OPTIMAL+
Manufacturing Intelligence

Outlier Detection

White paper

With more than 35 billion semiconductor devices analyzed every year, Optimal+ is in a unique position to observe and identify the root causes of device failure across the entire semiconductor industry. And with increasing focus on quality and reliability across all segments beyond just automotive, medical and mil-aero, it is more critical than ever for companies to leverage every byte of test data at their disposal to ensure that they deliver the lowest possible DPPM (defective parts per million) rates to their customers.

With semiconductor manufacturing operations now generating up to 100TB of test data annually, the ability to analyze trends across global manufacturing supply chains and generate actionable insights in real-time becomes a significant challenge.

Optimal+ Outlier Detection provides the industry's only complete, end-to-end solution for the detection of outlier units from good device populations and is a key component in the establishment of a "quality firewall" by rapidly identifying such outliers and triggering rules-based actions to automatically re-bin them with no manual intervention required.

This solution has been proven in multiple high-volume manufacturing environments to reduce outgoing DPPM rates to the single digit range, resulting in higher-quality electronic systems and lower RMA (return material authorization) rates in the future.

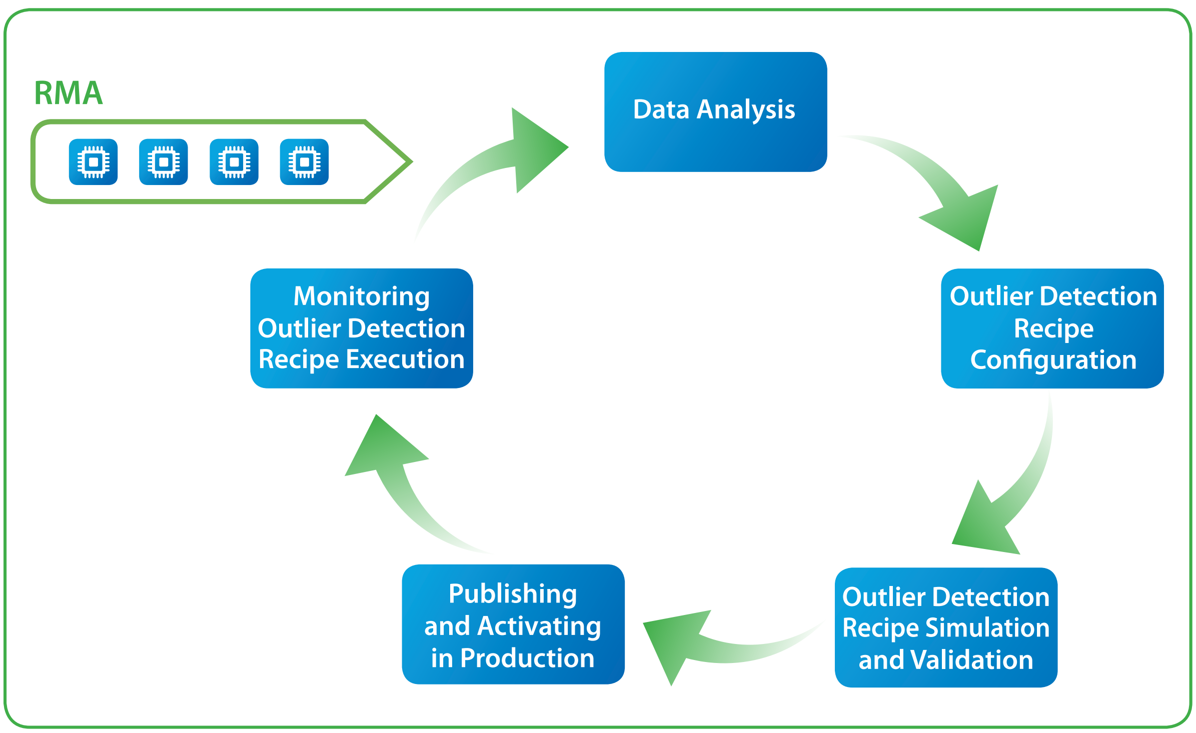

Figure 1: Closed loop solution

OUTLIER DETECTION METHODS

There are many different approaches to looking for outliers in semiconductor test data using the Optimal+ Outlier Detection statistical solution:

- Part Average Test (PAT) Algorithms
- Statistical Adaptive Limits
- Bivariate and multivariate analysis
- Drift Detection
- Quality Indexing

PAT ALGORITHMS

PAT algorithms are used to find an "outlier" across a good population of parts by identifying some combination of abnormal characteristics (parametric and/or geographical). PAT algorithms are statistical by nature and are run on manufacturing test data typically after wafer test. They can also be run after final test when Unit Level Traceability (ULT) data is available. The PAT algorithms used in the Optimal+ Outlier Detection solution consist of industry best known methods (BKMs) and are aligned with the Automotive Engineering Council (AEC) guidelines to identify geographic and parametric outliers.

The algorithms discussed below have been in broad production usage for many years by Optimal+ customers and have been used to successfully screen countless units in both IDM and fabless manufacturing operations. These PAT algorithms, known as "rules" in the Optimal+ environment, are also highly flexible and customizable which allows them to be easily tailored to a specific product's quality requirements.

The user can define a PAT rule (also called a PAT recipe) that is automatically run on the manufacturing data looking for results that fall outside a specific boundary. In addition, due to the high level of integration of the Optimal+ solution in the semiconductor supply chain, any outlier parts detected can be automatically re-binned before the next test insertion, saving significant costs associated with downstream test time and/or packaging and assembly costs.

The PAT algorithms in the Optimal+ Outlier Detection solution include:

- GPAT (Geographic PAT)
- DPAT and SPAT (Dynamic PAT and Static PAT)
- GDBN (Good Die/Bad Neighborhood)
- NNR (Nearest Neighbor Residual)

All of these rules can be aggregated to be run across multiple test insertions (e.g. wafer sort and final test) and across multiple OSATs to enable companies to establish a comprehensive "quality firewall" across their entire manufacturing supply chain. This will be covered in more detail in the Data-Feed-Forward and Quality Index sections.

GPAT

The user has many options to control the "cluster" settings within the GPAT algorithms as shown in Figure 2. The user can define on which devices (Good Bins) the algorithm will be used, and also set up the parameters for cluster identification and identify how to re-bin the devices determined to be surrounding that cluster.

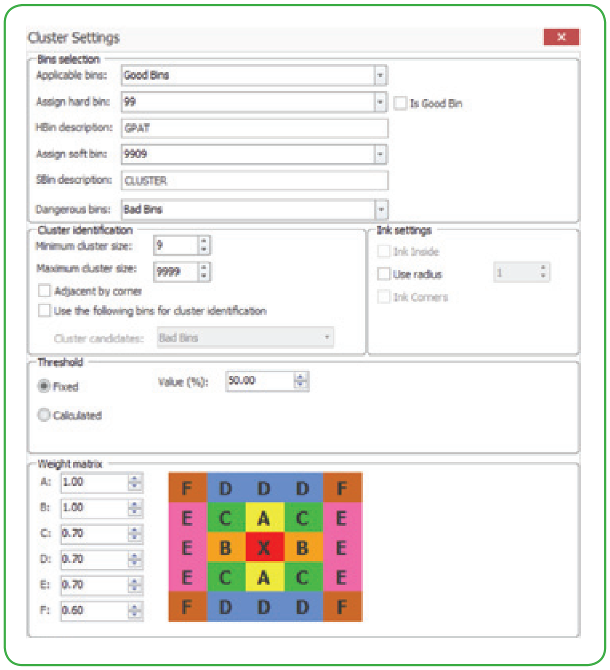

Figure 2: GPAT Algorithm Settings

The wafer map in Figure 3 shows a number of original good dice (marked in blue) which are automatically reassigned from good bins to bad bins after the GPAT algorithm has been run. The automatic bin reassignment is made possible through the Optimal+ global data infrastructure which is available to every Optimal+ customer.

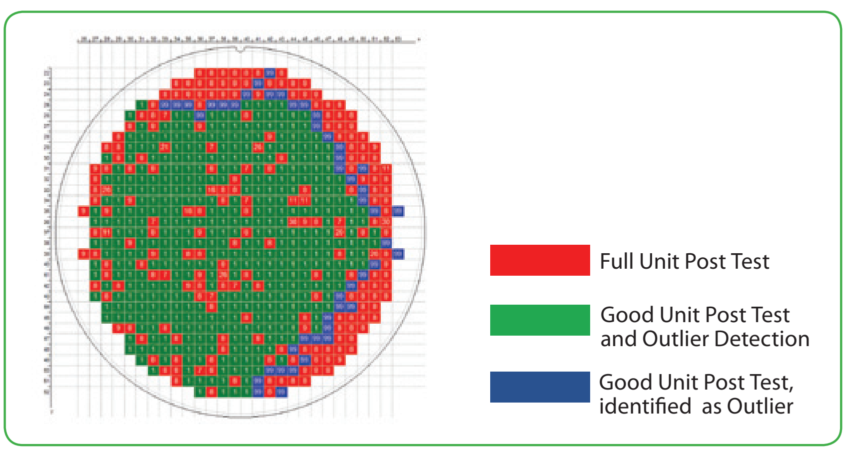

Figure 3: Wafer Map after Outlier Detection

DPAT AND SPAT

Optimal+ Outlier Detection allows users to run either Dynamic PAT or Static PAT algorithms on all tests or a user-selected subset of tests. Test entrance criteria can also be set to filter out tests with unwanted statistical distribution (such as tests which are not continuous). Similar to the GPAT algorithms, a high level of user configuration is allowed for rapid setup on full test coverage while maintaining a high level of flexibility to define specific algorithms per test. In addition, an option to use Automatic Dynamic PAT algorithms is available that takes into account each wafer/lot and test statistics during execution.

The user has many options to control the settings within the DPAT and SPAT algorithms. In Figure 4, the user can define on which devices (Good Bins) the algorithm will be used and how to re-bin such parts. The user can also select any configuration of DPAT algorithms per test or group of tests.

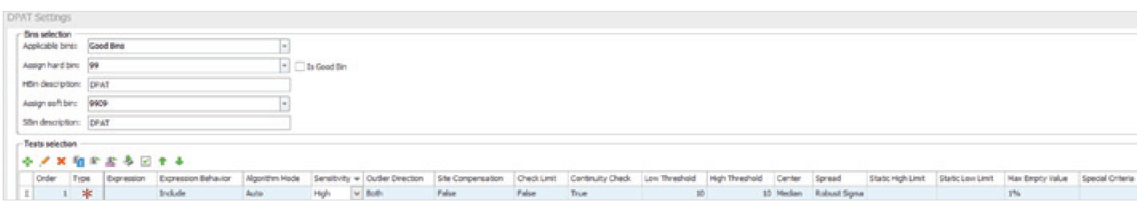

Figure 4: DPAT Algorithm Setting

The histogram in Figure 5 shows the distribution of a test for good parts. Using DPAT, a new upper limit was established resulting one significant outlier that can clearly be seen and will be binned out automatically as the PAT rule executes.

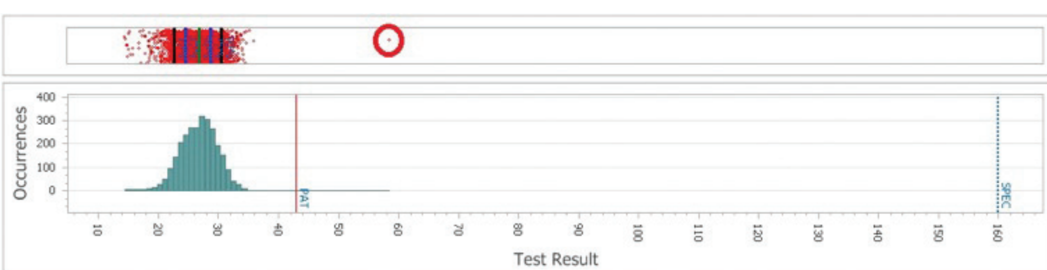

Figure 5: DPAT Algorithm Output

COMBINING RULES AND RUNNING SIMULATIONS TO REFINE RULES

As mentioned earlier, Outlier Detection is one of several software solutions from Optimal+. One of the benefits of being connected to the broader Optimal+ environment is access to a graphical scripting language called Sequoia.

Using Sequoia's simple graphical interface, PAT algorithms can be combined to create a more comprehensive solution for detecting outliers (See Figure 6). In addition, within the Optimal+ environment, users can run detailed simulations and generate reports to "fine tune" any rule and verify its efficiency before it is activated and deployed for use in volume production. Once a PAT rule is approved, its deployment into the entire global supply chain is managed automatically.

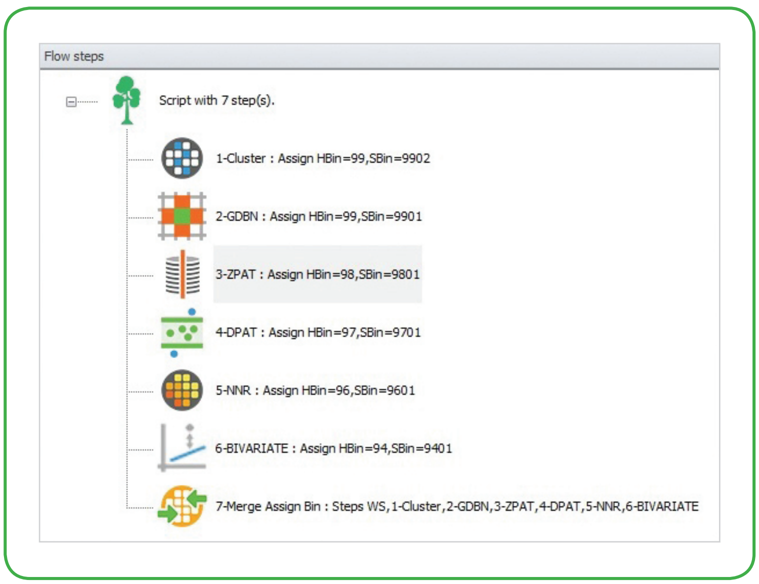

Figure 6: Example of Outlier Detection using multiple algorithms in sequence

STATISTICAL ADAPTIVE LIMITS

In addition to PAT algorithms, Optimal+ also provides real-time rules within the Outlier Detection solution. Users can identify outliers on devices based on statistical adaptive limits that are calculated automatically on baseline material and dynamically updated to the original test program limits. This capability is specifically designed to support devices where ULT data is NOT available and does not require a lot to be re-tested to segregate the outlier parts from the good parts. The major benefit of this type of outlier detection is that it takes into account any change in the performance of the test program results over time.

After the user sets the baseline population needed to start the adaptive limit process and specifies how often such control limits are updated, the test program limits are automatically adjusted by temporarily updating the original test program limits without requiring any involvement by the test engineers. This flow is shown in Figure 7.

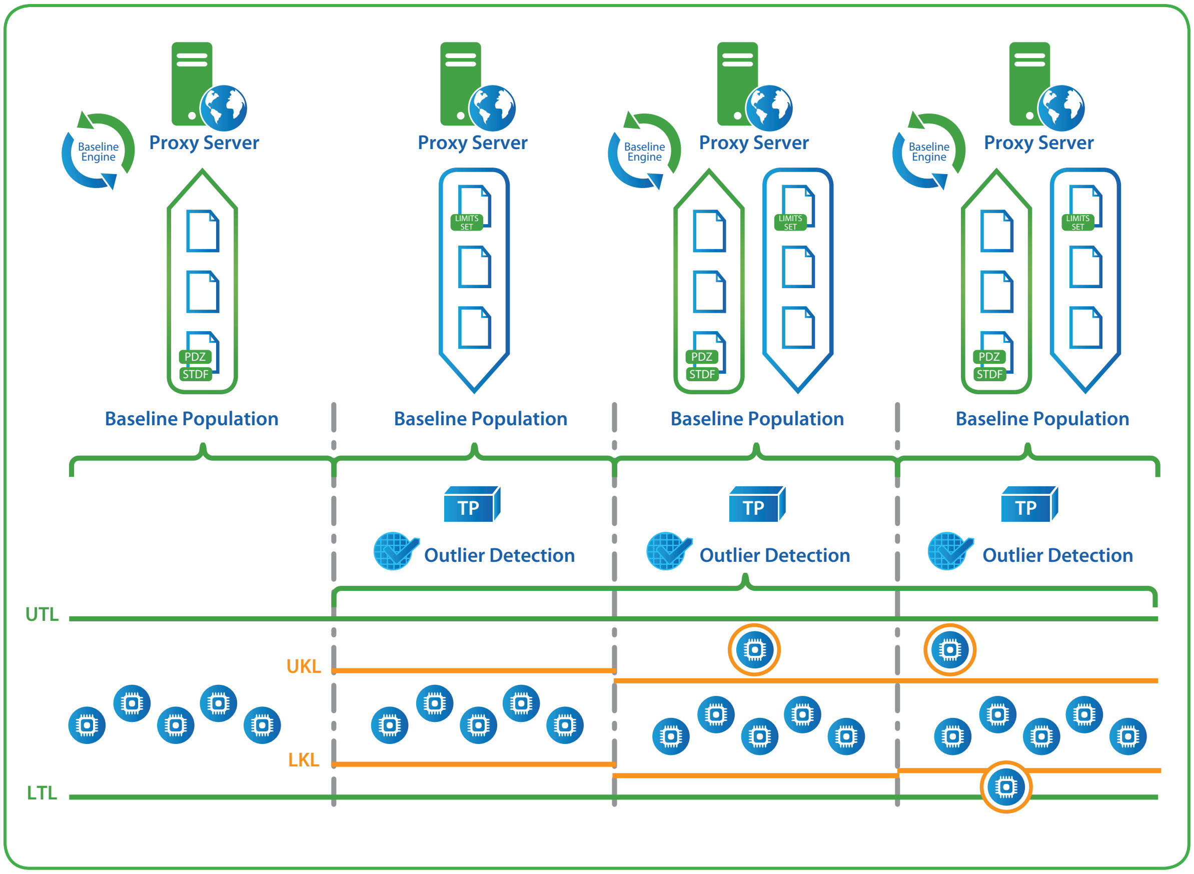

Figure 7: High Level Flow of Adaptive Limits

Outlier Detection also allows the user to track the "native outliers" ("fails" that are outside of the original test program limits) vs. the "adaptive outliers" ("fails" that are outside of the Adaptive Limits) as shown in Figure 8.

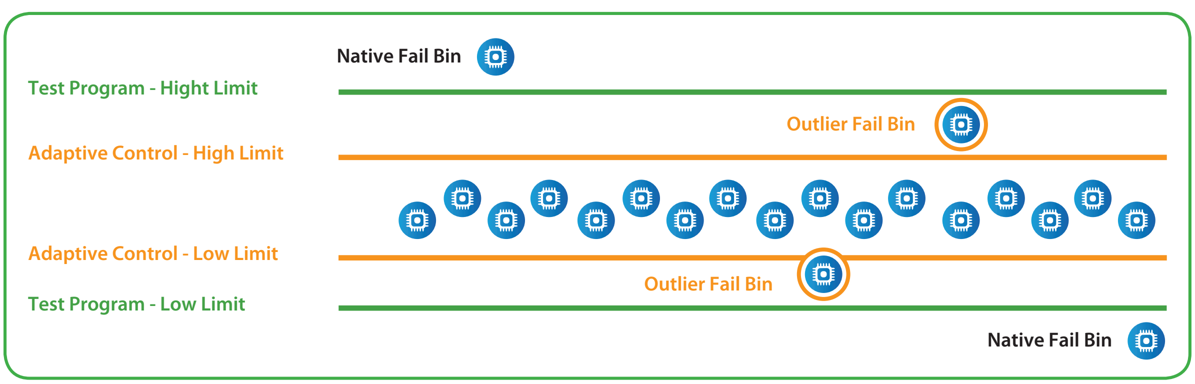

Figure 8: Native vs. Outlier Fails

The chart in Figure 9 shows the actual trend of one test across several tested lots. A user-specified number of lots are used as the baseline to calculate the adaptive tests limits (which are typically much tighter than the original spec limits, shown in the blue shaded region). Once such limits are applied on new lots being tested, outlier parts are automatically binned out in real time.

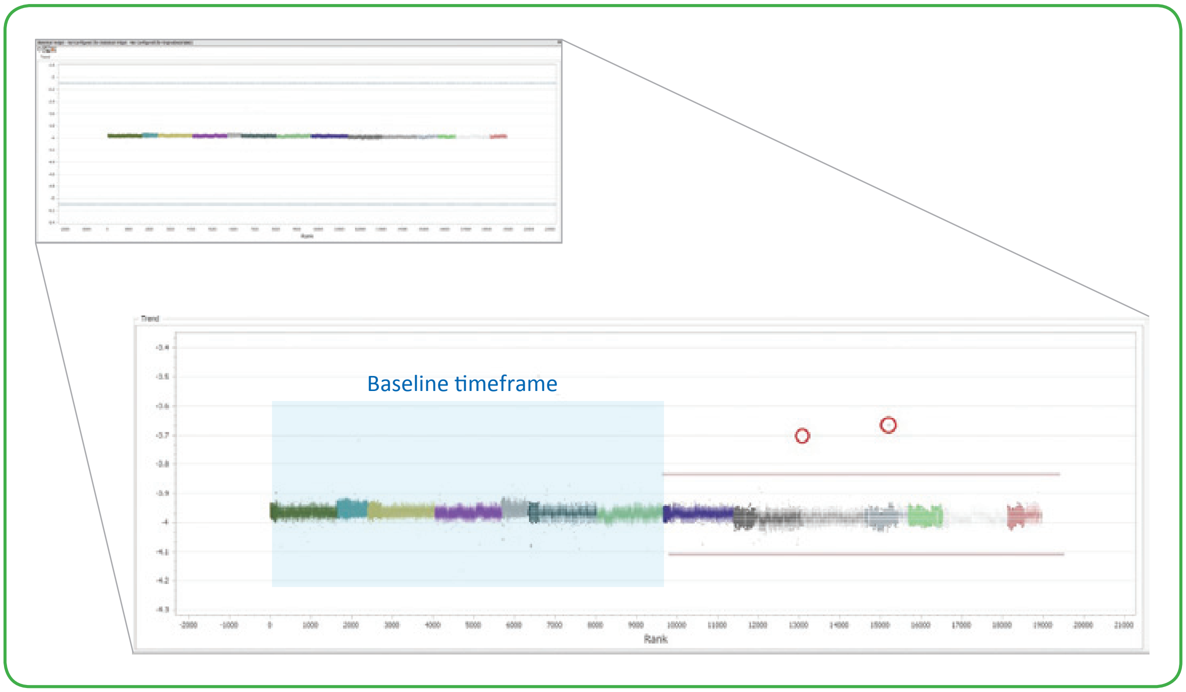

Figure 9: Outliers Identified Via Adaptive Test Limits

BIVARIATE AND MULTIVARIATE OUTLIER DETECTION

The Outlier Detection Solution also includes a Correlation App that supports both bivariate and multivariate analysis that allows the user to automatically find the best correlations among a large number of tests, either within the same test socket or between different test sockets. This capability has become a critical aspect of big data analytics for many companies since bivariate and multivariate outliers have a greater probability of failing at a later test insertion step or at the end customer.

Once any bivariate/multivariate correlation is defined and acknowledged, it is evaluated for every wafer in the dataset and then by using automated rules any detected outliers are re-binned accordingly.

The table and graph in Figure 10 show a strong correlation between 2 different tests (R^2 > 0.99) but a clear bivariate outlier is identified. Note that this outlier unit is well within the distribution when looking at each test individually.

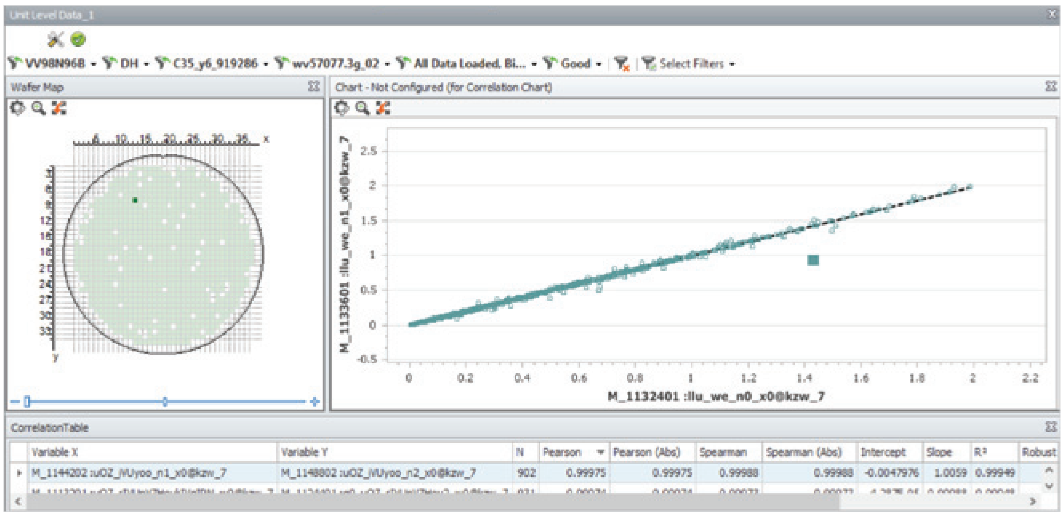

Figure 10: Bivariate Outlier Example

MULTIVARIATE

The charts in Figure 11 show how multivariate outlier detection can be performed using a Principal Components Analysis (PCA) approach. PCA is used for reducing the number of parametric tests by aggregating them into Principal Components (PC's). The left side shows the cumulative variation based on the sum of multiple Principle Components (PCs), with the first 10 PCs comprising ~98% of the variation. The images on the right show the PC distribution of a good lot (top right) and bad lot (bottom right). Using this type of analysis, it is easy to identify the long tail of multivariate outliers in the bad lot.

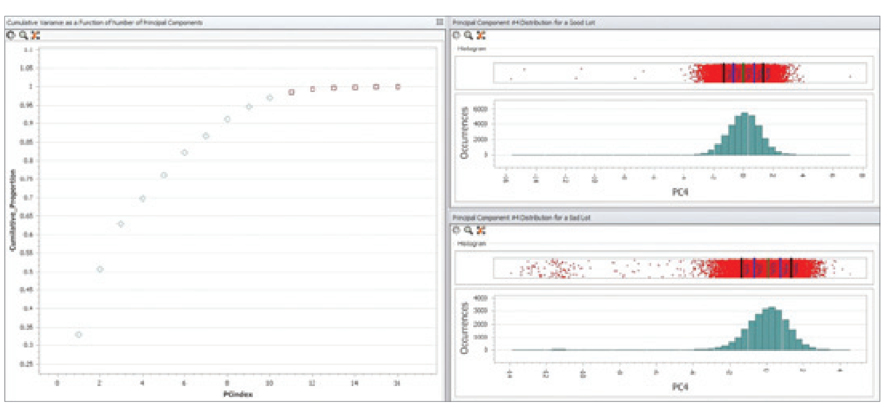

Figure 11: Using Principle Component Analysis to find Multivariate Outliers

DRIFT DETECTION

Another means for finding outliers is through the identification of a "drift" of any parameter measured at different test insertions (e.g. at different temperatures or before & after stress testing). The purpose of testing the same part under different conditions is to highlight a potential quality situation related to a statistically significant difference in measured results. Outlier Detection provides a comprehensive solution for this type of outlier identification which can also be implemented to take place automatically and in real-time through a Data Feed Forward process that can work across a distributed supply chain as well as within a single test floor during wafer sort or final test (usage at final test requires ULT).

For the example shown in Figure 12, while a specific result is measured at the second test insertion, the result from the first test insertion is automatically recalled from the manufacturing test database and the delta is computed between the two results. If the calculated "drift" exceeds a user-defined limit, the part is automatically assigned to a different bin to prevent it from being shipped into the supply chain. Drift detection is already implemented at several Optimal+ customers to ensure the highest levels of device quality for mission-critical applications.

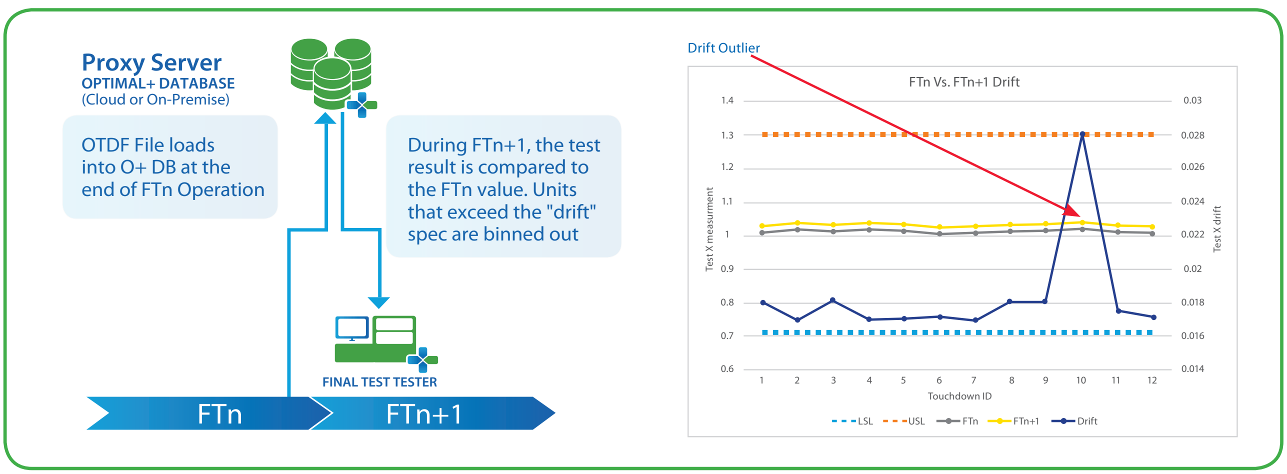

Figure 12: Drift detection example

QUALITY INDEX

The final facet of outlier detection provided by the Optimal+ solution is the Quality Index which is a measure of the "goodness" of the die through the computation of multiple results in the test data. The Quality Index can be comprised of any of the previously mentioned Outlier Detection results (PAT, statistical adaptive limits, bivariate/multivariate analysis, and drift detection) as well any user-selected metadata (the location of the unit on the wafer, the number of times the part was tested, the test equipment health during the time of testing etc.) to establish the complete "test DNA" of a device as shown in Figure 13.

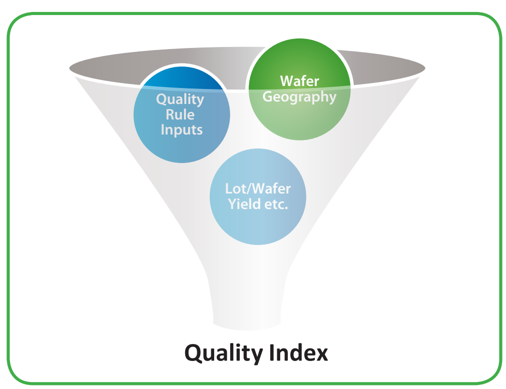

Figure 13: Quality Index – High Level Flow

The index result can then be used to make decisions such as pairing of parts in MCPs (multi-chip packages) or to initiate Adaptive/Selective Burn-In. In the case of Adaptive Burn-in, the index can be used to further reduce test costs with no compromise on the outgoing quality or DPPM rate. The data collection and computation of the Quality Index can be done in real-time and across distributed test insertions.

The plot in Figure 14 shows the distribution of the Quality Index on a large number of good parts. In this example, the parts with the lowest Quality Index are not sent to Burn-In in order to ensure meeting a customer's requirement for zero DPPM.

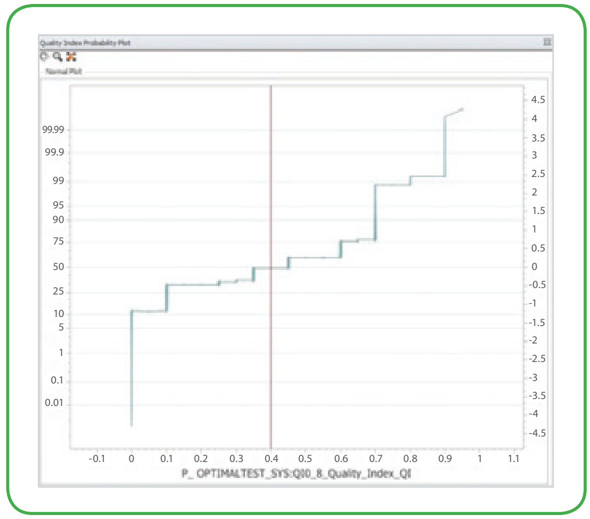

Figure 14: Quality Index Plot

SUMMARY

In closing, the Optimal+ Outlier Detection solution represents a superior approach to maintaining and ensuring the highest levels of product quality and reliability for the semiconductor industry. It is the only closed-loop, infrastructure-based solution in the market and has been proven to limit test escapes, lower DPPM rates and reduce costly RMAs. The solution comprises PAT algorithms, bivariate/multivariate detection capabilities along with fully integrated data-feed-forward analytics and real-time quality indexing to provide the most comprehensive quality coverage for your semiconductor manufacturing operations.

The focus of this whitepaper was to introduce the powerful statistical and outlier detection capabilities of the Optimal+ solution. Outlier Detection is just one component of the "quality firewall" that Optimal+ can provide. To learn about our deterministic Escape Prevention capabilities that compliment Outlier Detection or to schedule a demonstration, please contact your local Optimal+ sales representative at
http://www.optimalplus.com/contact_us.

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