanced Manufacturing Engineering managers as well as the Electronics Process Support Manager. The supervisor of ACSIM as well as Component Engineering Manager participate as needed as well. In order to facilitate its role as a Change Control Board, each team will have a statistician in order to evaluate the Continuous Improvement team proposals.

The team meets via audio-conference twice a week. 100% attendance at meetings is expected. The team is tasked with reviewing all the technical findings of the Continuous Improvement Teams as well as evaluating all proposed changes. The team, in conjunction with the Management Review Committee, has the final say on all significant process changes. The Core Team is also responsible for developing the Technology Roadmap and New Process Development Plan for the division as well as assuring progress is made on the metrics.

6.3.2.3 Continuous Improvement Teams

The heart of the new Ford CE Organization are the Continuous Improvement Teams (CITs). The Continuous Improvement Teams are very similar to Intel's Joint Engineering Teams. These teams consist of the manufacturing engineers in each of the

ELO SMD Assembly Operations. In general, each Continuous Improvement Team member has their performance review written by a member of the Core Team.

Each team of engineers is organized according to a core process technology (such as SMD Placement). They hold weekly conference calls (100% attendance was expected) and likely meet face-to-face a couple times a year during the SMD Technical Forum. Just as the Joint Engineering Teams are at Intel, the CITs are in charge of identifying key areas to improve and proliferating these improvements throughout the ELO plants. Whenever a new piece of equipment is purchased or line designed, the CIT is to provide technical evaluation of the advantages/disadvantages to the Core Team so to inform their judgment. Each team is assigned a coach/mentor from the Core Team to assist them in overcoming any roadblocks. It is expected that any one engineer would participate in at most two continuous improvement teams at a time. Each engineer is expected to dedicate at least 20% of their time to the Continuous Improvement Team.

6.4 Status of Ford's Implementation of Copy Exactly—April 1997

Approval was obtained during a 1st Quarter 1997 plant manager's meeting to implement the organizational proposals for Copy Exactly of SMD technology. The Management Review Committee was formed during this meeting. After becoming educated on the Copy Exactly process the MRC expressed strong, enthusiastic support for the process and tasked the teams with achieving $20 million in savings during the first year of implementation. The Core Team was launched in January 1997 and has experienced over 90% participation rate in the weekly conference calls as of April 1997. Although this process is new, reactions of the participants are favorable.

Four Continuous Improvement Teams — crossing all the Ford ELO sites — have been launched as of April 1997. These teams have received significant management support. In just 3 months the teams have identified over $4.5 million worth of savings. To-date attendance at the weekly conference calls have been respectable, but there is room for improvement.

The first Management Review Committee met during the 1st Quarter 1997 plant manager's meeting. They have become better educated in the CE process and have expressed their enthusiastic support for the process. It is difficult to assess the effectiveness of the committee after the first meeting, but indications are it is too large (over 30 people), but very committed to the process.

There are plans in place to extend the scope of Copy Exactly into the product engineering community. Additionally, after success is proven out by the four initial teams, Copy Exactly will next be extended to cover Assembly and Test operations.

7. Recommendations

7.1 Introduction

In the three months since the initial implementation of Copy Exactly at Ford Electronics there have been encouraging results. The teams have met regularly and have already identified $4.5 million worth of savings opportunities. As the initiative moves forward significant changes will have to take place to assure continued success. This section will review some of the recommendations which I have made to Ford concerning how to assure that Copy Exactly is successful at Ford Electronics. These recommendations fall into the following categories: cultural changes; teamwork; scope; large-scale changes; and institutionalization.

7.2 Recommendations

7.2.1 Cultural Changes

The initial success of Copy Exactly has come about as a result of a culture within ELO which is already quite facile, with collaboration across continents. As the manufacturing engineers became better acquainted with each other through the Technical Forum, videoconferences, joint benchmarking trips, and regular audio conferences it became clear that increased collaboration would be very beneficial to their work as engineers. Furthermore, by having the plant managers place express commitment to process standardization and commonization they knew that they had full support from upper management for Copy Exactly. Additionally, by having MEPS very active in getting to know each plant, the feeling that staff was out of touch quickly diminished. In short, the manufacturing engineers in the plants and staff got to know each other.

However, as these changes begin to take root, significant cultural changes will have to take place to assure success. These changes will directly affect not only the manufacturing engineers and their managers but also the plant and division managers themselves. Not only will there be an increasing necessity for true teamwork (discussed below), but the very means by which decisions are made will need to change.

To-date most equipment investment decisions have resulted from political negotiations among the plants and various staffs. If engineering data were used it was mainly to support or strengthen a position. Staff would gather their data to support their arguments and the plants would gather their own data to support their argument. Oftentimes, these negotiations would take place under severe time pressure. (The plant might have submitted their proposal late intentionally so as not to tip their hand, or staff might have delayed looking into the decision because there were bigger fish to fry. In any event, many equipment decisions occur with the inevitability of a firm install date rapidly approaching.) In this context significant capital investments decisions tend to come about as the result of political negotiations rather than technical or financial evaluations.

Decision-making under Copy Exactly will fit more closely under a 'rational actor' model for decision-making. The teams of engineers will make technical evaluations. These evaluations will be summarized in technical white-papers which will be evaluated by management. There will be regularly scheduled processes put into place to support this analysis with clearly defined milestones. This will affect both the manufacturing engineer who will have to develop proposals to be evaluated by peers for technical merit and the managers themselves who will have to evaluate the technical white papers.

7.2.2 Teams & Incentives

Some of Intel's basic incentive systems are profoundly different than Ford's. Incentives for teamwork are instititutionalized at Intel. In many cases one's fellow team members can have direct input on one's performance review. Additionally, significant option plans and bonus plans reach to the lowest level in the organization thereby providing an incentive for all employees to consider how their actions will optimize the whole company as opposed to just their local group.

Ford Electronics will have to develop increasingly strong incentives for teamwork. For example, there may be cases where a plant will need to migrate to a new equipment vendor so that the division as a whole benefits. This may impose uneven costs to the division. For example, if the division were to standardize on Vendor C, clearly this would benefit Markham more than Brazil in the short term. Brazil will need incentives to incur this transition cost. These incentives could take the form of lower equipment cost due to volume discounts which may directly make up for this added burden. On the other hand, there may need to be some other forms of compensation — such as those used at Intel — as well.

The sourcing of products based on competitive bids is a factor which was cited in many cases as being counterproductive to collaboration. Though all engineers seemed very open to sharing at the technical forum, this environment seemed likely to change quickly if a major product was resourced from one plant to another based on cost advantages. The sourcing decisions must be explained to the plants as resulting from a sound manufacturing strategy. The teams must realize that it is in the divisions long-term interest to share innovations, not protect them so they hold cost advantages over the other plants. Plants should be penalized for protecting an innovation, not rewarded by having product relocated to their plant.

7.2.3 Scope

It will be critical to expand the scope of Copy Exactly to product engineering as soon as manufacturing becomes comfortable with this strategy. Central to Copy Exactly will be the identification of standard design rules for the different product families. Design rules will result as much from disciplined manufacturing engineers designing standard processes as from disciplined product engineers designing standard boards. Product Engineering will thus serve a critical role in Copy Exactly.

Intel has several groups involved in Copy Exactly in addition to the Joint Engineering and Management Teams after which Ford has modeled their Core Team and Continuous Improvement Teams. Specifically, Ford may consider strengthening the Equipment Improvement section within MEPS to become more like Intel's "Process Equipment

Development Group", so to work with the equipment vendors to make sure that their technology will reliably support the next generation of products. Ford may even consider centralizing the installation and qualification of their new SMD lines into a central group of experts like the "Process Equipment and Installation Group" at Intel. Inevitably as Copy Exactly takes root it will necessarily result in a tighter and tighter integration/consolidation of ACSIM and MEPS.

7.2.4 Large-scale Changes

As we have seen most of the early benefits of Copy Exactly will result from the Continuous Improvement Teams identifying cost-savings opportunities resulting from standardization. Eventually, however, increasing level of process standardization/matching will require significant infrastructure changes. It is doubtful that an economic case can be made to completely remove the entire installed base of placement equipment within Ford Electronics. This will mean that some level of process variety will remain as a legacy.

Nonetheless, as new processes are designed, they should be designed in accordance with standard line configurations developed in accordance with standard product design rules and Copied Exactly throughout the division. There should be significant work done in identifying these optimal standard line configurations. After these are identified this may require significant changes in the layout philosophy in some of the plants. For example, either the exact conditions which lead to a central SMD area as opposed to the integration of SMD into final assembly lines will need to be defined or either the central SMD design or the in-line design must be eliminated.

7.2.5 Institutionalization

In order to institutionalize Copy Exactly, the exact quantifiable benefits of Copy Exactly will need to be captured. It is critical that Ford begin measuring the effectiveness of Copy Exactly in this initial pilot stage. Assuming a successful implementation of Copy Exactly within Electronics, it is likely that Copy Exactly will need to be integrated into the Ford Production System so that other parts of Ford can benefit from this approach to process standardization. The

Ford Production System team should continue to be apprised of this experiment and plans should be put in place to align these two efforts.

7.3 Conclusions

By improving communication between plant and staff through plant visits and the SMD Technical Forum, the author was able to set the stage for an increased level of knowledge-sharing throughout ELO SMD Assembly. A benchmarking trip to Intel provided Ford with suggestions for formal mechanisms to both facilitate and formalize this knowledge-sharing as well as begin to evolve more standard operations. The benefits of these efforts are just beginning to be realized as is testified by the $4.5 million of savings which were identified during the first 4 months of implementation. Though several factors — e.g., greater product variety, less monopolistic environment, significant installed base of different equipment — make it unlikely that Ford ELO will reach the level of standardization enjoyed by Intel, this project has shown that there is a significant amount of savings which can be realized by adapting some of Intel's organizational processes and disciplines to the Ford environment.

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