Analytic Solutions For Semiconductor

May 2020
Through the acquisition of OptimalPlus, NI accelerates companies’ digital transformation initiatives by coupling NI leadership in automated test with new advanced product analytics for enterprises.

“We’re confident NI’s enterprise software strategy unlocks the value of test data by embracing digital transformation and bringing it to the analog world.”

Eric Starkloff
NI CEO AND PRESIDENT
It’s A Changed World

Technological innovation has transformed our lives.

Products and devices are more intelligent and connected.

These products rely on thousands of electronic components that must be more reliable than ever before.
Car innovations and new features are driven by electronics\(^1\)

Warranty costs related to electronics and semiconductors\(^2\)

Car recall increase from 2014-2016 due to electronics\(^3\)

Ignition switch failure
Failure to park
Takata airbag recall

15x Drive per day\(^4\):
1.5hr traditional car vs. 22.5hr autonomous car

Audi says
1 car failure every hour\(^4\)

90M cars
$25B

1 Automotive change drivers for the next Decade, EY, 2016
2 BMW - AEC Automotive electronics reliability workshop, 2017
3 NHTSA Recall Data
4 Audi, DVCon Munich, 2017
<table>
<thead>
<tr>
<th>ni.com</th>
<th>SEMICONDUCTOR</th>
<th>AUTOMOTIVE</th>
<th>ELECTRONICS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Founded 2005</td>
<td>Big data analytics with expertise in manufacturing</td>
<td>Open innovation platform for edge deployment of real-time analytics and AI/ML</td>
<td>Product-Centric approach taking I4.0 and IIoT to the next level</td>
</tr>
<tr>
<td>~230 employees</td>
<td>Ready-made solutions for Automotive and Semiconductor industries</td>
<td>Lifecycle visibility across supply chains and industries</td>
<td>Cloud Or On-Prem AWS (partner), Azure, GCP</td>
</tr>
</tbody>
</table>

**Analyzing huge volumes of data**

100bn devices per year

ROI track record and loyal trusted partner
Trusted By Leading Brands

Customers

Supply Chain
Challenges We Address In The Semi Industry

1. Growing chip complexity, including advanced materials, processes, and packages
2. Quality requirements get more demanding
3. Efficiently manage fragmented supply chains – suppliers, sites, equipment, systems
4. Need to improve time to market of new products
5. Continuous pressure on profitability
6. Where and how to use AI/ML to maintain competitiveness
Our Vision

Lifecycle Analytics Through Product-Centric Approach

- Design Spec
- Machine
- Process
- Metrology
- Test
- Rework
- Genealogy
- Performance
- Reliability
- Usage
- Warranty
System Architecture

**Edge (Factory Floors)**

- Fab Data
- Assy. Data
- Tester A
  - O+ Proxy
  - Data ➔ Action ➔ Data
- Tester B
  - O+ Proxy
  - Data ➔ Action ➔ Data
- Tester C
  - O+ Proxy
  - Data ➔ Action ➔ Data
- Other Equipment And Data Sources
- MES

**Central**

- Control Room+
- Factory A (internal or outsourced)

**Factory B**

**Factory C**

**O+ Edge Analytics**

24x7 rule execution and orchestration

**O+ Data Platform**

Edge repository

**Central Analytics**

24x7 rule execution and orchestration

**O+ Data Platform**

Central repository

**Action/Rules**

**PLM, ERP, CRM**

**Portal+**

**www**

**Rules+**

**Cloud Or On-Prem.**

**Actionable Insights Across All Manufacturing And Test Processes**
Semiconductor Solutions

- Quality, Reliability and Brand Protection
- Yield Analysis and Reclamation
- Efficiency
- Time To Market
- Supplier Transparency

AI/ML Deployment For Manufacturing

Data Security

Data Lifecycle
Providing Innovative Solutions

- Collect lots of data
- Use it primarily when there is a problem: Bad Yield, RMA (Returns), Etc.
- Find the problem but frequently not the root cause
- Process is often manual and reactive, not proactive
- Use of many tools, but not an integrated solution

Collect
- Lifecycle data harmonization of any type
- Product, machine and process data
- Data security

Detect
- Prescriptive analytics
- AI / Machine Learning
- 24x7 analytics engine
- Real-time

Act
- Automatic
- Distributed
- Controlled

A unique, automated and proactive integrated solution
## The Value We Bring

<table>
<thead>
<tr>
<th>Quality, Reliability and Brand Protection</th>
<th>Minimize excursions</th>
<th>Minimize RMAs</th>
<th>Analyze root cause</th>
<th>Protect your brand</th>
<th>Comply with automotive standards</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yield Analysis and Reclamation</td>
<td>Improve overall yield</td>
<td>Minimize site-to-site variations</td>
<td>Optimize re-test policy</td>
<td>Identify equipment performance issues</td>
<td></td>
</tr>
<tr>
<td>Efficiency</td>
<td>Enable consistent tester availability and utilization</td>
<td>Avoid excessive index and pause times</td>
<td>Identify test time variations per tester</td>
<td>Ensure efficient retest policies and execution</td>
<td></td>
</tr>
<tr>
<td>Time To Market</td>
<td>Shorten NPI time</td>
<td>Optimize balance between time, cost, and quality</td>
<td>Facilitate multi-team collaboration</td>
<td>Share learnings from NPI to HVM and back</td>
<td></td>
</tr>
<tr>
<td>Supplier Transparency</td>
<td>Benchmark suppliers</td>
<td></td>
<td></td>
<td>Ensure supplier compliance with flows for every chip</td>
<td></td>
</tr>
</tbody>
</table>
Proxy+ is an agent running on the tester, enabling real-time data collection, control and action.

1. **Real-Time Data Collection**
   - Runs on all major semiconductor test platforms
   - Ensures consistent data quality and high-speed delivery
   - Includes a wealth of information not provided in regular data logs for accurate OEE analysis and software/hardware validation
   - Agnostic to, and supports all test programs

2. **Real-Time Control**
   - Identifies issues as soon as they occur
   - Alerts operators
   - Pauses the tester

3. **Platform For Real-Time Action**
   - Automated re-binning
   - Adaptive test time reduction
   - Drift detection
   - Data-feed-forward
   - and much more…

Real-Time Data Collection
- Identifies issues as soon as they occur
- Alerts operators
- Pauses the tester

Real-Time Control
- Identifies issues as soon as they occur
- Alerts operators
- Pauses the tester

Platform For Real-Time Action
- Automated re-binning
- Adaptive test time reduction
- Drift detection
- Data-feed-forward
- and much more…
Proxy+ – Optimal+ Ambassador On The ATE

For:
Data collection
Adaptive testing and tester control
Rules

Targeting Challenges 24x7

Library of standard rules accommodate most the challenges faced by our industry

Custom rules available for unique monitors and actions including support for R and Python scripts

Deployed at any level of your supply chain (central vs edge)

Rules engine running 24x7
# Rules Turning Challenges Into Actions

## Action Categories

<table>
<thead>
<tr>
<th>Category</th>
<th>Action 1</th>
<th>Action 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equipment Actions</td>
<td>Pause</td>
<td>Engineering tool alert</td>
</tr>
<tr>
<td>Process Actions</td>
<td>Put materials on hold</td>
<td>Re-binning</td>
</tr>
<tr>
<td>Recipe Adjustments</td>
<td>Re-test skip/add</td>
<td>Adaptive testing</td>
</tr>
<tr>
<td>Data Augmentation</td>
<td>Feed-forward</td>
<td>Feed-backward</td>
</tr>
</tbody>
</table>
| Alerts                 | Quality outlier alerts                          | Yield alerts                                 | Predictive/Anomaly alerts | Virtual operation
Data Security Solution

1. **End-to-end secure data lifecycle**
   - Authenticate with tester OS and test program (TP)
   - Secure channel between Tester and Local Server
   - Secure data at rest on tester and local server
   - Secure transfer of data logs to HQ

2. **Key exchange mechanism**

3. **Offline mode for offline data logs and recovery**

4. **Sensitive data filtering** to securely share data logs with suppliers

5. **Allowing Real-time and offline rules without exposing sensitive data**

6. **Compatible with older TPs not implementing encryption**
Solution Examples
Quality, Reliability and Brand Protection Solutions
Quality and Reliability

- Minimize excursions
- Minimize RMAs
- Analyze root cause
- Protect your brand
- Comply with automotive standards

Outlier Detection
Escape Prevention
Special quality algorithms – WECO, EWMA, SPL, Scratch Detection
Auto-hold (via MES)
Re-bin (via MES)
Data Feed Forward and Test Program API
Outlier Detection

NNR (Near Neighbor Residual)
Bivariate Outlier Detection

Bivariate outliers may be related to pairs of tests from the same or different operations.
Multivariate Outlier Detection

Several ML techniques can be used to screen multivariate outliers.

The methodology here is to use PCA (Principal Component Analysis) to define the main virtual tests, and then perform DPAT on such tests.
Specialty Algorithm Example

Scratch Detection
Escape Prevention Example

Not Enough Tests Performed On Parts

- Chart shows that the number of tests for a good device is 53 tests
- 5% of the units on one lot have 39 tests
- Automated rule detects this in production and prevents the parts from shipping
PAT For Packaged Units (FT PAT)

Skip next testing for units marked as ‘outlier’ bins
* Requires ECID
Defectivity Index (I-PAT) Correlation To Sort

Better screening using both test and defectivity data
Applying I-PAT defect outlier recognition
Using G-PAT to detect clusters using combination of test and I-PAT data

Smart I-PAT Map
Bin Map
Bin Map Post Standard Outlier Detection
Bin Map Post Enhanced Outlier Detection

I-PAT can identify individual statistical outlier die, and drill down to root cause

HB99 → G-PAT (test only)
HB998 → I-PAT Static PAT
HB997 → G-PAT outliers (test and defectivity)
Image Processing Flow

SAM inspection generates board image (jpg)

Image algorithm analyzes each welding location (pin) on the board

Parameters are loaded into O+ to allow analytics, rules and correlations to machine/product data

18 parameters are generated for each pin on the board (instead of just one parameter previously collected – the welding area)
Yield Analysis and Reclamation Solutions
Yield

Overall yield
Site-to-site yield
Re-test policy
Equipment and hardware performance issues

Baseline yield and SBL monitoring
Test equipment performance
Test and retest policies and execution
Tests limits validation
Cross-operation correlation
Targets against any measure/KPI
Customer Use Case: Operational Yield

Site Issue

Device: Network

Problem: Yield loss

Issue: Yield by tester varies

Standard O+ Rules Found
With no monitoring – Site-Site issue not detected – This case is 16 lots
Yield Improvement Example

Tight Spec Limits

- Current test limits are too tight, causing 0.4% yield loss
- Proposed test limits will reduce yield loss without impacting product quality
Efficiency Solutions
Efficiency

Inconsistent tester availability and utilization
Excessive index and pause times
Test time variations per tester
Inefficient retest policies and execution

Adaptive Testing using Machine Learning
Test equipment performance
Test and retest policies and execution
Testers availability and utilization (OEE analysis)
Classical Test Time Reduction (TTR analysis, ROA)
Adaptive Test Time Reduction (ATTR)
Cross-operation correlations
Shop Floor Control
Test Efficiency Opportunities

- Better resolution of time during test
- Actual test time maximization (vs. index time)
- Retest optimization
- Test time consistency
- Tester utilization – owned, consigned or paid for
Customer Use Case: Efficiency Problem

Increasing Test Time

Standard O+ rules found
Testers had different throughputs
Test Time Increasing from 120 Sec to 300 Sec

Result: Saved 8 test stations = $12M in CapEx and OpEx Savings
Overall Equipment Efficiency

O+ collects detailed data on tester operation.

Tester usage statistics allow to perform in-depth productivity analyses (e.g. OEE) which help eliminate wasted time.
Customer Use Case

Test Time Reduction

Identify tests that can be skipped, create rules and publish to the testers, wherever they are.
Adaptive Test Time Reduction

Example Run Showing TTR Element

Sampling
Zero fails validation (before skipping tests) in each run
Time-To-Market Solutions
Time-To-Market

Shorten NPI time
Optimize balance between time, cost, and quality
Facilitate multi-team collaboration
Share learnings from NPI to HVM and back

Adaptive test (reduction or augmentation) and smart ramp
Data loading rules
Load and create conditions
Sandbox to edit metadata

Datasets
- Virtual “workbench”
- Shared analyses and data augmentation
- Full chain of custody

Limits, Correlation and GR&R Applications
Report generation
NPI Areas Of Focus and Flow

- Proxy
- Drop Box
- STDF
- OTDF
- SAF
- Data Cleansing
- Mapping
- Validation
- Association
- Augmentation
- Attributes
- Templates
- PVT Analysis
- Correlation App
- Limits App
- GRR App
- Static/Scheduled
- Flexible
- Intuitive
- Customized

Minimize time to market
Analyze split lots
Determine production limits
Identify design sensitivities
Customer Use Case: Time-To-Market

Limit Simulation App

Device: Cell phone

Problem: Limits not optimized

Issue: Would not fail questionable measurements

Fix: Run analysis using limits application

O+ standard tools found: Limits too wide

Result: Immediate feedback = Faster product launch
Supplier Transparency

Benchmark suppliers
Ensure supplier compliance with flows for every chip

Site to site comparison
Supplier to supplier comparison
Customer Use Case

Suppliers Benchmark Dashboard For Key KPIs

- Provides consolidated views of operations across all suppliers mfg. sites
- Enables objective benchmarking of suppliers
- Highlights KPIs that require attention
- Enables drilldown for root-cause analysis

Supplier #1 has lower GPH than the others

Supplier #1 Avg. touchdown test time longer than others
Customer Use Case

Supplier Transparency Into Consigned Test-Fleet Performance

- Provides consolidated view of 100s - 1000s fleet tools
- Enables real time and consistent equipment sets benchmarking
- Highlights KPIs require attention
- Enables drilldown for root-cause analysis

~20% of the fleet under performing – FPY issues

Test tools wasting 60-80% of test time in Pause mode
Partner with us to enhance your big data strategy with our open platform

Synergetic With Any Data Lake | Cloud and On-Premise | Accessible Optimized Schema | AI and Machine Learning | Collect and Act Anywhere | Enhance Data Scientist Productivity
Data Platform Needs

Voice of the Market

“How can I combine, and do more with my siloed data systems?”

“I know we need to do ML, we just don’t know how to get started.”

“My teams are proficient in Python or R and I want to leverage this.”

“We already have a corporate license of Tableau, can we use this to visualize O+?”

“Our data retention is at least 10 years for our automotive products.”

“How can we store old data so it doesn’t take so long to reload and use?”

“Can we have programmatic access to O+ data?”

“I want to leverage fab/assembly data (i.e, defect and inspection) to improve my quality.”
**Consolidated Challenges**

<table>
<thead>
<tr>
<th>Group</th>
<th>Challenge</th>
</tr>
</thead>
<tbody>
<tr>
<td>CTO/CIOs and IT Professionals</td>
<td>Concerned about enterprise TCO (Total Cost of Ownership)</td>
</tr>
<tr>
<td>Product, Quality and Yield Engineering Teams</td>
<td>Need a solution providing analytics that scale</td>
</tr>
<tr>
<td>Data Scientists and Engineering Teams</td>
<td>Need a collaborative ecosystem</td>
</tr>
</tbody>
</table>
Platform Goals

1. Support bi-directional data integration with any customer data lake

2. Enable easy consumption of OptimalPlus data by 3rd parties and BI tools

3. Integrating with machine learning data science frameworks, leveraging OptimalPlus deployed infrastructure

4. Boost developer's innovation by leveraging OptimalPlus rich API’s, algorithms and infrastructure

5. Data security and encryption
Industry Focused Open Platform

Synergetic with any big data strategy
Connected to existing infrastructure
Open for all kinds of data
Accelerates innovation
Extensible through both data and algorithms

Optimal+ Platform
- Portal+ Desktop and Web UI
- Analytics Engine and API
- Data Pipeline
- Column Store Database
  Metadata index + “Hot” cache
  SQL over Hadoop
- Optimized “Manufacturing” Data
- Parquet

Customer Platform

Customer Data Lake
- Hadoop
- MapR
- Cloudera
- Hortonworks

Cloud
- (public, private, hybrid)
- AWS
- Azure
- Google Cloud
- IBM Cloud

IBM Streams
- Teradata
- MicroStrategy
- Tableau

IBM Watson
- Jupyter
- Spark

IBM Cloud
- Splunk
- Cassandra
- Apache Drill
- HBase

Synergetic with any big data strategy
Connected to existing infrastructure
Open for all kinds of data
Accelerates innovation
Extensible through both data and algorithms
The Full Machine Learning Lifecycle

- Learn from data and evaluate business value
- Deploy and act upon the model
- Monitor data and model performance to identify changes
- Understand changes and update model/process
AI/ML Deployment Challenges

**Learn**
- **Getting data**
  Data scientists waste time getting and organizing data
- **Feature extraction**
  It is difficult to extract complex features from the data set
- **Freedom of choice**
  Data scientists want to use their favorite tools and the latest-and-greatest algorithms

**Act**
- **Complex “plumbing”**
  Data scientists waste time dealing with the “plumbing” associated with getting a model into production
- **Actionability**
  Taking action requires integration with equipment and systems
- **Distributed mfg.**
  Issues compounded in distributed, outsourced mfg.

**Validate**
- **Ongoing validation**
  Production models need to be validated all the time
- **Ongoing data collection**
  Data collection becomes an ongoing concern
- **Technical debt**
  Data scientists end up spending time monitoring “old” projects instead of investing in new ones

**Adapt**
- **Stale models**
  Production changes inevitably cause models to go stale
- **Relearning**
  Model relearning is often manual
Hidden Complexity

The Google View

Configuration  Data Collection  Data Verification  Machine Resource Management  Serving Infrastructure

ML Code  Analysis Tools  Process Management Tools

Feature Extraction  Monitoring

Source: Google article from 2014: Hidden Technical Debt in Machine Learning Systems
Optimal+ Covers The Entire Lifecycle

Optimal+ covers the full scope all the way through ML deployment.

Source: Google article from 2014: Hidden Technical Debt in Machine Learning Systems
## Summary

<table>
<thead>
<tr>
<th>Lifecycle Analytics Solutions</th>
<th>turning data into actions or immediate ROI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Product-Centric Approach</td>
<td>for improved quality and reliability and operational efficiency</td>
</tr>
<tr>
<td>AI/ML</td>
<td>support digital transformation in manufacturing</td>
</tr>
<tr>
<td>Open Platform</td>
<td>industry focused for seamless integration with any big data strategy</td>
</tr>
<tr>
<td>End-To-End Supplier Transparency</td>
<td>across operations and industries</td>
</tr>
<tr>
<td>Domain Expertise</td>
<td>applying data science to solve industry challenges</td>
</tr>
</tbody>
</table>
**Significant Business Impact**

<table>
<thead>
<tr>
<th>Area</th>
<th>Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quality, Reliability and Brand Protection</td>
<td>50% case avoidance</td>
</tr>
<tr>
<td>Yield Analysis and Reclamation</td>
<td>increase up to 10% NPI 2% HVM</td>
</tr>
<tr>
<td>Efficiency</td>
<td>up to 25% test cost savings</td>
</tr>
<tr>
<td>Time To Market</td>
<td>from weeks to days NPI, TTM, RCA</td>
</tr>
<tr>
<td>Supplier Transparency</td>
<td>Consistency and compliance</td>
</tr>
</tbody>
</table>
Ask Our Customers

“Escape Prevention enables us to identify specific manufacturing and test issues that drive advanced quality screening and comprehensive product management.”

Michael Campbell
SENIOR VP OF ENGINEERING

“Optimal+ gives us real-time visibility of our test operations, enabling us to monitor every critical parameter to ensure that every product is of the highest quality and performs as expected.”

Keith Katcher
VP OF OPERATIONS ENGINEERING

“Global Ops for Electronics enables us to rapidly identify and respond to the source of any PCB and systems manufacturing issue, down to an operation, facility, line or station.”

Vincent Tong
SENIOR VP OF GLOBAL OPERATIONS AND QUALITY

“We see Optimal+ as a strategic partner. Their open architecture enables us to create synergy across different tools and systems across the globe and accelerate innovation”

David Reed
EXECUTIVE VP OF TECHNOLOGIES AND OPERATIONS
Thank You