Surface Mount Technology at Chromalox Instruments and Control Corporation

Concepts illustrated: Comparison of mutually exclusive alternatives, make versus buy decision, break–even analysis, and sensitivity analysis.

1. Background

Chromalox Instruments and Controls, located in LaVergne, Tennessee, is a manufacturer of industrial process controllers, monitors, and industrial and military control panels. Chromalox products are also used in a variety of industries in heating and cooling applications. While the sales level of industrial and military control panels has steadily increased over the past two years, the sales level of controllers has remained relatively flat and is forecasted to remain at this level for several years. The controller line is reasonably profitable; customers are willing to pay a premium for the consistent quality and sophisticated options not offered by the competition.

The smallest controller in the product line is the 1/4 DIN, which is designed to be installed into a 92 X 92 millimeter (mm) cutout. Management feels that Chromalox can increase sales by being one of the first manufacturers to introduce a 1/16 DIN controller. A 1/16 DIN controller is designed to be installed into a 48 x 48 mm panel cutout. Miniaturization has become increasingly popular in the electronics industry and customer demand for a smaller controller has been strong. To produce a significantly smaller product while maintaining the quality level desired, a surface mount technology (SMT) design must be utilized.

SMT is a printed circuit board (PCB) assembly process which uses components designed with soldering pads or short leads. SMT components are much smaller than traditional leaded components and are directly attached to the surface of a PCB rather than inserted into holes as leaded components are. This technology can reduce board size and thus the finished product size dramatically

The feasibility and profitability of undertaking this new design needs to be evaluated. The project will be evaluated based on purchasing the necessary equipment to provide in-house capability or by subcontracting the assembly.

2. Description of the 1/16 DIN Controller Manufacturing Process

All materials required to manufacture the controllers are purchased from outside vendors. Materials are received, inspected, and stocked (briefly) until needed for production. As jobs requiring the materials are scheduled and released, the parts are prepared and moved to the printed circuit board assembly stage.

2.1 Circuit Board Assembly Process

Not all electronic devices are yet available in SMT packages, therefore, the printed circuit boards used in the 1/16 DIN controller will be a “mixed" technology consisting of both SMT and leaded components (Fig. 4.1).

Blank PCBs are placed into an automatic dispensing machine, which is programmed to dispense solder paste onto the top side of the PCB. The paste is applied in the same pattern as the leads of the component that will occupy that portion of the circuit board. The automatic dispensing machine is also programmed to dispense adhesive onto the top side of the circuit board. Adhesives are necessary to hold components in place during handling and reflow soldering.

The second step is surface mount component insertion. The board is loaded into an automatic component pick and place machine which is programmed to select surface mount components and place them onto the pads of solder paste on the top side of the board.

Boards are then processed through an infrared reflow (IR) oven. The oven is designed to elevate the component terminations to solder reflow temperature in a ramp-soak-spike profile. The ramp phase preheats the board to 130-150°C. The soak phase gradually stabilizes the board to 170°C. It is in the spike phase that the board is rapidly elevated to reflow temperature and the connection between component termination and circuitry is made. The final phase is cooling. This oven profile is the major factor in assuring reliable connections.

After the board is reflowed, it is turned over and again placed in the automatic dispensing machine which dispenses solder paste and adhesive to the bottom side of the circuit board. The board next moves for a second time to the automatic pick and place machine for surface mount component placement on the bottom side of the board.

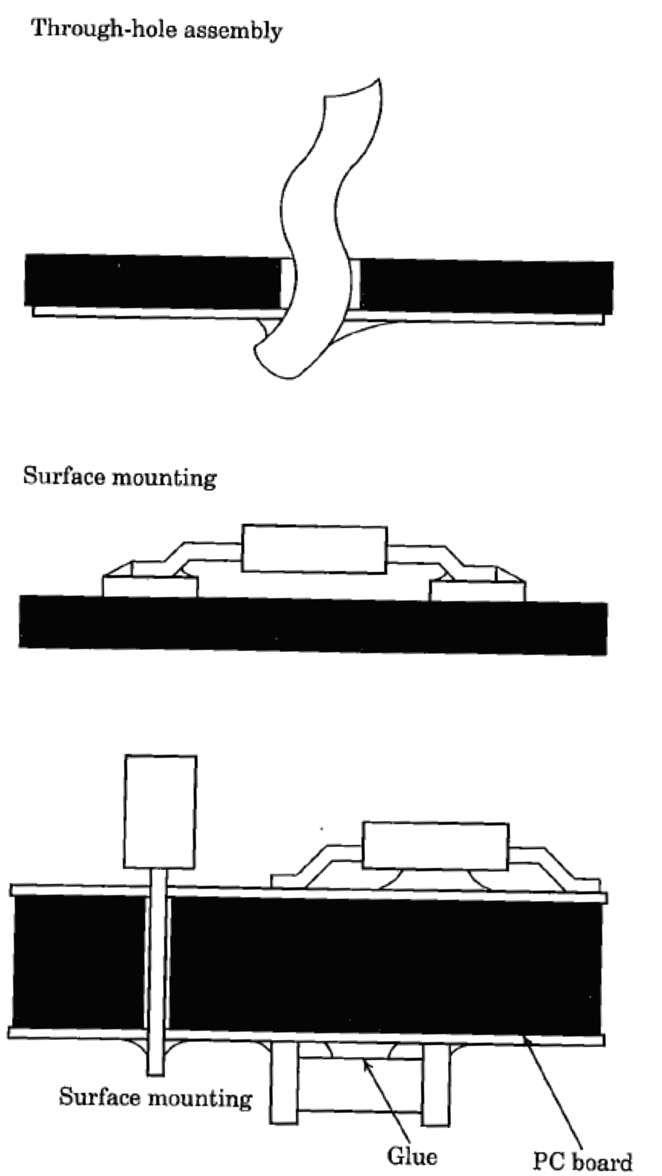
Leaded components are hand inserted through the top side of the circuit board at a Logpoint station. The Logpoint machines facilitate hand insertion by shining a fine light onto the holes of the board into which the components will be inserted. The lights will also indicate component polarity by flashing on and off in the positive location.

The final step in the circuit board assembly process is wave soldering. The wave-solder machine is a conveyor system programmed to preheat and elevate the board to approximately 95°C on the top side. The board travels across a pot of molten solder which is continually pumped and resembles a "wave." As the board passes across the solder wave, leaded components and bottom side surface mount components are bonded to the PCB.

2.2 Circuit Board Testing

Newly developed products are electrically and/or functionally tested by bench technicians after the preproduction run. This bench test allows data to be accumulated and any deficiencies to be corrected before the next production run. It is Chromalox's policy to have automated board testing installed prior to the first production run.

Figure 4.1 ■ Through-hole assembly surface mounting



2.3 Subassembly and Final Unit Test

Four circuit boards are required to manufacture the controller: a power supply card; a display card, which is the user interface; a microprocessor card, which is the "brains" of the unit; and a digital communications card that allows the controller to interface with personnel or microcomputers. These boards are assembled together by an operator via connectors, headers, or solder. The final test is performed at this point to ensure that the boards function as a unit and that all interconnections are properly made. The controller is then packaged and shipped.

3. Description of Investment Alternatives

In producing 1/16 DIN in-house, only the PCB assembly process is affected. The following two alternative assembly processes are being considered.

- Subcontract the circuit board assembly process to an assembly house. Chromalox would continue to purchase all materials, kit the materials for the jobs, and forward the kits to the subcontractor. The subcontractor would install surface mount and through-hole components to the boards and perform a visual inspection. Chromalox would continue to test electrically. Rework would be performed at Chromalox for minor repairs or at the subcontractor for major repairs.

- Purchase the equipment needed to perform the surface mount assembly process in-house. Chromalox would be able to utilize equipment currently available for the hand insertion, wave soldering, and board-level testing steps in the manufacturing process, assuming no capacity constraints. This equipment would need no additional maintenance or working capital but would require additional programming and setup.

3.1 Expected 1/16 DIN Controller Demand

During the first year of product introduction, sales of 2000 1/16 DIN controllers are forecasted. The marketing department estimates that sales levels in years 2-3 will be 3000 units and will likely remain at 4000 units per year for years 4-7. After 7 years, the product is expected to be replaced with a more advanced design. These estimates represent the base-case scenario with sales variations in either direction.

3.2 Capacity Constraint Evaluation

Currently all production occurs during first and second shift operations. The second shift comprises less than 10% of the total work force and presents an opportunity for expansion. The wave-solder machine, Logpoint machines, and automated test station are currently in use producing other products, so it must be determined whether the addition of the 1/16 DIN volume will cause a capacity constraint. All machines will be evaluated assuming maximum base-case sales of 4000 units per year. Recalling that each unit requires 4 PCBs, volume will be 16,000 boards.

3.2.1 Wave-Solder Machine Capacity Evaluation

Annual available wave-solder machine time is (250 days/year x 16 hours/day) 4000 hours. Current usage is confined to the first shift only for 4 hours per day, totaling 1000 hours per year. Maintenance is scheduled for 6 hours per week. It requires approximately 2 minutes (0.0333 hours) of wave-solder machine time to process one PCB assembly. Therefore, wave-solder machine usage for the 1/16 DIN will be (2 minutes/ board x 16,000 boards x 1 hour/60 minutes) 534 hours.

Wave-Solder Capacity

Total wave-solder capacity	4000 hours
Current usage	(1000) hours
Required maintenance time	(300) hours
Hours available for 1/16 DIN	2700 hours
1/16 DIN usage	(534) hours
Unused capacity:	
(2700 - 534)/4000	54%

3.2.2 Logpoint Capacity Evaluation

There are three Logpoint machines available for through hole component insertion. All machines can be run on both shifts for a total of (3 machines x 250 days x 16 hours/day) 12,000 hours. Programming is scheduled for 4 hours per week on one machine and data are transferred by diskette to the other two. Maintenance is 10 hours per month for all three machines. Total maintenance and programming time are [(10 hours/month * 12 months) + (4 hours/week * 50 weeks)] 320 hours.

Currently usage is 20 hours per day on the first shift and 12 hours per day on the second shift a total of 8000 hours per year. The SMT design boards will have a minimal amount of through hole components and will require less Logpoint time than a traditionally designed PCB. The estimated Logpoint time per mixed technology board is 2 minutes, approximately 50% less than a pure through hole board. Logpoint usage to support the 1/16 DIN is (2 minutes/board x 16,000 boards x 1 hour/60 minutes) 534 hours.

Logpoint Capacity

Total Logpoint machine	12,000 hours
Maintenance and programming	(320) hours
Current usage	(8000) hours
Hours available for 1/16 DIN	3680 hours
1/16 DIN usage	(534) hours
Unused capacity:	
(3680 - 534)/12,000	26%

3.2.3 Automated Test Equipment Capacity Evaluation

The automated test equipment (ATE) capacity can be operated on both shifts for a total of (250 days * 16 hours/day) 4000 hours. Programming and maintenance require 8 hours per week. Biannual calibration requires 32 hours. Calibration time is 32 minutes (0.533 hours) for each unit. The annual volume of boards currently tested on the ATE is 8000 boards.

ATE Capacity

Total ATE capacity	4000 hours
Maintenance and programming	(400) hours
Calibration	(32) hours
Current usage	
(8000 boards x 0.133 hours/hoard)	**(1064) hours**
Hours available for 1/16 DIN	2504 hours
1/16 DIN usage	
(4000 units X 0.533 hours/unit)	**2132 units**
Unused capacity:	
(2504 - 2132)/4000	9.3%

3.2.4 Capacity Evaluation New Equipment

According to the manufacturer's specifications, the component pick and place machine can process 2000 components per hour (approximately 20 boards); the dispensing system can process 12,000 applications per hour (approximately 30 boards); and the IR oven can process approximately 30 boards per hour. Annualized, this capacity will be more than sufficient to meet 1/16 DIN controller demand.

3.3 Cost Data

The capacity requirement analysis indicates that there would be enough capacity to assemble the 1/16 DIN in-house. Therefore, both in-house and subcontracting alternatives are technically feasible options. This prompted Chromalox engineers to look into cost aspects of each alternative.

3.3.1 Subcontractor Alternative

For the projected sales at the base-line scenario, the subcontractor will assemble 8000 boards in year 1, 12,000 boards in years 2-3 and, 16,000 boards per year in years 4-7.

In the electronics industry, 16,000 boards per year mixed among four designs is considered a small-volume production. Many assembly houses will not quote on such a small volume. In addition, the only feasible quote received was dependent on the subcontractor running all of the boards in one batch. Therefore, Chromalox would have to carry additional work in process as assembled PCBs. Additionally, a one-time set-up charge of $2500 (primarily tooling) would be incurred.

Baseline Scenario

Year End	*1I16 DIN Sales*	*Total Volume Of PCBs*	*Assembly Cost per Board*
1	2,000	8,000	$10
2	3,000	12,000	9
3	3,000	12,000	9
4-7	4,000	16,000	8.5

3.3.2 In-house Production Alternative

To assemble the 1/16 DIN in-house, Chromalox must purchase the SMT equipment package. The estimated equipment costs, which include both installation and set-up for each machine, are as follows.

Equipment	Description	Cost
Zevatech	Pick and place	$ 30,000
Cam/Alot	Solder paste & adhesive dispensing	30,000
Electrovert	Wave soldering	sunk
ABW	IR oven	35,000
SMT-10	SMT rework station	10,000
Summation	Automated testing station	sunk
Software	Programming ATE	10,000
	Total equipment cost	$115,000

Note that, for in-house production, there will be $10,000 in programming costs for automated test equipment (included in the above $115,000 figure). Chromalox views this programming activity as Part of the SMT installation, so the cost will be capitalized. Chromalox has already made investments in the wave-soldering machine and automated testing station for other assembly processes. Since the 1/16 DIN production takes advantage of the unused capacity of these machines, there is no opportunity cost. The above estimated costs include set-up and installation costs. Each machine is considered a 7-year MACRS property with no salvage value after the 7-year service life due to the rapid technology advances in this industry.

3.3.3 Sales Revenues and Material Costs

Chromalox expects to price the 1/16 DIN at $175 per unit during the first year. However, due to market competition, the future price would be slashed at an annual rate of 8% over the product life. This price reduction will decrease the profit margin over the years' but it allows Chromalox to maintain the sales volume at the level forecasted previously. Material costs are estimated at 30% of the sales dollar for the in-house production. However, for the subcontract option, the material costs will be much higher than those in-house, as many assembled parts are purchased from the subcontractor. As the sub-contractor's assembly cost per board decreases (due to automation) over the years, there will be a corresponding drop in material costs. Therefore, Chromalox estimates that the material cost will be 51.85% of the sales dollar during the first year, 49.57% during years 2 and 3, and 48.42% for the remaining years.

3.3.4 Operating and Indirect Costs

For in-house production, overhead costs are allocated at a rate of 24% of the sales dollar. For the subcontract situation, the overhead costs are decreased due to reduced assembly activities to 12% of the sales dollar. Labor for the 1/16 DIN is estimated to be 6% of sales for the in-house option and 3% of sales for the subcontracted option. Selling, administrative, and engineering costs will be 21% of the sales dollar produced for each alternative.

3.3.5 Investment in Working Capital

Chromalox uses a just-in-time inventory policy. Only materials that will be used to support forecasted demand are purchased. This policy will be adjusted if the subcontractor alternative is selected. Recall that the subcontractor quoted with the restriction that the annual volume of boards would be produced in one batch. Therefore, all boards needed to support forecasted sales are assumed to be purchased for the beginning of each year.

Carrying a year's supply of inventory incurs two types of costs. First, since the entire amount needs to be purchased at the beginning of each operating cycle, there will be an investment in working capital. For example, to support 2000 units of 1/16 DINs, the total volume of PCBs will be 8000 boards, costing $10 each during the first year. Therefore, Chromalox has to expend $80,000 at the beginning of the first year. During the second year, the production volume is increased to 3000 units, or 12,000 PCBs. With the price at $9 per board, the required investment in working capital will be $108,000 at the beginning of the second year. However, the investment of $80,000 in working capital made at the beginning of the first year will be recovered as the products get sold at the end of the first year. Therefore, the net additional investment in working capital will only be $28,000. The total investment made in working capital is expected to be recovered in full amount at the end of project life

Second, to store and keep the inventory in good shape, there will be some inventory carrying costs, such as warehousing, humidity control, and insurance. The accounting department has estimated inventory carrying costs to be 2% of the PCB purchase cost. This carrying cost excludes the cost of a lost opportunity due to funds tied up in warehousing, and forgone purchases of other inventories. This opportunity cost will be reflected in discounting cash flows.

3.3.6 Tax Rate and Cost of Capital

Chromalox is a company of the E. L. Weigand Division of Emerson Electric. Financing for capital equipment over $10,000 must be approved by the division financial manager. All projects must be evaluated using the Emerson Electric guidelines based on the internal rate of return approach. A project cannot be accepted unless the project's rate of return meets or exceeds 20%. Emerson also mandates an accelerated cost recovery (MACRS) method of depreciation. Total state, local, and federal taxes are 39%.

4. Economic Analysis

Part 1: Pre-tax Analysis

Base your pre-tax analysis on the projected sales at the base-line scenario of the 1/16 DIN controller. Use the cost of materials, labor, and overhead from the past history of the most similar 1/4 DIN controller with the exceptions previously noted. Find the PW at a MARR of 20% for the in-house production alternative and the subcontract alternative. For the subcontract alternative, remember the inventory carrying cost and tooling costs. Also find the IRR for both alternatives.

Based on your analysis, which alternative is preferred? In deciding between the in-house and subcontracting options, what additional factors should be considered other than economic factors? Submit a written report (maximum 3 pages) summarizing your analysis and recommendation.

Part 2: After-tax Analysis

I. Economic Comparison Based on Most-Likely Estimates

Base your analysis on the most-likely forecasted demand of the 1/16 DIN controller. Use the cost of materials, labor, and overhead from the past history of the most similar 1/4 DIN controller with the exceptions previously noted. Find the PW at a MARR of 20% for the in-house production alternative and the subcontract alternative. You will need to create tables, including revenues, expenses, taxes, depreciation and investment. For the subcontract alternative, remember the inventory carrying cost and tooling costs. Also find the IRR for both alternatives. Which alternative is preferred?

II. Sensitivity Analysis

The sales of the 1/16 DIN controller are assumed to be strong. However, since this is a new-product introduction, there is a high probability that actual demand will vary from the initial projections. Therefore, the economic analysis has been reassessed at worst case and best-case demand. Find the PWs under these three scenarios and the expected PW (E(PW)) for each alternative.

	Sales (No. of Units)		
Year End	***Worst Case***	***Most-Likely***	***Best Case***
1	500	2000	2500
2	1000	3000	3500
3	1500	3000	3500
4-7	2000	4000	4500

III. Further Analysis

1. Suppose that Chromalox did not have sufficient assembly capacity to produce the 1/16 DIN internally. Determine the maximum level of capacity expansion (in dollar terms) required to make the in-house option equivalent to the subcontracting option.

2. What break-even equal annual demand would make the in-house option equivalent to the subcontracting option?

Chan S. Park, Contemporary Engineering Economics Case Studies

Helps and hints for the case study:

1. Working capital: for the subcontract option, the working capital is needed at the beginning of year one, which is end of year 0. Therefore, this cost ($80,000) falls in year 0. It is an expense, not taxed, not depreciated, a straight cost. It is the same for the additional $28,000 for the other 2 different years. The entire amount is a positive cash flow at year 7, again, not taxed. It is like a security deposit, your money back to you, but not income.

2. In subcontracting, tooling is a one-time cost recorded at the end of year 1. It is part of business expenses, so you pay less taxes due to lower taxable income.

3. For taxes, you need the net income (sales minus all expenses) and the depreciation. Remember that depreciation is not a cash flow, but does help on taxes. Taxes are then part of your cash flows.

4. MACRS is 7-year property (by law), even though it technically goes to 8 years, there is no salvage value.

5. For the questions, what I am looking for is for you to perform sensitivity analysis, trying to look at how you would meet larger demand, which option would be best and why, or some combination of that. Everything is dependent on the sales demand, so take a look at options there. At what point do the options break even?