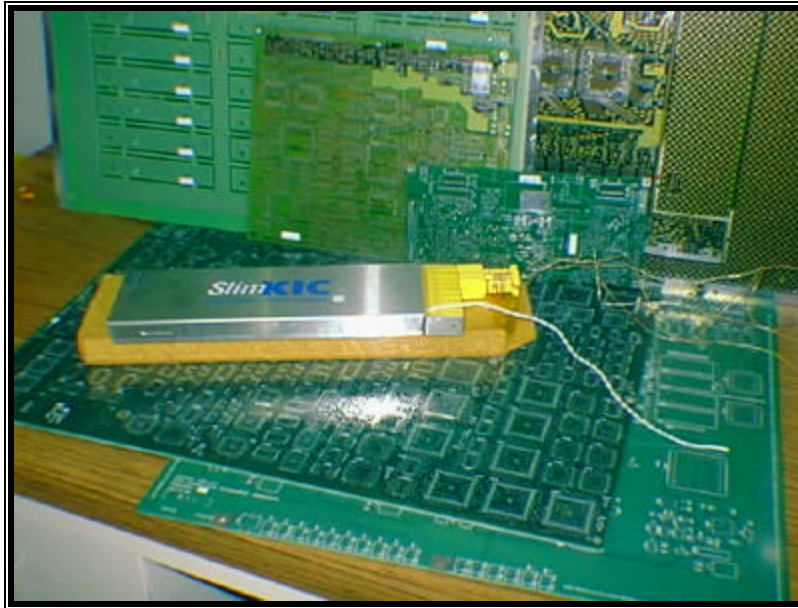


# Reducing Oven Changeover Time by Finding Common Recipes for Mixed Production Lines

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## High Changeover—Low Yield

This paper will discuss the potential for reducing changeover time at the solder reflow oven for manufacturers running multiple products on a single SMT production line. The use of an automated profile prediction tool to generate a single common oven recipe for dissimilar products has the potential to provide significant increases in production throughput.

The experiment to determine whether it is possible to develop a single common recipe was conducted at Solectron Corporation's new contract manufacturing facility in Everett WA. This facility currently processes an unusually large variety surface mount board types on a given line in the course of a year. Often the lot sizes are less than 50, so machine changeover time is the pacing factor to overall throughput. The goal of the experiment was to find a single set of oven temperature setpoints and then change only the oven conveyor speed for different board types. This is a critical throughput improvement. Every time the temperature setpoints of the oven need to be changed to achieve a particular product profile, from 5 to 20 minutes or more of downtime is required for the oven to stabilize. Conveyor speed changes can be made almost instantly, so changing only conveyor speed to achieve the correct product profile has the potential to significantly reduce line downtime and increase throughput and yield.

## Thermal Profiling Tools

Solder Reflow is a process for connecting electrical components and assemblies to printed circuit boards. The purpose of the reflow oven is to heat the product to a precise temperature at a precise rate for a precise period of time. When this combination of time and temperature are plotted, the result is a "Thermal Profile". Maintaining a proper profile is critical: if the board does not get hot enough the solder will not bond the components to the solder pads properly; if the board gets too hot or is heated too quickly, the board and components will be damaged.

The standard method of monitoring the reflow process is to run product profiles using a pass-through product profiler. Prior to 1989 and the introduction of "prediction" software, ovens were profiled by "trial and error". A process engineer ran a profile, made changes to the zone setpoints and/or conveyor speed according to his/her "best guess", and then ran another profile. The process was repeated until an adequate profile was found. This took hours, and in some cases could take days.

The introduction of “prediction” software allowed users of pass-through profilers to make changes to oven setpoints and conveyor belt speeds on the computer, and quickly view the “predicted” affect of the changes to key product profile statistics such as ramp rate, soak time, peak temperature, and time above reflow. “Prediction” could evaluate a change to an oven recipe in about five seconds—roughly the speed at which the operator could enter the change into their computer. This was a dramatic improvement over the conventional method of profiling thermal processes, but it was still a time-consuming “trial and error” method.

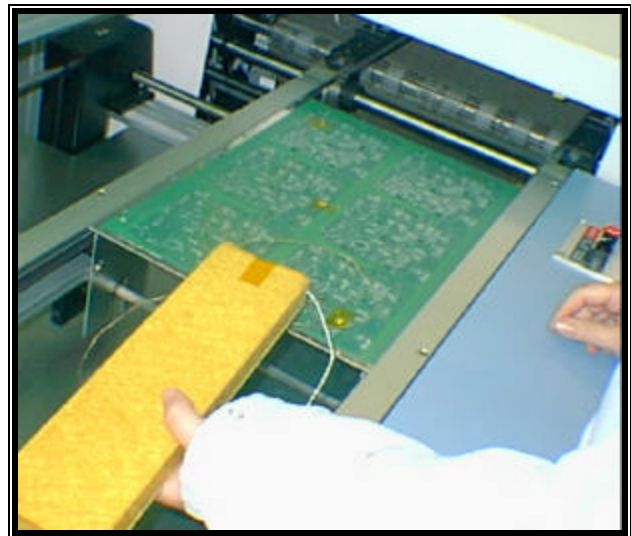
## Automated Prediction Tool

The most recent development in thermal process management is the automated prediction tool. The automated prediction process is initiated by determining the critical process statistics. Generally these are determined by the solder paste manufacturer’s specs, and sometimes by critical component ramp and peak temperature tolerances. At Solectron, the thermal profile process specification for all the boards is the same:

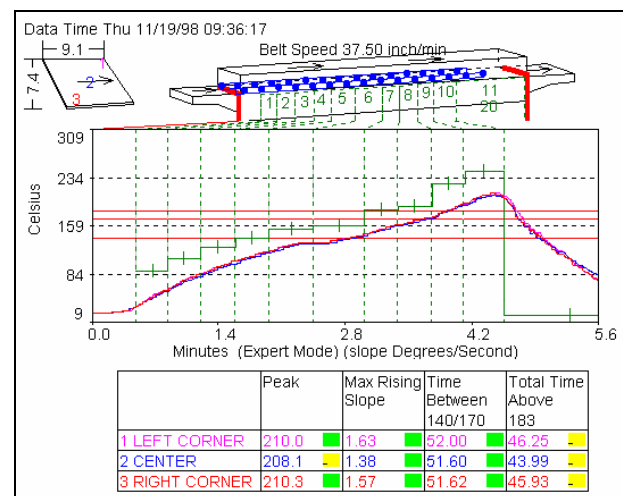
	Peak Temp	Maximum Rising Slope	Rising Time Between 140~170°C	Total Time Above 183°C
Maximum	225°C	3.3°C/sec	90 sec	75 sec
Minimum	210°C	No min	50 sec	50 sec

*This table shows the four original sets of setpoints that, between them, are capable of processing all 21 board types within spec.*

These specifications, along with a physical description of the board to be processed, were entered into the profiling software. Three thermocouples were attached to the board with a small piece of aluminum tape covered by a larger piece of Kapton tape. The thermocouples were attached to a pass-through profiler and the initial product profile was run.



The completed profile includes a table of the selected profile statistics, with each statistic rated as red, yellow or green. When all the statistics in the table are green, the profile is within spec.



The automated prediction tool creates a mathematical model of the oven environment that is based on the thermal profile data collected by the product profiler. Like standard “prediction” software, the automated prediction tool calculates what a new product’s thermal profile will be based on changes to setpoint temperature and/or conveyor speed. The automated prediction tool calculates hundreds or even thousands of potential process recipes at a rate of up to a hundred calculations *per second*. As the possible combinations of oven setpoints and conveyor speeds are calculated, they are evaluated and ranked according to the Schultz Index. The Schultz Index of a profile can in theory be anywhere from zero to infinity, but in practice ratings usually fall between 50 and 500. A Schultz Index of 100 or greater indicates one, some, or all process statistics are outside of the specified process limits, while a value of 99.9 indicates that all process statistics are being met, though just barely. The lower the Schultz Index, the better the “fit”. A Schultz Index of 85 would indicate that the process is using 85% of its specification limit, and all the individual profile statistics would be green. A Schultz Index of 155 is using 155% of the process spec and some of the individual profile statistics would be yellow or red.

	Schultz Index	Total Setpoint Change	BS
Original	83.19	0	32.6
	35.47	0	30.0
	53.99	0	31.0
	66.16	0	29.0
	71.76	0	32.0
	93.48	0	33.0
?	117.06	0	34.0
?	143.09	0	28.0
?	204.12	0	27.0
3	229.49	0	26.0
4	139.82	0	35.0
5	156.26	0	36.0
6	170.06	0	37.0
1	183.37	0	38.0
1	201.37	0	39.0
2	266.88	0	25.0
2	217.56	0	40.0
2	290.07	0	24.0

The automated prediction tool has calculated the Schultz Index for a single set of setpoints at the conveyor speeds between 20 and 50 inches/minute in 1 inch/minute increments.

## The Problem

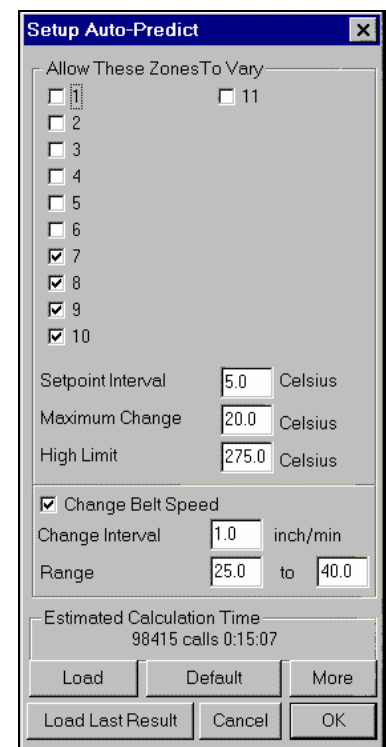
Solectron is a contract PCB assembler, and their Everett facility typically runs many different products in the course of a year. This is a very high-mix/low-volume plant, generally running 30-100 boards of a single type before they switch the line over for the next product. With a large investment in surface mount equipment on each of four lines, maximizing throughput is critical. On these lines, the key issue, or pacing factor, is the oven. It is a new 10 zone forced convection oven with both a rail system and a belt.

When they change the line over, there is already a screen made up for the screen printer, the data is down loaded into the pick and place machine and the appropriate parts are loaded, and these are very quick turnovers—a maximum of ten minutes. At the reflow oven, if the board has previously been run, they look up the recipe and set the oven to this recipe. The problem is that whenever they have to change the setpoint temperatures, it takes time for the oven to stabilize, especially if they’re waiting for zones to cool down, as it takes longer for the oven to cool off than it does to heat up. It can take 5-20 minutes for the oven to stabilize; time during which the line is shut down.

The solution that I hoped to find for Solectron was a common set of oven setpoints for all board types processed in that oven, requiring only changes to conveyor speed to meet the appropriate product profiles. This would allow the oven to be ready to process product within a minute. They had been looking for common set of set points that would allow them to only change the conveyor speed, and on the line on which this experiment was run, they had found four different combinations of oven setpoints, that would process twenty one different board types. They arrived at these recipes essentially by trial and error, by looking at the board’s overall size and population, and assigning it to the big, medium, small, or very small recipe. This did succeed in reducing oven changeover times.

## The Solution Process

I approached Solectron and suggested an experiment to determine whether we one common set of setpoints would run their 21 most recently profiled board types. The means of finding common oven setpoints was an automated prediction tool capable of finding hundreds and often thousands of different oven recipes that will process a given board within spec. Using product profile data from the 21 board types as input, the automated prediction tool was used to generate 6561 different combinations of setpoints for each of the



boards. This was done by varying the last four zones  $\pm 20C$  in 5C steps. For each set of setpoints, sixteen different conveyor speeds in one inch increments from 30 to 45 inches per minute were tried. This, in effect, meant that 98,415 different combinations of setpoint and conveyor speed per product were calculated and ranked from best to worst by their Schultz Indexes. This took a 200 MHz Pentium about 12 minutes for each board.

For each board type, from the 98,415 recipes, the best 8000 were imported into EXCEL. I sorted the 8000 recipes by zone setpoint temperature and removed all of the ones that had the same set points but different conveyor speeds, keeping the recipe that had the best Schultz Index. This reduced the number of recipes from 8000 to between 1200 and 2000 per board. I then combined the recipes for all 21 board types into the same EXCEL file and sorted them to see if there were any sets of setpoints that appeared in all 21 of the files. There were about 200 that appeared in all 21 files, and of those, 19 were “green” solutions, meaning that they were within spec (Schultz Index <100) for all 21 board types. The best set of setpoints had a high Schultz Index of 91, meaning that none of the 21 board types would use more than 91% of the spec.

Schultz Index	Zone			
	7	8	9	10
91.02	165	205	225	245
92.68	175	200	225	245
93.24	170	200	225	245
93.63	180	195	225	245
94.73	160	205	225	245
94.90	170	205	225	245
95.82	165	210	225	245
96.39	165	205	230	245
96.77	180	200	225	245
97.57	160	210	225	245
97.69	165	200	225	245
98.17	170	205	235	240
98.61	185	190	225	245
98.68	160	205	230	245
98.97	160	210	230	245
99.17	155	205	225	245
99.35	175	205	225	245
99.39	160	210	235	240
99.42	175	195	225	245

*This table shows 19 different sets of setpoints that will process all 21 board types within spec. The SI column shows the worst Schultz Index that is expected. (The first six zones are not displayed because they were not changes from the original recipe.)*

Board Type	Belt Speed	Schultz Index
1	33	67.34
2	31	63.61
3	32	91.02
4	36	71.40
5	35	68.30
6	31	31.02
7	35	76.15
8	35	71.12
9	35	61.31
10	37	88.93
11	35	74.50
12	37	86.79
13	36	56.04
14	42	85.39
15	32	48.19
16	36	64.34
17	37	55.99
18	40	55.64
19	38	49.72
20	36	52.12
21	40	58.99

*This table shows the Conveyor Speed required, and the resulting Schultz Index value for each board type when it is processed using the first set of setpoints in the previous table (Common Setpoints #1).*

## Results

Our clients at Solectron were impressed that a single set of setpoints gave them an in spec profile for 21 different board types *on the computer*. However, they were skeptical that this would hold up in the real world.

We changed the oven to the “common setpoints” and let it stabilize. We then decided to profile the board they were going to run next. They had never profiled the board before, so we had to guess on the conveyor speed, putting it right in the middle at 37.5 inches per minute. The resulting profile was far too cool with a Schultz Index of 150. We ran the automated prediction tool, and it told us that changing the conveyor speed to 31.5 inches per minute would lower the Schultz Index to 45. We changed the conveyor speed and the new profile was within a degree and a half of what was predicted and had a Schultz Index of 59.

Our clients at Solectron were impressed that it worked for the current board, but suggested that we try some different boards that were significantly more difficult. We tried four other boards which were all supposedly more difficult than the last. It was established that all the profiles could be brought in spec by changing only the conveyor speed. One of the Solectron people suggested we run some extremely thin boards. These boards very unusual. We ran them both, and the best conveyor speed we could find for the first board gave us a Schultz Index of 104. The best we could find for the second board was even worse with a Schultz Index of 125.

I believed I could find a new set of common setpoints that would process all the previously tested boards as well as the new “thin” boards. I set up an analysis on the 7 boards we had just run at Solectron. Starting with the “common setpoints” and the recipes for each of the new boards, I varied the last 5 zones up and down by 10 degrees in 5 degree increments for a total of 3125 different sets of setpoints. Then I added 5 different conveyor speeds including the current speed, +2”/minute, and +4”/minute. After combining them all, there were a total of 105 sets of setpoints with a Schultz Index of under 100, and 18 under 95. This verified that at least one solution would turn all 35 board types “green”. At the time of this writing, Solectron was testing the new “common setpoints”.

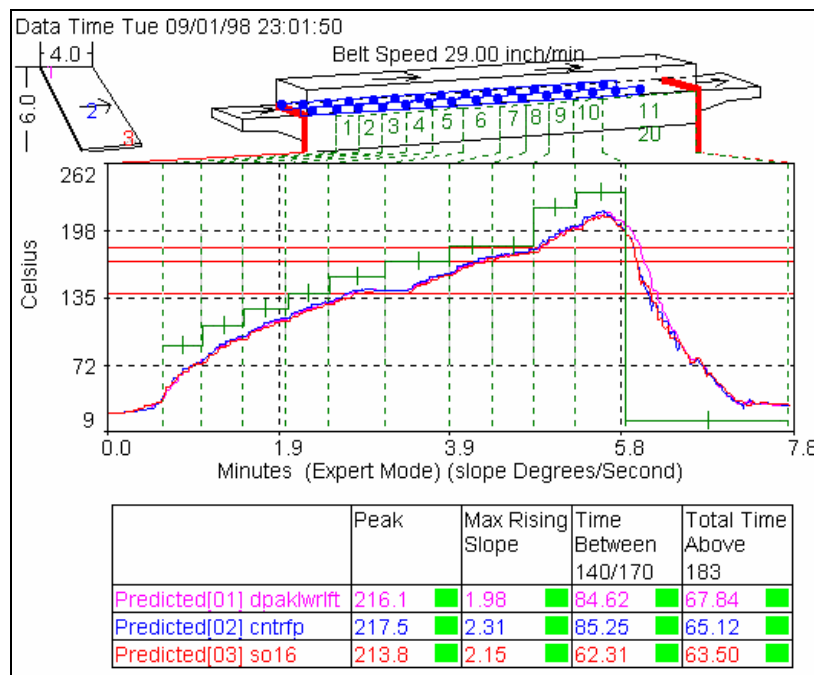
Setpoints	Zone										Boards Processed
	1	2	3	4	5	6	7	8	9	10	
Original 1	90	110	125	140	155	160	170	190	230	250	31/35
Original 2	90	110	125	140	155	160	170	195	245	250	24/35
Original 3	90	110	125	140	155	160	170	190	230	245	34/35
Original 4	90	110	125	140	155	160	170	200	240	250	23/35
Common 1	90	110	125	140	155	160	165	205	225	245	33/35
Common 2	90	110	125	140	155	170	185	185	220	235	35/35

*This table shows the four original sets of setpoints as well as the two new sets of “Common Setpoints”. Notice that Common Setpoints #2 is able to process all 35 boards within spec.*

One critical caveat needs to be pointed out. “Common Setpoints” developed for one oven cannot be expected to work in other ovens. We tried our Magic Setpoints from Line #1, on Line #3 and Line #4, which were both using apparently identical reflow ovens (same make and model). On Line #3, 6 out of 23 board types were not processed within spec, and on Line #4, 3 out of 24 board types were not processed within spec. This is because all ovens, even ovens that are of the same manufacturer and model, will have significantly different thermal characteristics. This is caused by differences in the efficiency of heating elements and irregularities in gas flow.

## Conclusion

The experiment was successful. The automated prediction tool proved capable of finding a set of setpoints that reflowed all 35 different board types within spec with only changes in conveyor speed. This should allow Solectron to change oven recipes without ever having to wait for the oven temperature to stabilize, removing a significant constraint from their production lines and increasing throughput. The implications of the success of this experiment are clear for any SMT assembler running multiple products on a single line.



*Example of a thermal profile using the “common setpoints” that brought all 35 board types on this line completely within spec.*