Increasing Profit Potential with Precision Control and Monitoring of the Reflow Process

By Ron Lasky, Ph.D., Cookson Performance Services
and Greg Jones, Ph.D., KIC Thermal Profiling

Introduction

The Electronics Industry is the most rapidly growing industry in the world, recently passing the $1 trillion per year mark, while averaging a rate of 6% compounded annual growth. Annual price reductions of approximately 6% a year make the true net growth rate in number of units shipped about 12% per year, which is six times greater than the 2% per year growth in the world gross domestic product. Achievement of this phenomenal growth while reducing cost per unit price has been made possible by two factors: continuous technological advancement and significant improvements in manufacturing efficiencies.

In the SMT assembly process, the challenge is to increase both throughput and quality to meet this demand. The growth of the Contract Electronic Manufacturer (CEM) sector has been one of the major trends responsible for increased production efficiency, and the fact that CEMs focus exclusively on assembly has allowed them to make significant improvements to the electronics assembly process. The growth of the CEM sector has brought an intense level of competition to the electronics assembly market, which has brought heavy pressure to bear on SMT assembly equipment manufacturers. It is no longer enough for an equipment manufacturer to merely offer cutting edge technology. Equipment with functionality, performance, and reliability at levels that were unimaginable just a few years ago is a given. For a piece of equipment, especially a peripheral piece of equipment, to be placed on an assembly line, it must be justified in financial terms.

Current efforts to improve production efficiency are focused on two areas: improving individual machine performance, and improving the performance of the line and the facility as a whole. Most of the focus on equipment has gone to the pick and place machine and the screen printer, which are commonly acknowledged to be both the point of constraint and the greatest source of defects. But, to obtain maximum line efficiency, all operations must be analyzed and improved. Since the advent of forced convection in the early 90's, the soldering process has not received the attention it warrants. A recent study[1] has found that precision control of the reflow process, paired with continuous automated monitoring of the process, can result in a significant increase in potential profits by increasing line productivity.

The Problem

The burden of proving a piece of equipment's value to a prospective purchaser obviously falls on the equipment manufacturer, and in today's market, cost justification is essential to make the final sale. KIC Thermal Profiling knew that the real-time automated thermal management system offered users significant value, which is recognized by most process engineers. The system offers multiple benefits, including automated monitoring of the thermal processes in real-time, increased equipment utilization by eliminating periodic confirmation profiles, and dramatically reduced reflow process setup time. But, despite all of these technical advantages, there was little objective financial data available to help convince the final decision maker of the benefits of the system.

To help increase industry acceptance of thermal management systems, KIC investigated methods to provide potential users with objective financial data for their specific applications. After an extensive search, KIC approached Cookson Performance Solutions to discuss possible solutions for this difficult task. The Cookson Performance Solutions Consulting Team was able to provide extensive assistance in this project due to their comprehensive knowledge in electronics manufacturing and cost modeling software.

Getting Started

At the first meeting, Dr. Ron Lasky, CPS Consulting Director, explained the various methods of financial analysis currently in use for evaluating changes or additions to a SMT line. They include: Cost of Ownership (COO); Return On Investment (ROI, or Payback time), and Cost/Profit Analysis. Although Cost of Ownership and Return on Investment provide valid measurements to define cost, there are many advantages to using a Cost / Profit Analysis method to quantify financial decisions.

Cost/Profit Analysis starts with the premise that any increase in uptime on a given line will result in an increase in productivity. This increase in productivity then results in an increase in profits. Because the fixed costs of the line equipment have already been paid, the only cost associated with increased production is the cost of materials. By producing more products at a faster rate, this uptime provides additional product at a higher profit margin. Uptime can be increased by replacing equipment, upgrading it, or finding methods to increase the utilization of the current equipment. The key question that Cost/Profit raises is: "How much more profit can I make with this additional production time?" While all electronics assemblers are actively seeking greater profits, few are willing to disrupt production to conduct experiments on existing lines. This makes the ability to develop a computer simulation of a proposed SMT production line essential for meaningful Cost/Profit analysis.

The recent development of real time costing software, such as SPACE™ (Surface Mount Process Assembly Cost Estimator), makes it possible to perform Cost/Profit Analysis without disrupting production. Real-time cost estimating (RTCE) is based on the total sum of material costs, indirect and direct labor, equipment amortization, rent and utilities, adjusted for yield. Once the figures for a "baseline" assembly line have been entered, the software is capable of evaluating "what if" scenarios relating process changes to potential cost savings and profit calculations. RTCE has proven to be a valuable tool for evaluating new equipment purchases and upgrades.

Potential Time Savings with Continuous Automated Real-time Process Monitoring

RTCE can be used to evaluate the benefits of the continuous automated real-time reflow process monitoring system. Although the system has several thousand installations with satisfied users worldwide, and there is substantial anecdotal evidence attesting to the system's effectiveness and value, a cost justification model had to be developed to achieve greater market penetration.

The real-time thermal manager can detect critical process temperature variations that standard oven control thermocouples cannot measure, and displays these temperature drifts and their location immediately on the user's PC screen. Thirty thermocouples embedded in two slim stainless steel probes are permanently mounted just above or below the conveyor. The probe thermocouples monitor process temperatures continuously, taking readings as frequently as every five seconds. These temperatures are displayed as "Process Profiles" on the oven controller's PC screen. All data is recorded permanently to the hard drive, giving users the ability to review process data from any previous production date.

By creating a mathematical correlation between product profile, as measured by a pass-through profiler, and process temperature, as measured by the thermocouple probes, real-time thermal management provides a product profile for every board processed. This "Virtual" product profile is calculated every 30 seconds, and Virtual Profile statistics such as peak temperature are also calculated and updated continuously. The Virtual Profile allows users to monitor their processes accurately, automatically, continuously and in real-time. An option to the system is automated profile prediction. This tool is capable of finding optimum oven setups that will yield a profile in the center of the process window, as well as the recipe with the highest possible conveyor speed to maximize throughput.

The list below includes both quantifiable cost benefits as well as qualitative advantages of the use of the thermal management system:

Quantifiable Cost Benefits included:

1. Eliminate confirmation profiles: Cost savings depend on frequency of profiling—once a shift, day, week, or month are common intervals. Potential time savings: ~20 minutes per profile.
2. Start production as soon as oven is stable: Many facilities have a policy of waiting ~20 minutes after the oven is powered up to be sure it's stable, even though a good oven will stabilize in 5-10 minutes. With the real-time thermal manager, users know when the oven is stable. Potential time savings: 10-15 minutes per oven start up.
3. Rapid Automated setup and changeover:
   A. Profiling a new product: The automated prediction tool can find the optimal profile for a given product with a single profile pass. Setup time is reduced to a maximum of 30 minutes to develop a new optimized process, as opposed to running several profiles and guessing. It could take hours to find a good enough profile using the best guess method and "tweaking zones", though obviously most facilities just go with a profile that's close enough. The automated prediction tool can calculate and evaluate 100 potential oven recipes per second as opposed to a single recipe every 5 sec with manual prediction tools.

B. Changeover: With pre-profiled products, the thermal manager eliminates the need for confirmation profiles when oven settings are changed. Time savings: 20 minutes per oven changeover.

4. As needed scheduling of PM: Using the thermal manager to continuously monitor oven performance and modern ovens with flux management systems, some facilities have been able to push preventative maintenance out from monthly to bi-or tri-monthly intervals.
5. Troubleshooting: The thermal management system allows the thermal process to be instantly assessed and eliminated as the cause of a yield problem.
6. Other benefits include automated process documentation for ISO, live data output to automate SPC data collection, and the ability to network process data.

Qualitative Benefits Include:

1. Zero-defect reflow process: With an alarm relay, the thermal manager can automatically shutoff the feed conveyor if the thermal process drifts outside process limits—this virtually eliminates the potential for thermal process related defects.
2. Production documentation and traceability: In several cases of component failures during assembly (popcorning), users of the thermal manager have been able to prove that their thermal process was in spec and force the component manufacturer to reimburse rework costs.
3. Higher quality solder joints and increased product reliability: It has been established that the more precisely controlled the thermal process is, the higher the quality of the resulting solder joints, thus limiting rework, field failures, and providing superior overall product reliability

Potential Profit Analysis

To estimate the possible time savings from improved control and automated real-time monitoring of the reflow process, it is necessary to determine how much additional profit is generated with this saved time. SPACE™ is a real-time cost estimating software package developed by Cookson Performance Solutions as a proprietary costing tool to support cost-benefit analysis.[2-5] SPACE™ utilizes detailed inputs of the process, such as the cost of materials, labor, equipment depreciation, interest, facilities, and throughput, and calculates the total cost, profit and other cost and productivity metrics. SPACE™ has been in use since 1996 and was calibrated to match the cost metrics of the NEMI[6] Roadmap.

To evaluate the potential profit effects of installing the thermal manager on an SMT assembly line, the following scenarios were developed and evaluated:

- A 24/7 cell phone line
- A high-mix CEM line
- A high value/low volume military line

Each of the scenarios included data on current line uptime, downtime, setup time, first pass yield, rework—in all nearly 200 data points were entered into the model.

High Level Analyzer				
Description	**CEM Baseline**			
Assembly Equipment(SP:200K, PP:900K, RO:100K, T:400K, BH:100K)	$1,700,000			
Floor Space and Utilities (sq ft) - Cost (per sq ft/month)	20,000.00	$0.83		
Components (per unit)	$25.00			
Stencil - squeegee - lifetime (cost each, uses)	$600.00	$200.00	1000000	
Solder Paste ($/g) - number of grams	$0.1000	5		
PCB ($ per unit)	$7.00			
Workers (number, rate per hour)	10	$28.00		
Selling Price ($) - Gross Margin (%) (enter '0' for item not used)	$45.00	0		
Hours per shift - Shifts per day - Days per week	8	3	6.333	
Cycle time (seconds)	20			
Downtime (%)-Setup (hours per week)-Maintenance (hours per week)	8	50	12.5	
Workers Supported (number, rate per hour)	10	$42.00		
I/O	950			Yield Used
Yield first pass (%) - Yield first pass ppm/I/O (N if not used) - Percent Reworkable	97	N	100	97
Unit RW Materials Cost - Minutes/RW - RW Labor ($/hr)	$0.50	20	$30.00	
Years Equipment Depreciation - Interest Rate (%)	5	9		
Length of Simulation (weeks) - Number of Boards (enter '0' for item not used)	52	0		
Warranties: Extended, Site, GPSA, CPSA: $/year all equipment		$0		$0

Figure 1: Baseline Data for High Mix CEM model

The scenarios were based on data compiled by Cookson Performance Solutions: for example, the high-mix CEM scenario was based on a study of one of the major contract manufacturing companies. It was found that each of the CEM's lines produced approximately $30M per year in revenue and gross profit was approximately 9%. Line uptime was conservatively estimated at about 50% because of lost time due to setups, changeovers, confirmation profiles, preventive maintenance, etc. SPACE™ was calibrated using these figures and an accurate model developed for this study. Once "baseline" cases were established, additional analyses were run with incremental improvements in uptime resulting from the use of the thermal management system. (See Figure 1)

Using the potential time-savings available from the use of the thermal management system, these analyses resulted in the potential yearly increase in profit as a function of hours saved per week as shown in Figure 2 and Table 1.

When first viewed, most people are stunned by these results. For a High Product Mix CEM, an additional hour of production time per week can result in $114K of additional profit per year!

Table 1 demonstrates the tremendous additional profit available to a thermal manager user, even if small amounts of time are saved. For example, if using the thermal manager saves the customer 2 hours per week [20 minutes per week in setup, 40 minutes in confirmation profiles and 1 hour in PM], the total potential profit for a contract manufacturer is approximately $228K (2 hrs x $114K/hr) annually. Even with the use of conservative estimates, it is easy to see the correlation between time savings and the impact on profit.

The Report

In each of these scenarios, the real-time cost estimating software showed the thermal management system provided significant increases in uptime, which results in increased profits. The value of eliminating one 20 minute confirmation profile per month, per week, per day and per shift was used in compiling Table 2. Time savings used were 4.61 minutes per week, 20 minutes per week, 2 hours and 20 minutes per week and 7 hours per week.

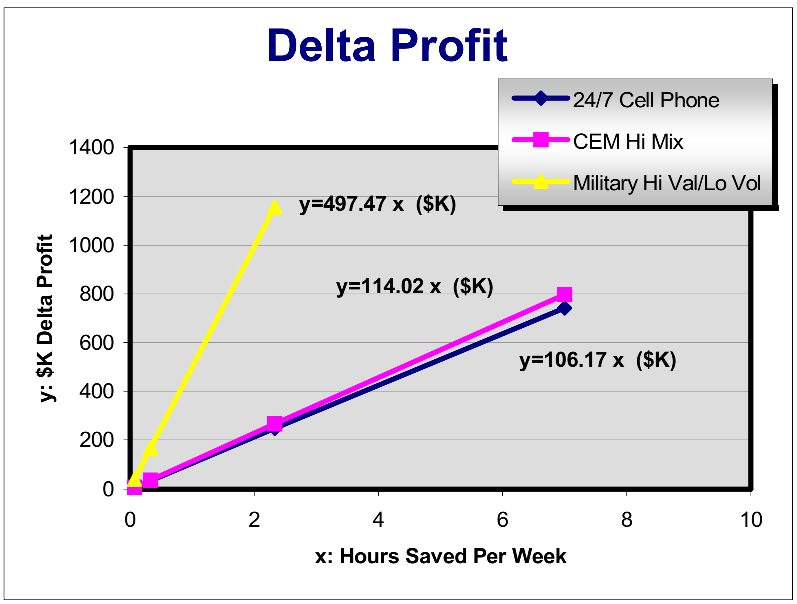

Figure 2: Potential profit as a function of hours saved per week for three scenarios.

Type of Manufacturer	Profit Potential per Hour Saved per Week ($K)
High Volume Low Mix Manufacturer	106.2
High Product Mix Contract Manufacturer	114.0
Low Volume, High Value Manufacturer	497.4

Table 1: Potential Profits per hour for three scenarios.

Simple Run Comparison	Unit Cost	Unit Profit	# Units	Weeks	Total Profit	Δ to Baseline
CEM Baseline	$41.24	$3.76	723,802	52	$2,721,121.66	
CEM: One Profile/Month	$41.23	$3.77	724,522	52	$2,729,894.28	$8,772.62
CEM: One Profile/Week	$41.20	$3.80	726,922	52	$2,759,136.36	$38,014.70
CEM: One Profile/Day	$40.99	$4.01	745,642	52	$2,987,224.59	$266,102.93
CEM: One Profile/Shift	$40.54	$4.46	789,322	52	$3,519,430.44	$798,308.78

Table 2: Potential Profits from elimination of confirmation profiling in CEM scenario.
(Table based on 20 minutes per profile and frequency of profiles eliminated at CEM facility.)

There are also significant savings associated with reduction in preventative maintenance. Assuming that oven maintenance takes approximately 16 hours and that the use of the thermal management system reduces scheduled PM from a monthly interval to bi-monthly, 16 hours is saved every other month (or an estimated 1.85 hours per week). The graph in Figure 2 can be used to estimate the additional profit potential. By reducing PM from once a month to every other month, the increased profit potential is over $210K/yr (1.85 hrs x $114.0K/hrs) for the CEM scenario.

Another variable that can be effected by the use of the thermal management system is profile troubleshooting. A conservative estimate is that troubleshooting consumes a minimum of 8 hours per month/per shift. Assuming the thermal manager provides for a 10% reduction in this time, this saves 0.2 hours per shift per week. This savings results in a potential savings of $1.2K/yr for labor alone or $68.4 K if the time saved is used for production in a 3 shift CEM operation.

The Results

Cost/Profit analysis is rapidly gaining acceptance as a tool to help electronic assemblers get the most from their existing equipment and make the optimal decision when making new equipment purchases. From the examples above, it is clear that process improvements result in lower costs per unit and the production of more units to sell, and that decreasing cycle time or increasing uptime has an exponential effect on gross profit. It is also clear that significant increases in line uptime and potential profits can be found in the generally overlooked reflow process by using an automated continuous real-time thermal manager to setup and monitor the reflow process.

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