What's Process Control Good For? Real Data from Real Sites

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Abstract
This paper presents data collected from a set of electronics manufacturers using an automated optical inspection post-place system for the purpose of both defect detection and process-control and process monitoring. The data represent a range of geographical locations (US, Europe, Asia), a variety of different products (cell phones, PC motherboards, etc.), and a long period of time (seven years). Based on these experimental data, we provide real-life dramatic examples of how analysis of both attribute and variable data over the short and long term can help increase first-pass yield, keep first-pass yield steady, and decrease set-up time. These analyses methods can be used in combination with real-time feedback to continuously improve product quality and, thereby, achieve earlier returns on investment.

Introduction
It's no secret that most electronic assembly lines are susceptible to process defects. Paste may be missing, smudged, or excessive. Parts may be missing, mis-oriented, or misplaced. Solder joints may be defective. Such faults play havoc with first-pass yields, sometimes over short time frames, but more typically over extended periods of time, leading to a gradual increase in boards with incidences of faults. Figure 1 shows an all-too-typical yield pattern.

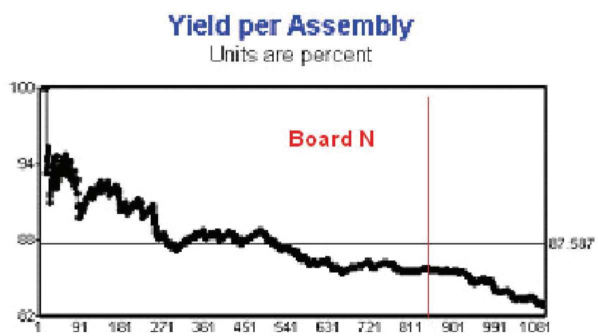

Figure 1 - Typical First-Pass Yield Over Time

Inspection systems in manufacturing environments need to move beyond merely detecting faults to helping prevent those faults through continuous process monitoring. In a typical printed circuit board manufacturing environment, most analysis of how effectively the line is working is performed post reflow or end of line. Defects are detected and data collected either by automated optical inspection equipment or human inspectors. Such data seen in aggregate at discrete chunks of time provide a binary "good/bad" assessment of the process. Typically, this assessment comes too late to do anything about the problems found as large quantities of boards have already been manufactured.

It stands to reason that one can control the printed circuit board manufacturing process more effectively and efficiently by monitoring the quality of the product early in the line and by collecting continuous-valued data and process measurements. Early defect detection and trend analyses can be used to improve line performance and prevent defective product from being produced if the conclusions from the analyses are implemented on the line in a timely fashion.

In order to uncover the root cause of these defects, and take corrective action before the faults become catastrophic, a line manager needs to determine whether the defects are random occurrences or instead are systematic, arising, for instance, from progressive temporal drifts in paste, place, or oven equipment. For non-random faults, the fundamental challenge is to catch the problematic trends early so as to prevent the problems from manifesting themselves later as gross faults. However, in order to meet this challenge, one needs data of the kind that few companies currently have.

Few manufacturers making the choice to implement AOI have sufficient long-term data about what is happening in their lines at post-paste, post-place, and even post-reflow to make an informed decision about whether these process measurement machines provide sufficient return on investment. Thus, most of them settle for end-of-line defect screening and repair.

There are several reasons why such data have historically not been collected and systematically analyzed. The first is that data collection and analysis takes time and resources. Often line managers and AOI experts are so preoccupied with trying to keep the line up and continuously running that they do not have a chance to gather data for subsequent systematic analyses.

The second reason is that for the kind of process-monitoring scenario we have outlined, it is much more useful to have the inspection system produce variable data rather than merely “go/no-go” decisions (attribute data). Furthermore, the repeatability and accuracy of the variable data needs to be nearly an order of magnitude higher than that of the assembly device, such as the pick-and-place machine. The ability to provide variable data with the required accuracies and repeatabilties have simply not been readily available thus far. For a post-place inspection system, this means that to look for drift in the placement of a 0402 device, a post-place inspection machine has to have a precision of 100 microns and a repeatability of measurement of +/- 10 microns or a GR&R of 10%.

Data & Results

Over the past seven years, we have used the Landrex Technologies Optima 7200 AOI system to profile the assembly processes of several different customer accounts and analyze their post-placement process. The Optima 7200 is a post-place inspection system that provides attribute data (such as “missing part,” “wrong part,” “wrong label”) as well as variable data (e.g., precise and repeatable measurement of part position). This analysis was done at electronics manufacturers in Asia, Europe, and the United States, and included a range of board types (cell phones, PC motherboards, server boards, etc).

We have found a number of surprising results that show how careful analyses of the data, at a few different “levels,” can generate significant first-pass yield improvements over short spans of time.

In the rest of the paper we describe six different “levels of analyses:”

1. Machine-Level Analysis
2. Part-Level Analysis (Attribute Data)
3. Part-Level Analysis on One Board (Variable Data)
4. Part-level Analysis Across Boards (Variable Data)
5. Board-Level Analysis Across Lines
6. Board-Level Analysis During Setup

Machine-Level Analysis

Collecting and analyzing AOI data at the simplest level can reveal defect patterns that if fixed or rectified can change the yield of a line dramatically. At one customer account, the customer inspected 1 million boards. Three separate placement machines were assembling each board. After analyzing the defects over several months, the customer found that the third placement machine contributed 71% of the defects. (See Figure 2.) When the customer corrected the defects caused by this placement machine, the first-pass yield had a significant jump.

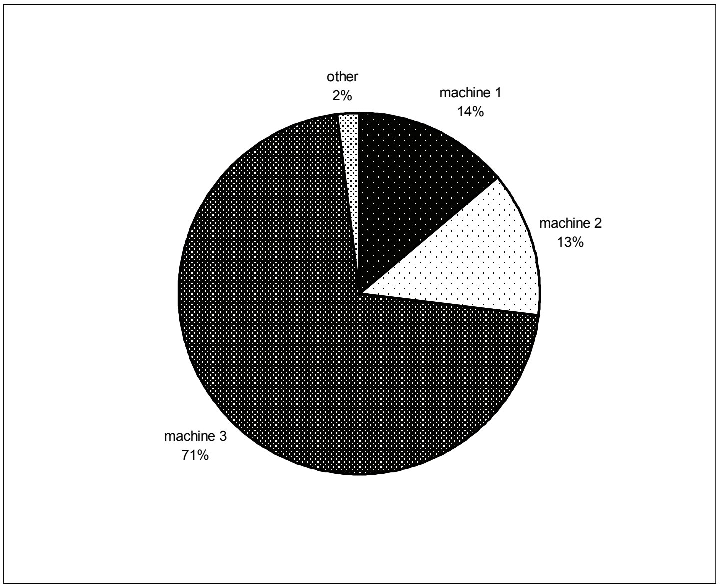

Figure 2 - Defects Analyzed By Parts-Placement Machine

Part-Level Analysis (Attribute Data)

Sometimes the root cause "fat rabbit" of the yield drop is related to only a few parts, as Figure 3 illustrates. We analyzed the data from a run of boards over a two-week period. A simple Pareto chart of the defects shows that only three parts contribute to the majority of the defects. In this case, the offending parts were a SOT, BGA, and tantalum capacitor. Finding and correcting the source of the problem for these three parts decreased the number of defects on the board by 80%.

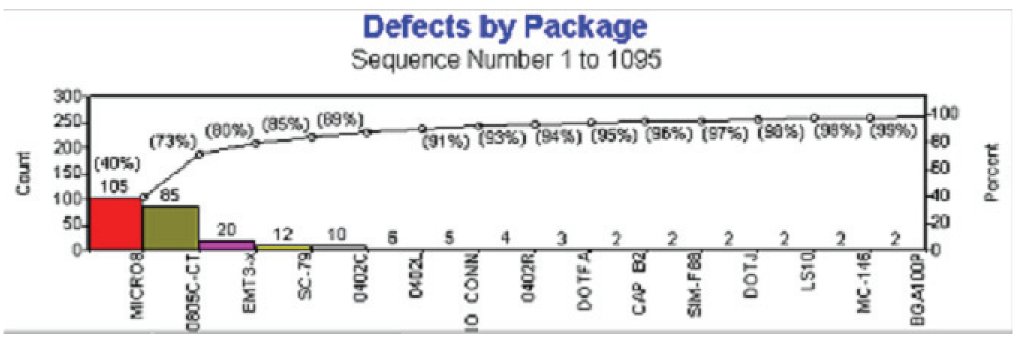

Figure 3 - Defects Analyzed By Device

Part-Level Analysis on One Board (Variable Data)

Variable part-level analysis yields an even greater level of information regarding the causes that are contributing to low yields. We analyzed the variable data associated with the attribute data presented in Figure 3. The attribute chart in Figure 3 shows a very simplistic view of the process. However, the variable data reveals far more information.

In this case, we reviewed all the part placements for one particular board. We plotted the difference between the expected part location and the found part location (see Figure 4). This view of the board tells an even more dramatic story about what is happening in the process.

In the scatter plot chart (Figure 4), each black dot represents a different instance of the part on the board, and each rectangle represents a class of parts denoted by their reference designator. The plotted rings around the part dots are the 4-mil and 8-mil process limits. From the plot, it is easy to see that there are five classes of parts that are significant positional defects because one or more instances of the part are placed more than 8 mils away from their expected position. Reference designators H11, U2, J5, U4 and C33 all have one or more part placements over or around the 8-mil limit circle. Some of these major defects are captured on the Pareto chart in Figure 3.

However, the real story is more interesting. A deeper analysis shows that there are three to five more classes that are not currently gross defects (e.g. they are not outside the 8-mil process control limits). These include reference designators J3, U6, U5, and H115. However, these parts are being placed more than 4 mils away from the expected position. These parts soon will become real defects. In addition, the plot shows that the majority of the parts are being placed off center. If this centering issue is not corrected, then there could be a catastrophic number of defects later on subsequent boards. Board-level analysis of several boards in the sequence shows the same signature pattern, indicating that this is not a "one-off" problem.

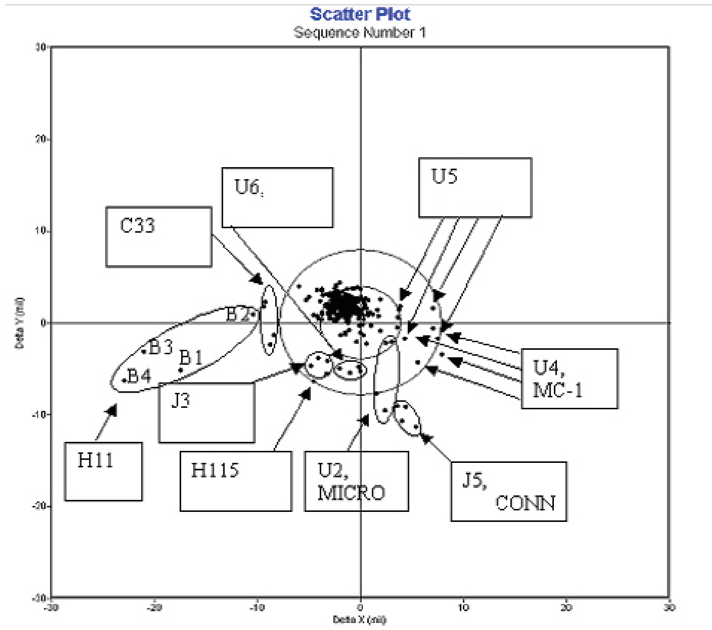

Figure 4 - Scatter Chart Showing Difference between Expected and Actual Part Position

Part-level Analysis across Boards (Variable Data)

One question is what is the root cause of these positional defects? The plot in Figure 4 suggests that there may be a centering problem. However, this doesn't account for the whole story. One of the parts being consistently misplaced is a SOT. When we review the positional data for the SOT *across boards (*Figure 5), we see that the SOT positions are always off pad but in a seemingly random manner. When we plotted the dx, dy data for the SOT over time, however, it was easy to see that the SOT was not being placed in a random manner but was being placed at a constant displacement in a radial direction around the expected position. This telltale signature is indicative of a bent nozzle. Once the root cause was identified, the problem was quickly fixed.

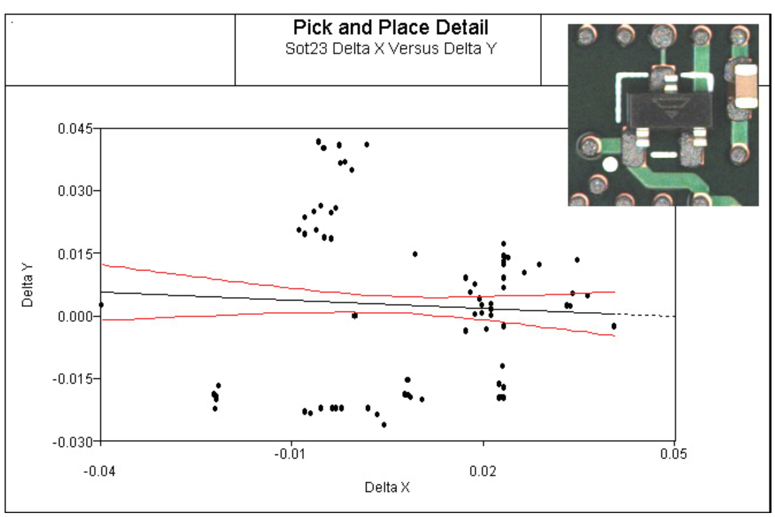

Figure 5 - Positional dx, dy Data for the SOT over Time

Board-Level Analysis across Lines

Board-level analysis shows interesting patterns both across different machines and within the same machine. One common hypothesis is that two lines with the same equipment building the same board should produce similar processes and similar yields. We tested this hypothesis by performing an experiment in which we put two Optima 7200 AOI systems in two seemingly identical lines building the same board and characterized the process on each line over time.

Remarkably, we found that the two lines had completely different defect profiles and different processes (see Figure 6). The first line had many gross defects (about three times as many as the second line). However, the majority of the parts were being placed well within the 4-mil tolerance window. The second line, in contrast, had relatively few gross defects. However, the placement process was not well controlled. The majority of the parts were being placed anywhere from 2 to 6 mils off center. While the first line may look like the more problematic line due to the number of real defects it was producing, the second line was likely to be far more problematic in the long run. The good news is that with access to the variable process data, one can catch both large and subtle issues before any more boards are built incorrectly.

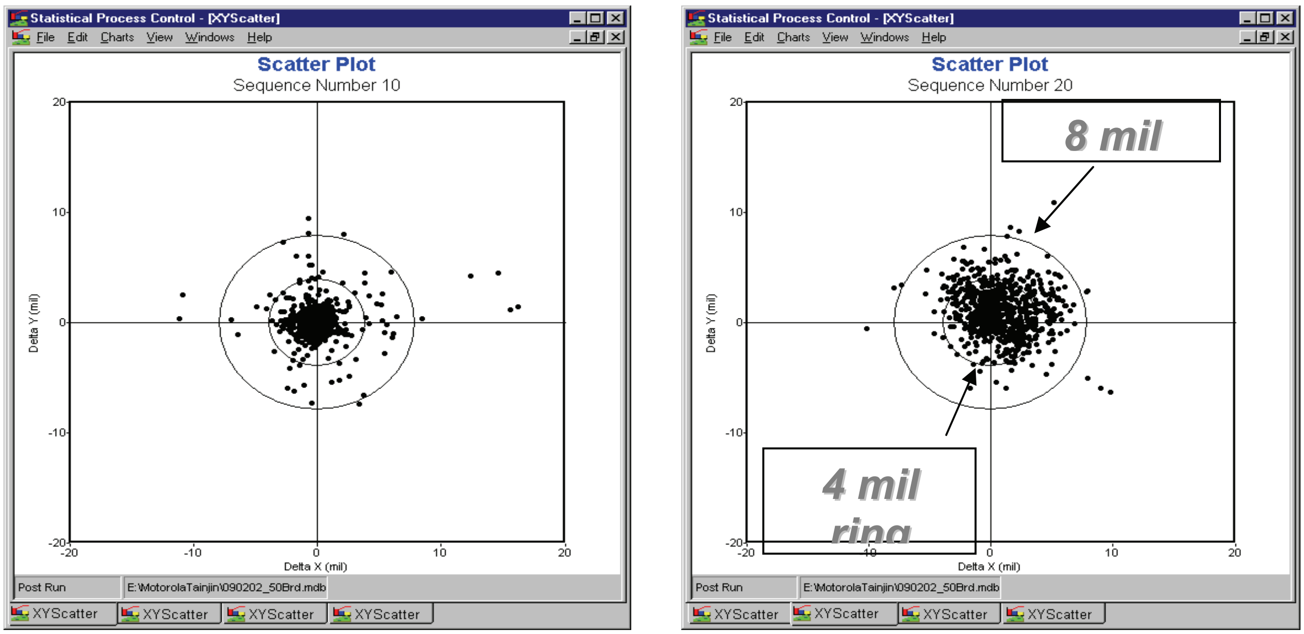

Figure 6 – Scatter Plots Showing Unique Defect Profiles of Two Supposedly "Identical" Lines

Board-Level Analysis during Board Set-up

Tweaking the parameters of the paste-deposition machine, placement machines, and oven profiles can have a large effect on the performance of the line. However, it is difficult to tell just how much of an effect changing a parameter on each of these machines makes in creating good/bad boards. Many times adjustments are made, the results are "eye-balled," and further adjustments are made as a result. It is very useful to have variable data that has high-resolution accuracy and repeatability to actually measure the effects of changes. Figure 7 shows the actual placements of 0402s under different placement machine parameters (e.g. speed, height). The resulting plots are dramatic. They show how even small differences in the machine parameters can have dramatic effects on the placements of the 0402s. The following plots show 0402s from six sequential boards produced under different placement conditions. The difference between the expected position and found position is plotted. The outer visible ring is the 8-mil process limit.

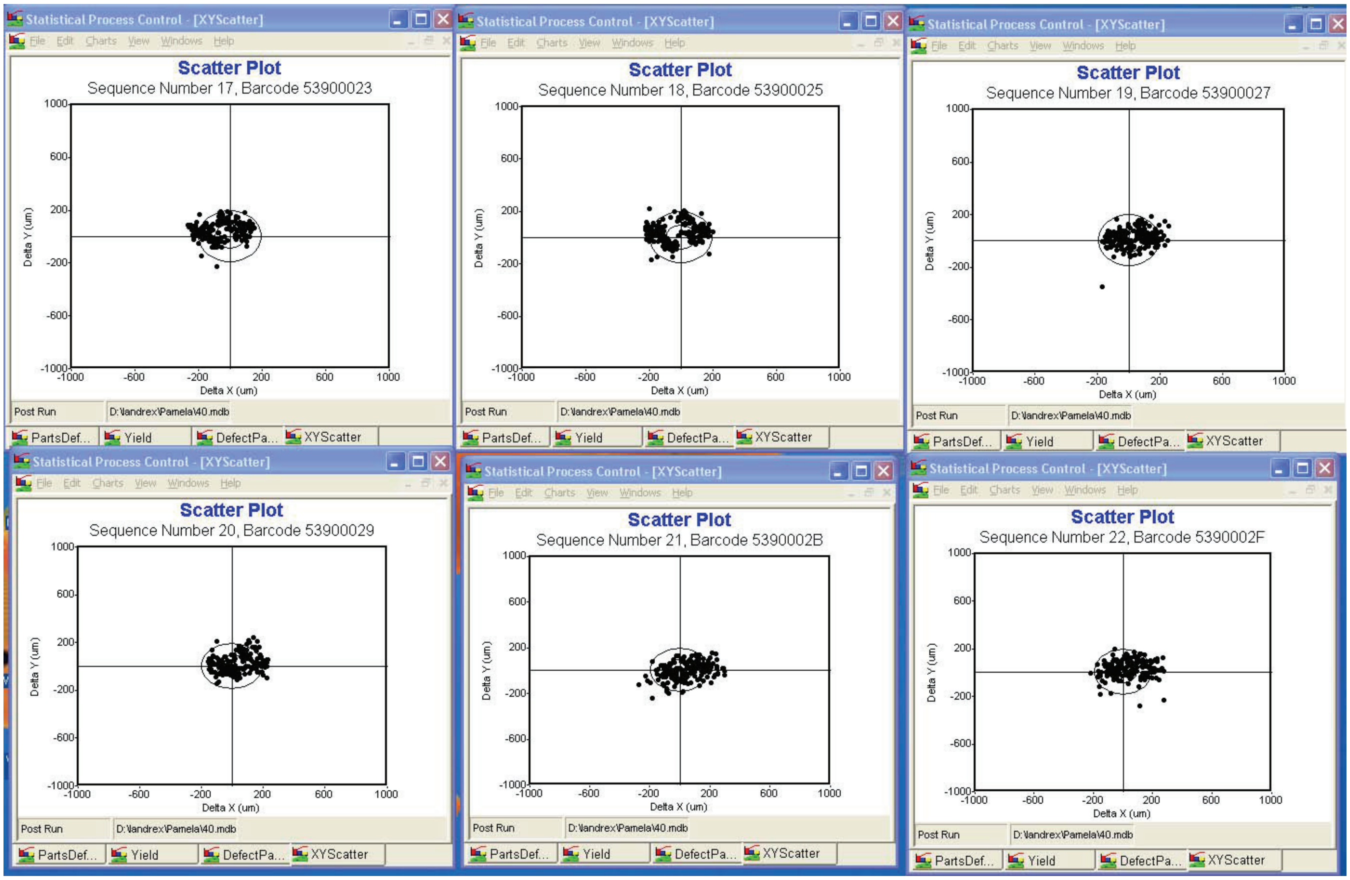

Figure 7 – Scatter Plots from Six Sequential Boards Produced under Different Placement Conditions

The first observation is that none of these sets of components are being placed within the 4-mil limit. Each has a different scatter plot signature – one lobe, two lobes. Some have tighter placement distributions, while others have widely scattered distributions. The boards also differ in the average center of the component placements.

The lesson learned from this example is that small changes to the placement machine make a big difference in how the components are placed. Analyzing the actual measurement data during the set-up process can help machine programmers to find the optimal parameters for the manufacturing equipment prior to building a great deal of boards.

Conclusion

Our primary goal in this paper has been to show that different levels of analysis can signal various process attributes and issues. Patterns evident in attribute and variable datasets provide insights regarding root causes of problems, and permit their correction before they can become catastrophic in their consequences. Using process data generated over time by an optical inspection machine enables the user to make informed decisions about the line performance and to reduce the need for reactive tactics.

Process monitoring provides three significant benefits. The first is increased first-pass yield–a direct consequence of fixing major problems and preventing problems before they can create faults. The second is that yields for an existing board can be kept exceptionally high. We found a striking illustration of this at a line where a customer used the Optima 7200 AOI system to increase line performance over a five-month period and over a set of 1 million boards. The customer was able to decrease defects by an order of magnitude and keep the defect level consistently low by using data from the machine to make process corrections on a regular basis.

The third benefit is a reduction in setup time. We have found that customers can use data from the AOI machine to quickly stabilize a new board being built on a line. Customers have been able to stabilize their line in less than 50% of the time it took them before they resorted to process monitoring. They were thus able to build boards right the first time, thereby reducing scrap and rework and increasing margins.