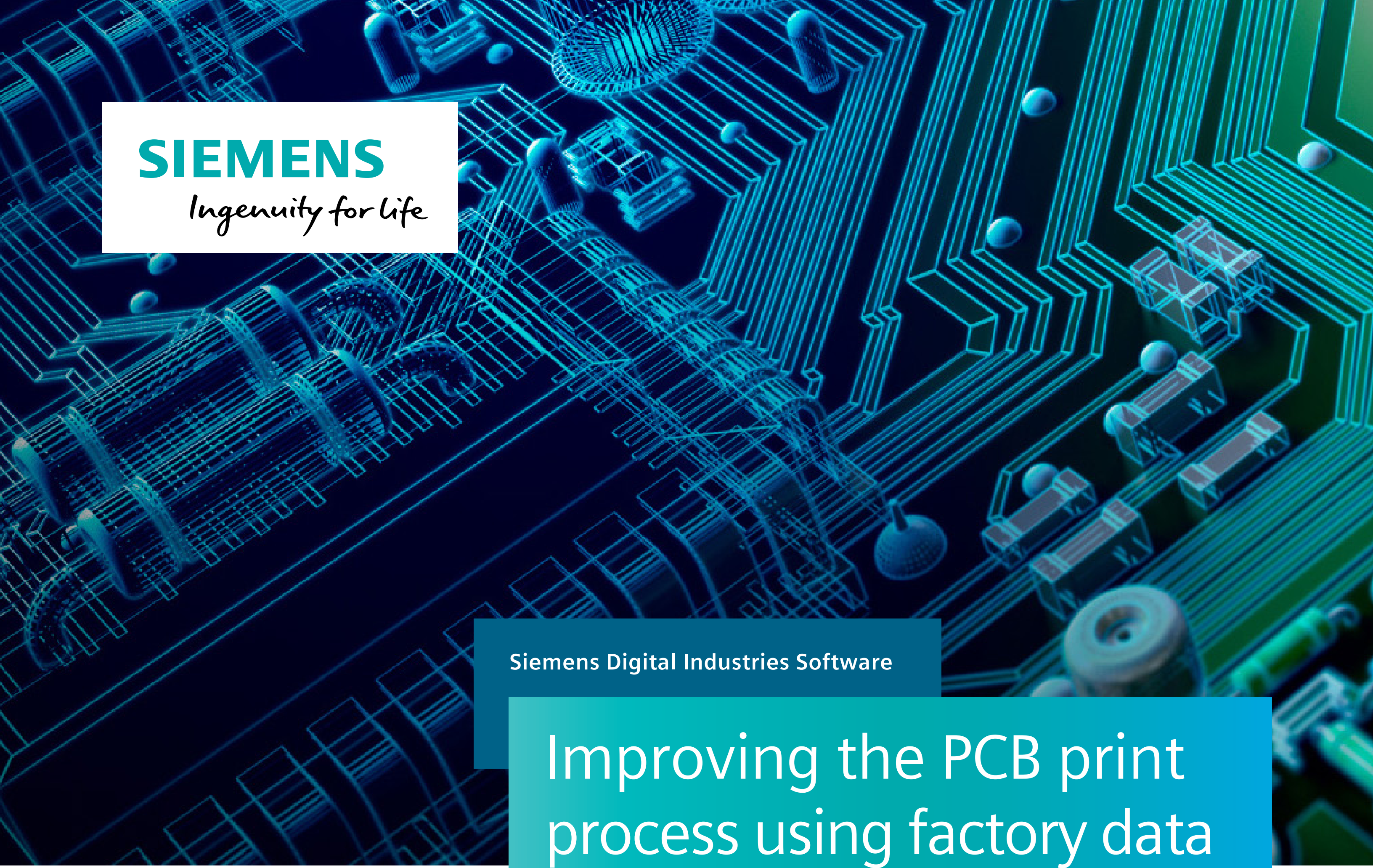

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Improving the PCB print process using factory data

Industry 4.0 – How we transform a buzzword into manufacturing excellence in electronics

Executive summary

Data collected from the shop-floor drives the MES operation and the material flow. However, the value to this data does not stop there. Digitalization of the operation enables analysis and understanding of what is happening in the factory, why it is happening, and how to improve and finally how to avoid it. Although the amount of data generated by manufacturing operations is increasing exponentially, only a small portion of it actually gets collected, and an even smaller portion is analyzed in the electronics industry. In the use case presented here, we will demonstrate how manufacturers can benefit from collecting this data and applying analytics.

Martin Franke, Siemens AG, Corporate Technology, Research in Energy and Electronics, and Izik Avidan, Director of Customer Success, Valor-Mentor Graphics

Introduction

The competitive pressures that electronics companies experience today are exceptional, even for an industry accustomed to a relentlessly high rate of innovation. Manufacturers are challenged to keep up with customization (lower volume and higher mix) and globalization. Material shortages and longer lead times means it is harder to maintain inventory. Compliance is also a challenge as more requirements are coming from customers, as well as new demands for example with electronic vehicles. New manufacturing best practices are crucial to meet these challenges.

Data collected from the shop-floor drives the MES operation and the material flow. However, the value to this data does not stop there. Digitalization of the operation enables analysis and understanding of what is happening in the factory, why it is happening, and how to improve it. Although the amount of data generated by manufacturing operations is increasing exponentially, only a small portion of it actually gets collected, and an even smaller portion is analyzed in the electronics industry. In the use case presented here, we will demonstrate how manufacturers can benefit from collecting this data and applying analytics.

The biggest challenge with collecting data is turning big data into smart data that provides insight or foresight, can be understood as the point of consumption, and is immediately actionable on the shop-floor. There are three areas in which big data can be useful today in production to take immediate advantage from the amount of data.

The first is to improve our understanding of the process, so that we understand better the physical effects of what we are doing on the process. For example, we know that there might be an influence of the temperature at the reflow soldering in a certain extent, but we do not know if the temperature varies about three to four Kelvin in the reflow soldering process. We do not know whether this already has an impact on the AOI (automated optical inspection) quality or on the soldering quality. The analytics of big data could help us to understand that process better. If we understand our process better, we can buy better equipment and select the parameters more carefully. This could generate ROI in the long-term.

The second area is to improve quality. For example, we could better understand the impact of the incoming quality of our materials, which can reduce our scrap rate on a longer run. In this paper, we will present an example of how to use the data to improve quality in the printing process.

The third area is the most profitable: using the data to improve throughput. Once we have the data in-hand and are able to read the relevant information out of the data, we can judge from the overall quality on the line that the quality in all the single processes is so good, we can reduce the test level without jeopardizing overall quality.

Methodology

The printing process is the first process step in the assembly. We print solder paste, then we pick-and-place components, and finally the board is reflow-soldered. The printing process is a major contributor for yield losses in electronics production. As a rule of thumb, people say that around 60% of all the failures in electronics production have their origin in the printing process. To understand this process and to have this process under control is key in keeping the quality level in the line.

The solder paste, which is the major material working with in this process step, has a so-called "shelf life". Once we open the package, then the shelf life starts, and it defines how long you can work with a material once a package is opened. The other important time consideration for solder paste is the dwell time. The dwell time is the time once you stopped the process. Assuming the solder paste is on the stencil, the solder paste will remain there while the line is not running. Solder paste changes its viscosity and printing properties over time. If you move the solder paste over the stencil, it changes its viscosity. Once it sits idle for a while, the viscosity will be different in comparison to continuous production.

Among others, a factor called "transfer efficiency" is widely used to monitor the quality of the printing process. The transfer efficiency is a ratio between the volume of the paste, which was deposited after the printing on the circuit board, and the (theoretical) volume of the stencil aperture. This is a factor we are looking at in this use case: how is the transfer efficiency affected by the solder paste that has been sitting idle on the stencil? If we can keep the transfer efficiency above a certain level or even improve it, we have the potential to reduce the scrap rate and rework efforts.

We conducted these tests in the Corporate Technology lab in Berlin. Figure 1 shows the line, with the screen printer and solder paste inspection machine (SPI). The line is connected via a closed-looped IoT network infrastructure, so we were able to gather the data directly from the machines automatically as we ran the tests. We collected the process data into a SQL working database first. Then it was normalized, enriched with design data, and finally loaded into a Hadoop database, also this task was performed automatically. Finally, we used business intelligence software to visualize the data.

We selected one of our test structures for this experiment: an 80 x 80 mm printed circuit board without electrical function (Figure 2). This board reflects a typical range of electrical components used in state-of-the-art electronic products. The stencil thickness is 120 µm. The solder paste has a powder type 3. For our tests, we ran six lots through the line with 20 boards per run, and tested the three dwell times (0, 60, and 120 minutes) and two paste conditions – fresh and used.

Figure 1: Machines used for this study.

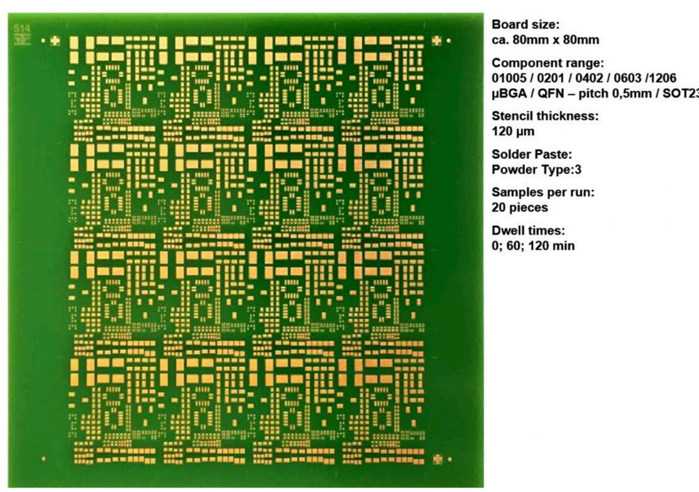


Figure 2: The test structure we used.

Data

We wanted to visualize the effect of the dwell time on the transfer efficiency. We tested different package forms for passive components (capacitors, resistors, inductors); our example here shows component package "0201", which is a passive component mainly used in the mobile phone industry (Figure 3). In the two pictures shown here, we can see the effect of the dwell time. The amount of solder paste was reduced dramatically after 120 minutes. We wanted to understand this effect in more detail, such as when does it get critical, where are the limits, and what can we do as a corrective measure?

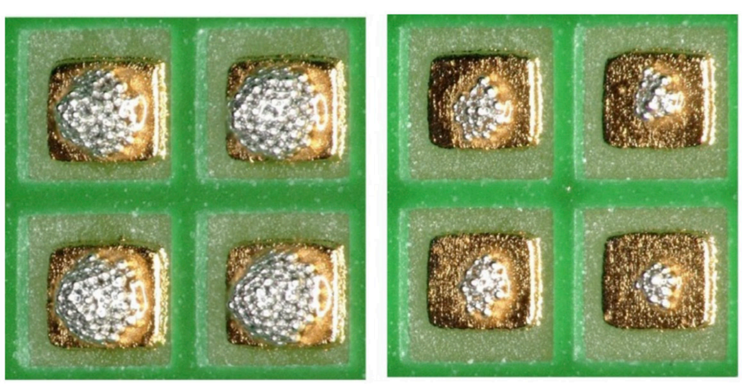
Table 1 shows the test parameters used in the experiment. We made and tested 120 boards. Each board has 3,504 measurement results. SPI results deliver the relevant data of the printed solder paste deposits. We measured the printed area/volume, offset in X, offset in Y, and the height of each solder deposit.

The following analysis was done on the result set so that we could understand the data patterns, possible correlations, and data distribution:

- Outliers detection using 6 Sigma model.
- Box plot analysis for each measurement name and each test parameter.
- Statistical analysis for tests results.
- Population clustering for each measurement name.

Run	PrintSpeed	SqForce	Cleancycle	PasteType	PastePrecon	DwellTime
[#]	[mm/s]	[N]	[#]	[$]	[$]	[min]
01	80	40	5	1	fresh	0
02	80	40	5	1	fresh	60
03	80	40	5	1	fresh	120
04	80	40	5	1	aged	0
05	80	40	5	1	aged	60
06	80	40	5	1	aged	120

Table 1: Test structure parameters.



Component 0201 @ 0 min **Component 0201 @ 120 min**

Figure 3: Dwell-effect on solder paste.

Results

Initial analysis indicated two out of four test parameters had an impact on printing efficiency: print order and dwell time.

(Paste state and type did not have enough variety to make an impact.) The age of the paste does not seem to have enough variety to conclude on an impact. There is a noise effect, but this is not a significant effect.

The box plot analysis (Figure 4) is a way to describe a statistic of distribution. We ran statistical analysis for the test results, and the box plots show a population clustering for the relevant components on one board. Each colored column represents one printed board with 736 equal solder deposits for the 0201 component. A box plot is a graphical display of statistical data based on the minimum, first quartile, median, third quartile and maximum.

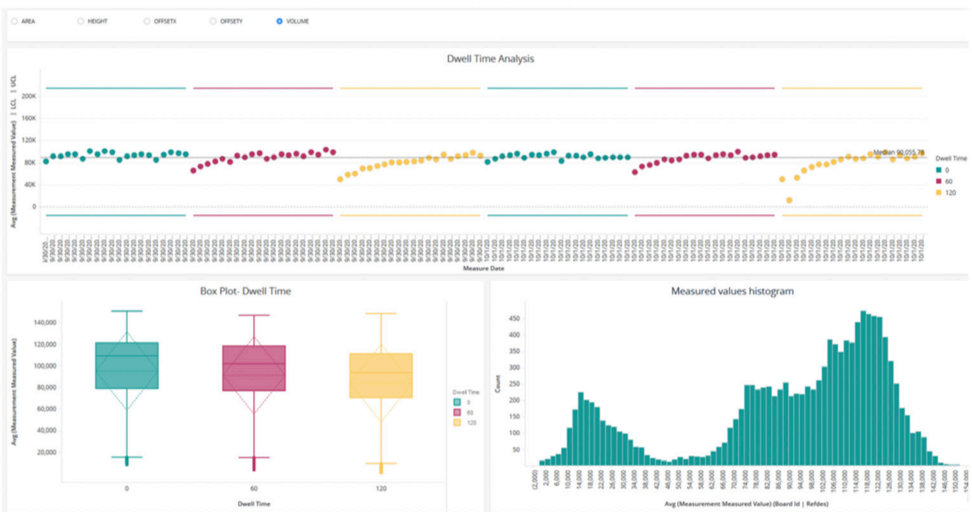


Figure 4: Using business intelligence to analyze the test results.

Dwell-time analysis was conducted for each measurement separately. The impact appeared significant for two measurements: volume and area.

In the following example for the volume test, we see three distinct patterns for each dwell time (Figure 5). The longer the dwell time, the lower the first boards' measured values and the population mean.

In Figure 5, we can see the effect of the dwell time on the transfer efficiency. We have three groups. One is a group of 0 minutes dwell time, 60 minutes dwell time, and 120 minutes dwell time. Let us look at 0 minutes dwell time.

The plot shows we have 100% transfer efficiency, with some process variance.

Once we stop the process for 60 minutes, it takes as many as one to five prints for it to return to the earlier transfer efficiency. So that means we must ensure the first prints have sufficient solder paste on the boards. This effect increases as we wait for 120 minutes. It takes around seven to eight boards until the print process is stabilized again. This demonstrates why making use of the data available is important. Once we understand the effects on the process, we can clearly define limits in the

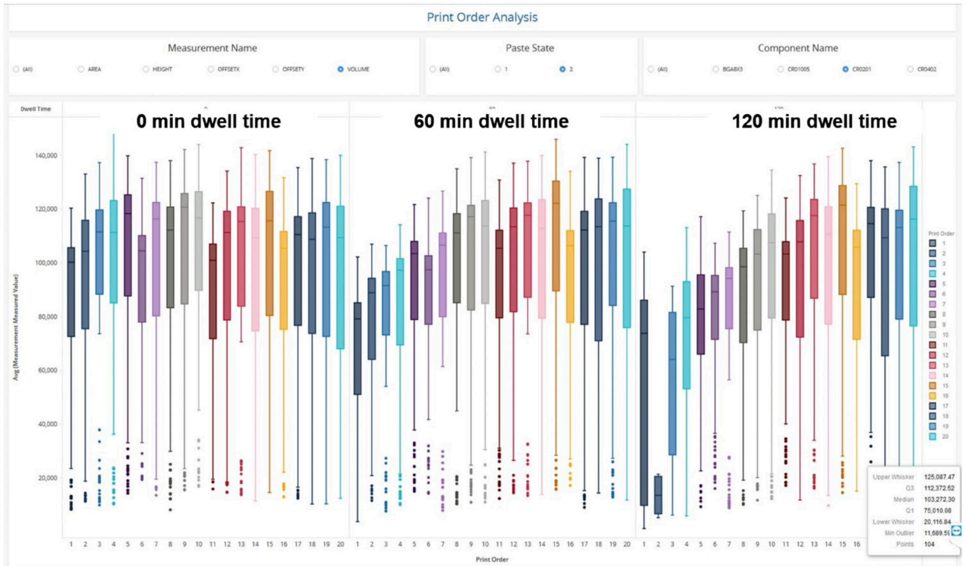


Figure 5: Box plot showing the effect of dwell time.

dwell time, such as a maximum dwell time. For example, if it exceeds 60 minutes, the first five boards have to be removed and cleaned. Alternatively, we have to move with the pace back and forth, for example, on the first board for the first print, before printing productive boards again. This example shows how we can read the data and extract information out of the data, which we can then use directly for the production process.

We could also use the data generated in real time to define process alert levels (Figure 6). For example, if the volume goes below certain level, we could send out in real-time an alert signal to the line operator, to the process engineer or at least to the line to say, "Careful, you are just violating your process control levels." The data also could be used for a kind of statistical process-control approach.

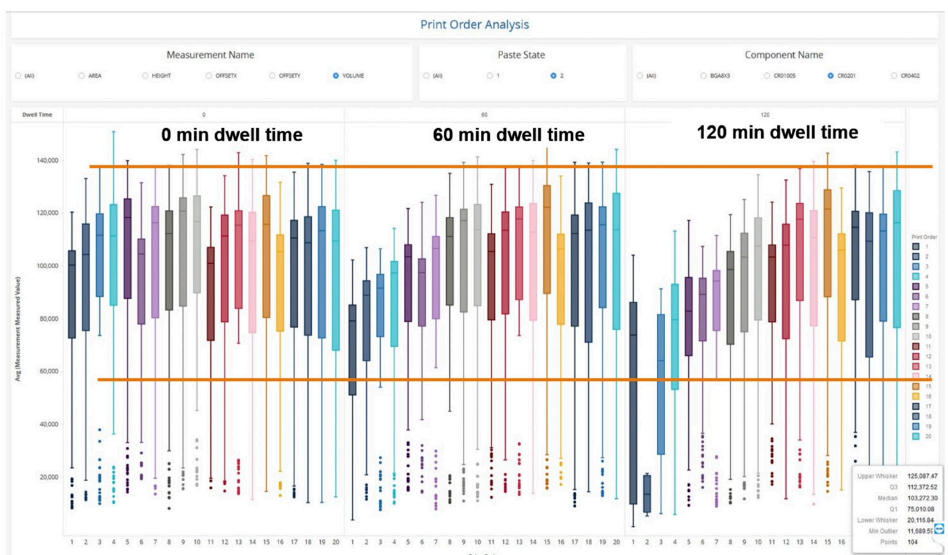


Figure 6: Using the data to determine violation of process-alert levels.

Figure 7 is a box plot that shows the effect of stencil cleaning.

It is clearly visible that a cleaning cycle has been carried out after every fifth board. But, is that really necessary?

Because we can clearly see the effect of the stencil cleaning, we can play with this data to optimize the process; for example, whether this is showing that the effect is that the volume increases, and will further increase until it is cleaned, and if it will increase again. Looking at the data, we could decide to clean after every seventh or eighth board instead, which would save time, money, material, and equipment usage. In this way, we can optimize the cleaning frequency.

As an extra item of interest, we decided to test the effect of paste state (Figure 8). We ran tests with new paste and three-month-old paste. We found that the age had no effect on the process. This was a good demonstration for how we can look at the data to exclude an effect for further investigations.

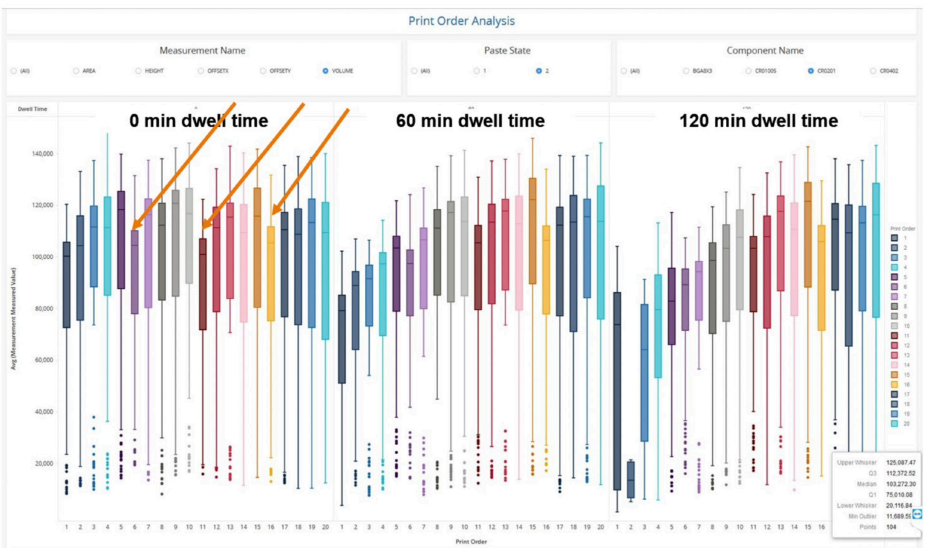


Figure 7: Box plot showing the effect of stencil cleaning.

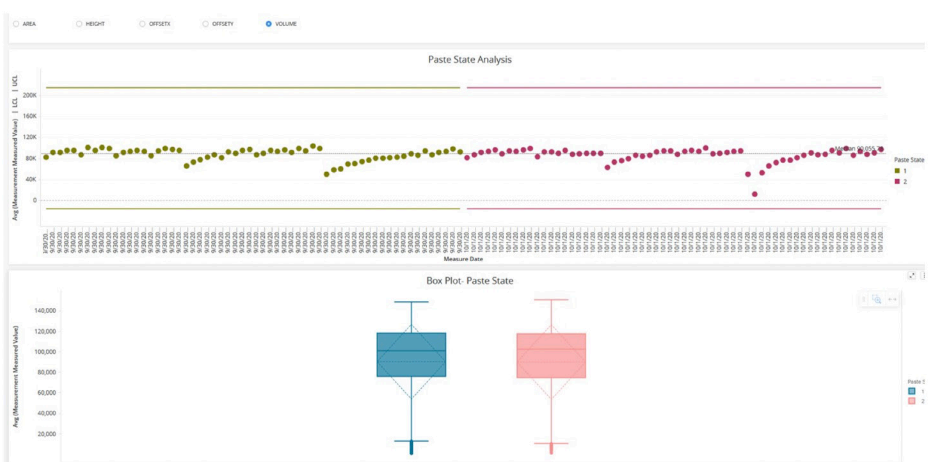


Figure 8: We found that paste state does not appear to affect results significantly. We recommend repeating these tests with additional age groups.

Conclusion

This experiment is one of many where we can demonstrate real-world ROI for the data we are gathering off the shop-floor. By using the data in a systematic way through a connected factory network and analyzing with the business intelligence tools available, manufacturers can take advantage of their data to improve their product and processes today.

The analysis also shows the potential of automated data extraction and preparation, thus giving an process engineer more time caring about evaluation of the data, than preparing it for the evaluation.

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Siemens Digital Industries Software

Headquarters
Granite Park One
5800 Granite Parkway
Suite 600
Plano, TX 75024
USA
+1 972 987 3000

Americas
Granite Park One
5800 Granite Parkway
Suite 600
Plano, TX 75024
USA
+1 314 264 8499

Europe
Stephenson House
Sir William Siemens Square
Frimley, Camberley
Surrey, GU16 8QD
+44 (0) 1276 413200

Asia-Pacific
Unit 901-902, 9/F
Tower B, Manulife Financial Centre
223-231 Wai Yip Street, Kwun Tong
Kowloon, Hong Kong
+852 2230 3333

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