Should You Automate Control of Moisture-Sensitive Devices?

Jean Lamontagne, Jean-François Rouleau and François Monette

Perhaps. A return-on-investment analysis confirmed the benefits of an automated control system for MSDs.

Shorter development cycles, ever-smaller device sizes, new materials and larger chips are resulting in a rapid increase in the quantity of moisture-sensitive devices (MSDs) and higher levels of moisture/reflow sensitivity. In the electronics manufacturing services (EMS) industry, numerous trends are intensifying the implementation of automated electronic tracking of moisture-sensitive plastic integrated circuits (ICs). This control of MSDs before surface-mount reflow is a critical assembly issue, with a direct positive impact on final product reliability, customer satisfaction and manufacturing cost.

The guidelines for storage and handling of MSDs are defined in the joint IPC/JEDEC *Standard J-STD-033*. However, proper identification, tracking and calculations are very challenging with manual procedures. Such procedures as identifying MSDs, filling out log sheets and entering data and time calculations are time-consuming and open to human error. Manufacturers may take shortcuts to implement such a demanding program. But, shortcuts can have undesirable effects:

• When simplifying on the safe side, users will bake parts that do not really need it. Unnecessary baking can degrade lead solderability and solder joint reliability due to intermetallic growth. It also affects material availability, which can disrupt production schedules, on-time deliveries and inventory levels.

• With a relaxed and simplified standard, many components that should have been baked will be assembled and reflowed. This error may only happen with a few lots, but it typically involves a partial tray or reel containing many parts. Because many MSDs may be on each printed wiring board (PWB) and they are typically the most expensive components, even a small level of "escapes"—less than 0.1 percent by component—can increase both material costs and early life failures.

A better approach is to use an automated control system that is easy-to-use and ensures a very high level of control. The foremost objective is to avoid assembling components that have exceeded their allowable moisture limits. This objective is achieved by automatically tracking each reel or stack of trays from the time they are removed from their original dry bag or environment until all parts are placed before reflow. The second objective is minimizing the number and duration of bake cycles by integrating all applicable industry standard rules and ambient conditions, while providing real-time status and advance warnings.

Automated System Evaluation

In 2001, one EMS provider integrated an automated system into one surface-mount line for a two-month trial. During this study, the EMS engineers conducted a return-on-investment (ROI) analysis that compared the automated control system to an optimized manual procedure.

The EMS surface-mount line produces single-sided PWBs for multiple products. The line averages one changeover per shift, so it is a high-mix environment. The following summarizes the moisture-sensitive components in production:

• Number of different lots (bags) of MSDs used during the evaluation: 188
• Average quantity per lot: 80
• Total number of components: 15,040
• Average cost of MSDs: $110 (USD)
• Number of times that a lot of MSDs was loaded on a placement machine: 334 (On average, each lot was loaded twice.)
• Number of bake cycles: 13 (Two additional lots were baked upon reception due to improper packaging.)

In the production line, 62 different part numbers (PNs) are moisture sensitive, with the following moisture-sensitivity level mix:

• Level 1: 3 (5 percent)
• Level 2: 2 (3 percent)
• Level 2a: 1 (2 percent)
• Level 3: 36 (58 percent)

- Level 4: 12 (19 percent)
- Level 5: 8 (8 percent)
- Level 5a: 0
- Level 6: 0.

Automated Control System

The automated control system uses radio frequency identification (RFID). The most obvious elements of an RFID system are the radio frequency (RF) tags that can be attached to trays and components. The tags contain IC circuitry and are programmed with relevant component information including sensitivity level and expiration date/time. In addition to the RF tags, the automated control system uses a reader/controller to read and write information to the tags, and application software to process the information to and from the tags based on the operator input.

One RF tag design for JEDEC trays has a small spring-loaded plastic clip that slides over a hook-shaped tab at the tray end. For reels, a very thin reusable disk is inserted in an adhesive traveler pouch. Information is stored on the tags during the initialization process, when first attached to the trays and reels. The part number is scanned from an existing barcode label on the outside of the dry bag.

In production, RF tags are quickly scanned in front of a local reader/controller, and all calculations are instantly performed by the control system (Figure 1). The RF tags are scanned whenever a reel or tray is moved to another location. The user-interface simplifies the selection of the appropriate environment and provides a warning if an illogical operation is attempted; for example, load in bake before unloading from placement machine. The reader/controller displays real-time lists of all MSDs with their remaining floor life. Audible or visual alarms can be used to alert operators to take action before a component reaches its expiration.

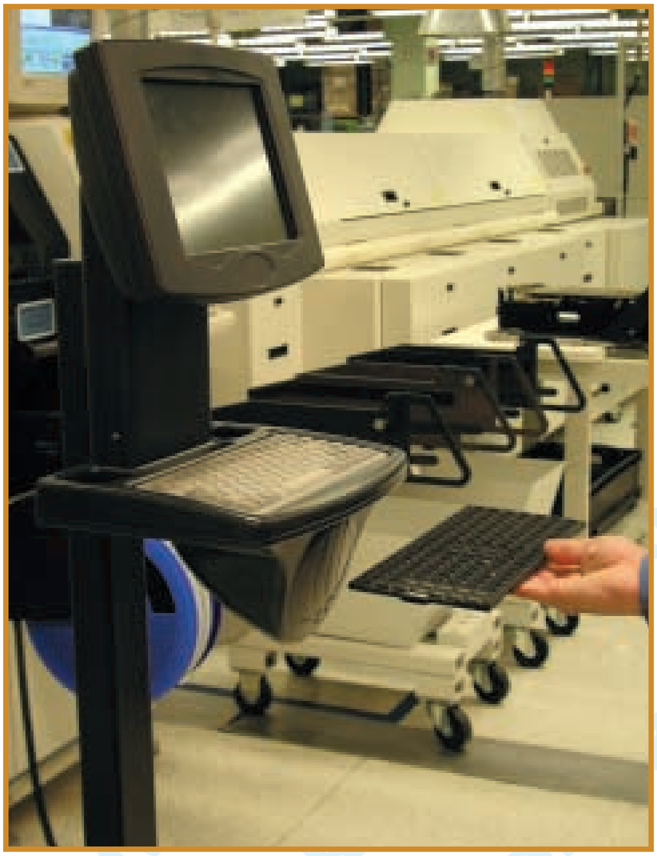

FIGURE 1: RF tags are scanned by a reader/controller.

Real-Time Visibility During Dry Storage

In a high-mix production environment, most component lots will be returned from the production line in partial trays or reels. Even with trays and reels properly identified, this information becomes difficult or impossible to read once the parts are loaded on feeders or on a placement machine. With each product changeover, partial trays are removed from the placement machine and located in dry storage until needed again.

In this EMS line, the 13 bake cycles are based on adherence to the IPC/JEDEC standard relative to dry storage. The exposure time clock is not stopped when previously exposed components are returned into dry storage.

Some assemblers that deviate from the standard assume that stopping the exposure time clock is acceptable when previously exposed components are returned to dry storage. However, when analyzing production statistics during this study, 10 of the 13 baked lots would not have exceeded their floor life if the clock had been stopped during subsequent dry storage. This simplification would have represented a very significant exposure deviation that could impact finished product reliability.

To account for the drying effect of the desiccant inside resealed dry bags, the MSD control system was configured to automatically apply the short duration rule when the proper conditions were met. This approach allows users to reset the exposure time clock when parts are exposed less than eight hours followed by five times the dry storage duration. The system applies the rule based on the exact amount of time the parts have spent in each environment. During the study, this rule was applied 73 times and avoided an additional 54 bake cycles.

Additional Opportunities

The standard provides a derating table to account for actual factory conditions. The automated system can automatically apply this derating factor if needed. In many cases, actual conditions are well

	Manual procedure	Control system	Savings
System efficiency	75 percent	99 percent	
Number of expired components escaping	120 (0.8 percent)	4.8 (0.03 percent)	
Defects at electrical test	12 (0.08 percent)	0.48 (0.00 percent)	
Cost	$1,560.00	$62.40	$1,497.60
Defects in the field	12 (0.08 percent)	0.48 (0.00 percent)	
Cost	$3,720.00	$148.80	$3,571.20

TABLE 1: Comparison between a manual procedure and the automated control system.

	Manual procedure	Control system	Savings
Number of bake cycles	13	6	
Average duration of bake cycles	48 hours	19 hours	
Cost	$2,028	$370.50	$1,657.50
Number of components with one bake cycle	1040 (6.9 percent)	480 (3.2 percent)	
Number of components with second bake cycle	36 (0.48 percent)	8 (0.10 percent)	
Cost of scrapped components	$3,955.32	$842.55	$3,112.77

TABLE 2: Cost-savings associated with a reduction in bake cycles and scrapped components.

	Manual procedure	Control system	Savings
MSD set-up and verification	60 minutes/day	10 minutes/day	
Machine cost	$1,920.00	$320.00	$1,600.00
Operator cost	$320.00	$53.33	$266.67

TABLE 3: Machine set-up costs for the manual procedure versus the automated control system.

below the default of 30°C and 60 percent relative humidity (RH), which can significantly increase floor life process windows and reduce unnecessary bake cycles.

During this study, the system was set at the 30°C/60RH default value, but the actual ambient conditions never exceeded 25°C and 40 percent RH. An analysis of each baked lot showed that more than half of the bake cycles (7 of 13) could have been avoided.

This derating is most significant for common Level 3 "thin" components with less than 2.1-mm body thicknesses—thin small outline packages, small outline integrated circuits, thin quad flat packs and tape ball grid arrays—that have an unlimited floor life below 40 percent RH. Reviewing the MSD component database shows that 29 different part numbers were classified as "thin" Level 3 parts; 80 percent of all Level 3 components or 47 percent of all components.

ROI Analysis

The ROI financial analysis performed in this study includes the following major elements of savings associated with a higher level of process control: final product reliability; improvements in in-circuit test and functional test yields; reductions in the baking cost and number of scrapped components; increased productivity; and training and support costs. When needed, very conservative assumptions and estimates were made and are clearly documented. All these savings are applicable to the one surface-mount line over a two-month period.

Final product reliability and improvements in ICT and FT test yields

These two savings elements are nearly impossible to measure directly. This reflects the relatively low defect levels and the technical difficulty in performing the appropriate component removal and subsequent failure analysis. This result is very similar to experiences many years ago when manufacturing engineers tried to calculate the ROI for electrostatic discharge (ESD) controls. However, unlike ESD, many elements of a control system (exposure time, number of bake cycles, etc.) can be measured and used to quantify the expected level of defects.

During this study, 480 components (six out of 80 lots) exceeded their floor life limit. The number of defects during in-circuit test and in the field are conservatively estimated to be only 10 percent of the expired components that escaped through the control procedure or system (Table 1).

Reductions in the baking cost and number of scrapped components (prior to assembly)

Because of cumulative component degradation associated with bake cycles, the standard states that only one bake cycle is allowed per component. The automated system tracks the first bake cycle by logging this information on the RF tag and displaying a message when a second bake cycle is attempted on the same lot. The EMS provider's internal procedure is to scrap these components to avoid potential issues.

In calculating the savings in baking cycles and scrapped components, the following assumptions were made:

- An optimal manual procedure could take into account the short duration rule, but not the ambient derating factor. Therefore, the number of bake cycles would have been 13 for a manual procedure versus six for the automated control system (Table 2).
- A manual procedure uses the standard default bake duration of 48 hours for simplicity reasons. The automated control system provides optimal bake duration based on the MSD level and body thickness for each level, so multiple bake cycles with different start and finish times can be tracked.
- The cost of a bake cycle is equal to $3.25/hour for energy and handling.

Increased productivity

The automated control system requires a simple scan to read and update the RF tags every time a lot of MSDs is loaded or unloaded from a placement machine. With a manual tracking procedure, cumbersome date/time calculations and verification of different rules are needed. This procedure is time-consuming and has a measurable impact during product changeover, when many different parts have to be unloaded and reloaded from the placement machine (Table 3).

Training and support costs

The typical MSD manual control procedure is considered to be one of the most difficult tasks on the manufacturing floor. It must be regularly updated based on changing conditions, such as new process, equipment, material logistics or revisions to the standard. Generating and maintaining a good manual procedure requires significant time from a qualified engineering resource, especially if no data are available to make informed decisions. (In this analysis, engineering time is divided by the total number of surface-mount lines, to be consistent with the overall savings per line.)

Significant amounts of time and effort are needed to train each employee involved in handling MSDs. Operator training must be refreshed, and training materials must be updated regularly due to the complex and ever-changing nature of the procedures. In comparison, the automated control system only requires operators to scan the RF tags and follow instructions provided by the system's interface whenever the parts are moved from one location to another (Table 4).

	Manual procedure	Control system	Savings
Update procedure	16 hours	2 hours	14 hours
Engineering time	$256.00	$32.00	$224.00
Ongoing training and support	20 hours	4 hours	16 hours
Engineering time (1/3)	$106.67	$21.34	$85.33
Operator time (2 per line)	$320.00	$64.00	$256.00

TABLE 4: Updating and operator training/support costs of the manual procedure versus the automated control system.

Because the automated system cost was under $22,000, the payback was less than four months (Table 5). The actual ROI will be even greater as additional production lines switch over because multiple lines will share the cost associated with the central workstation in the stockroom.

	Manual procedure	Control system	Two months savings	Yearly savings
Defects at electrical test	$1,560.00	$62.40	$1,497.60	$8,985.60
Defects in the field	$3,720.00	$148.80	$3,571.20	$21,427.20
Bake cycles	$2,028.00	$370.50	$1,657.50	$9,945.00
Scrapped components	$3,955.32	$842.55	$3,112.77	$18,676.60
Productivity machine	$1,920.00	$320.00	$1,600.00	$9,600.00
Productivity operator	$320.00	$53.33	$266.67	$1,600.00
Update engineering time	$256.00	$32.00	$224.00	$1,344.00
Training engineering	$106.67	$21.34	$85.33	$512.00
Training operator	$320.00	$64.00	$256.00	$1,536.00
Total projected annual savings				**$73,626.40**

TABLE 5: Summary of cost savings.

Conclusion

Many positive intangibles cannot be directly quantified with this ROI evaluation but should be considered. One significant factor is improved customer satisfaction through inherent quality improvements. Customers who visited or audited the EMS manufacturing area were positively impressed by the automated system.

System robustness with a complete historical database provides a very high level of confidence that the MSD element of the manufacturing process is under control. Over time, the EMS provider expects that the system will improve on-time delivery by reducing the number and frequency of bake cycles. This automated material and process control system can become a differentiating factor when original equipment manufacturers evaluate and compare different EMS partners with otherwise similar offerings.

The ongoing historical database provides detailed, real-time information to measure the key metrics of MSD process control, including number of bake cycles and average exposure time. These data are essential to continuous process improvement and allow the EMS engineers to predict the impact of future changes in operations. The system has a very high level of control for all MSDs before reflow. For new products that include MSDs on both sides of the board, the system programming can be adjusted to track boards and associated components between the first and second passes through reflow.

The system and associated database may be integrated with other manufacturing monitoring/control systems to further improve material planning and inventory control for other limited shelf-life materials. With some changes, the system can also track and control other expensive components that may not have floor life limitations, but would benefit from a higher level of traceability and control.

The EMS provider's study of the automated control system and subsequent shop-floor analysis confirmed that MSD process control is a very complex logistical issue with far-reaching implications in material flow and assembly process yields. Even the best manual procedures have significant shortcomings, so automating MSD control yielded significant savings, productivity and material costs while improving quality. Increased customer satisfaction and confidence are important intangible results although difficult to quantify. ■

__Jean Lamontagne__ is a manufacturing engineer and __Jean-François Rouleau__ is an engineering manager, both with Solectron, Sherbrooke, Quebec, Canada; e-mail: jeanlamontagne@solectron.com. __François Monette__ is a founder of Cogiscan Inc., Bromont, Quebec, Canada; e-mail: fmonette@cogiscan.com.