PDF/SOLUTIONS™

2023 PDF Users Conference:

AI for tomorrow's manufacturing and R&D

Location:
Santa Clara Marriott - 2700 Mission College Boulevard Santa Clara, California 95054 USA

Solutions for Fabless

Presented by Marc Jacobs
October 23, 2023

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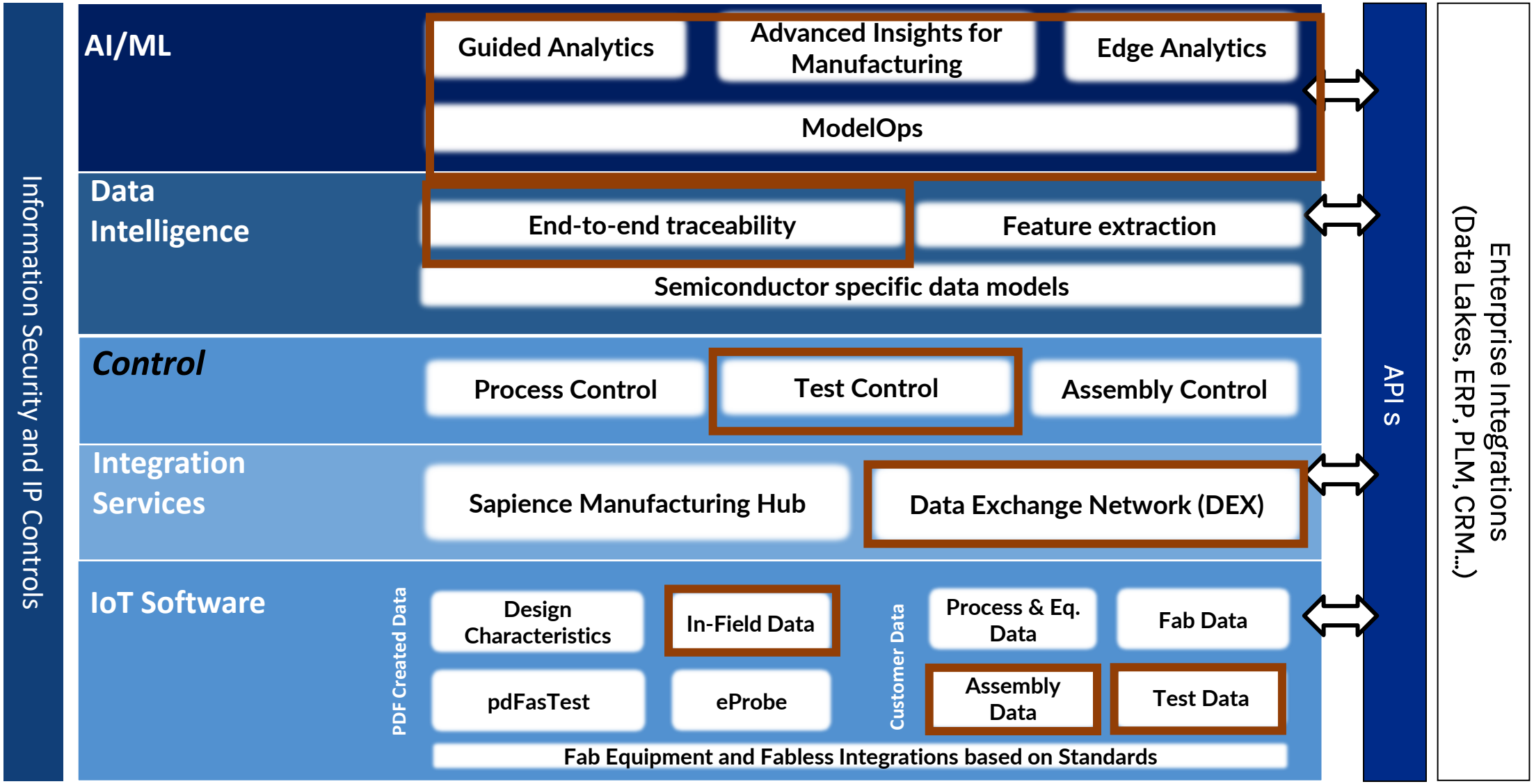
End-to-end Integrated Platform for Semiconductor Analytics



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Fabless Product Lifecycle

Design	• Sensors
NPI/Char	• Managing Wide Data • Characterization
Yield Ramp	• Accelerating Yield Analysis • Machine Learning for Optimized Test • Adaptive Test • System Scalability
HVM	• Best-in-Class Operations at Test • Supply Chain Visibility & Security • Leveling Up Your Engineers • Executive View
In-Field	• Failure Analysis & Returns

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Design Phase Challenges & Solutions

- **Sensors for Performance, Reliability & System in Package (SiP)**

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In-die Sensors for Performance, Reliability and SiP

CV® Core System

Circuit Performance

Circuit Aging

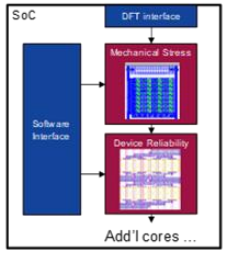
Package Performance

Customer Sensors
***e.g.*, PVT**

proteanTecs

DESIGN

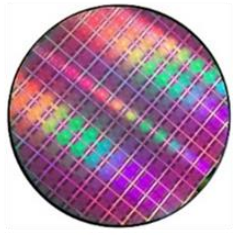
Chip Design



Sensor insertion

BUILD

Wafer Manufacturing



Sort yield/parametrics correlation
PCM/Spice correlation

PACKAGING

Chip/Module/System Assembly and Test

Sort to FT/SLT correlation for Pkg/Test optimization
Die mission profile based aging readout (t=0)

MONITOR

Field Deployed Systems

Exensio CV Core Edge

In-field performance monitoring and mission profile optimization (t>0)

Sensor Data Processor

Sensor FOM Results

Configurations

DEX node

DEX node

DEX node

Exensio Manufacturing Analytics

Customer System & Analytics

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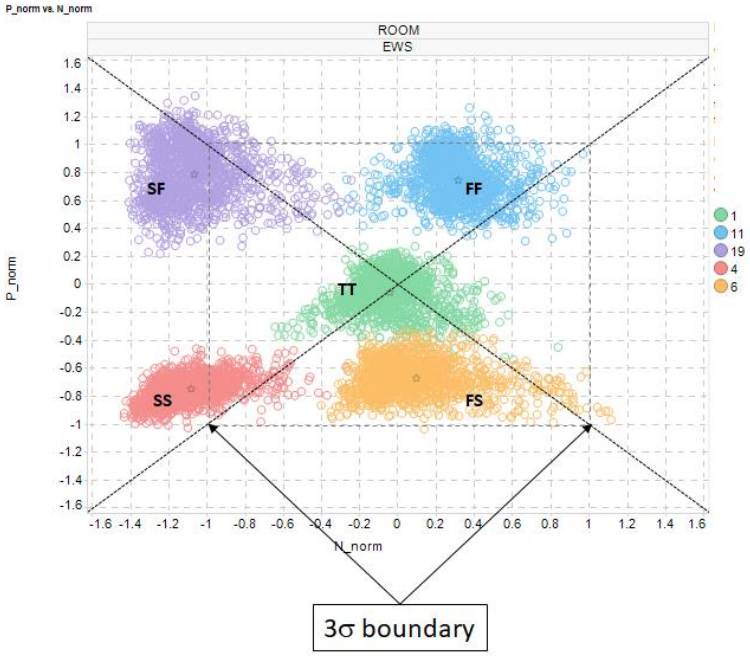
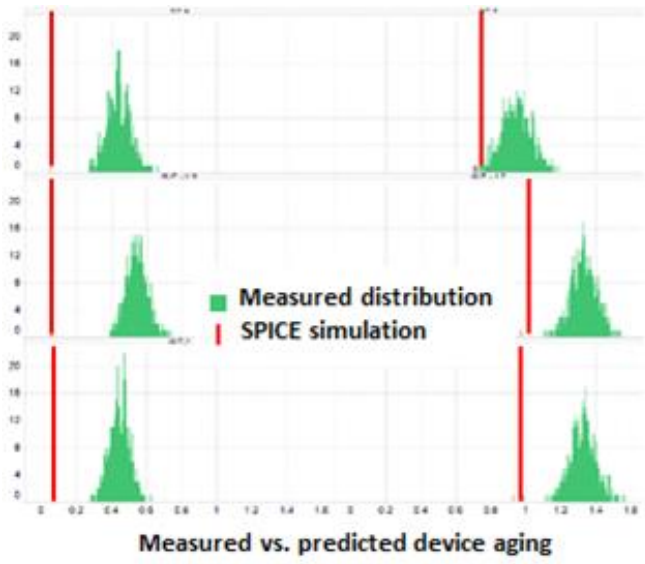
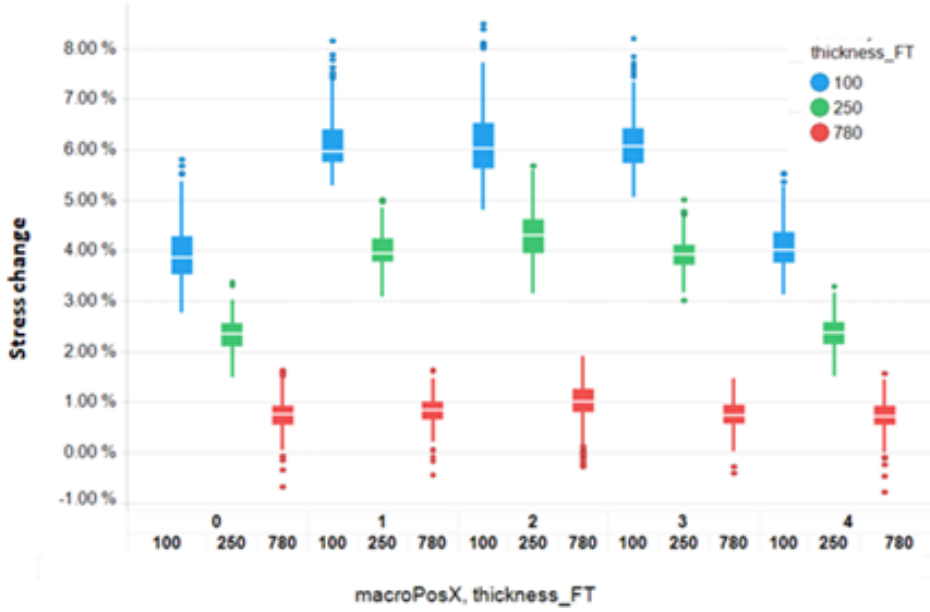
CV® Core: A view into the health of die fundamentals



Die performance across corners



Die-specific aging response



Die mechanical stress dependency

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NPI Challenges & Solutions

- Managing Wide Data
- Characterization

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Managing Wide Data – The "Test Item Explosion"

- IP instances multiplying **AND** char complexity multiplying
- Modern complex SOCs have millions of test items
  - Especially during characterization and NPI
- RF or Analog example: Frequency Sweep tests on ATE
  - Repeat test across range of input frequencies
  - Limits may vary, too
- Digital example: Shmoo test on ATE
  - Conventional shmoo example: 2D - V_{dd} vs f_{clock}
  - Challenging shmoo: 3D - V_{dd} vs f_{clock} vs REGISTER SETTING
- NPI Engineer wants
  - Load all my data at once
  - Analysis must be speedy

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Managing Wide Data – The "Test Item Explosion"

- Recent versions of Exensio have implemented improvements
  - Leveraged big data Spark & Cassandra cluster architecture
  - Plus novel data integration techniques
- Initial benefits shown below

Data Type	Retrieval Type	Number of Columns	Demonstrated Improvement
>1 M Parametric Results	Summary on the Fly	>1 M columns	**Up to 11x**
	Raw Data Retrieval	>1 M columns	**Up to 55x**
Parametric Pass/Fail	Continue-on-Fail Analysis	>1 M columns	**Up to 35x**

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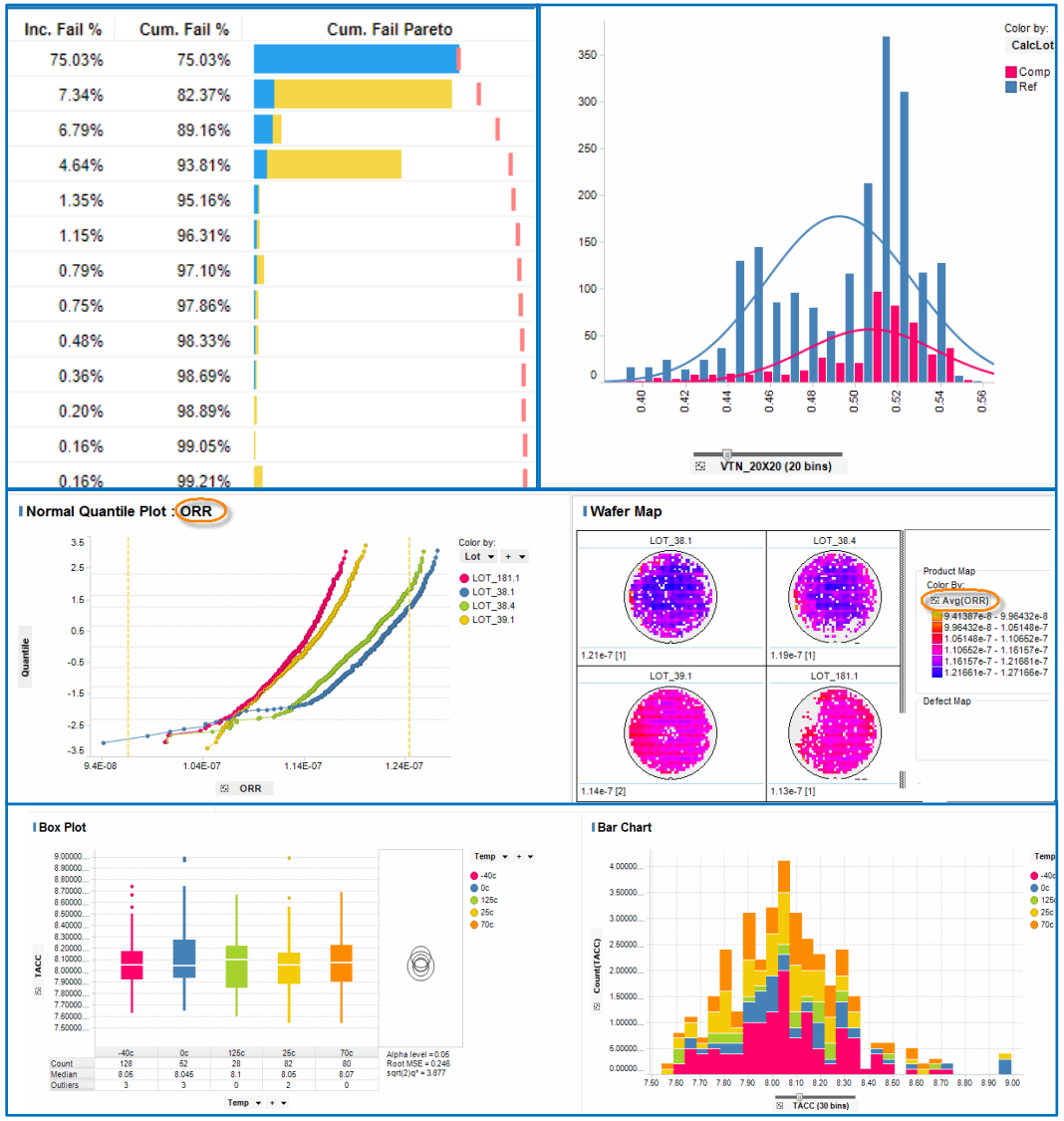
New Product Introduction & Characterization Feature Matrix

Capability	Exensio Manufacturing Analytics	Partnership
Test Program Validation & Optimization		
Test Coverage (Never failing / Redundant tests)	✓	
Limits Analysis		
Specification, Guard band Limit Setting	✓	
Product Characterization		
Wide / Sweep Data Handling	✓	
CP / CPK Analysis, VDD / Temp Char Analysis	✓	
Fab / Supplier Matching & Qualification	✓	
Reporting / Templates / Release to Production	✓	
Design / Layout Sensitivities to Process		
WS / FT to WAT: Die Level Process Sensitivity	✓	
On Chip Agents	✓	✓
Fault Diagnostics		✓
Fab/Foundry		
Design layout sesnitivities	✓	
Split Lot Analysis	✓	



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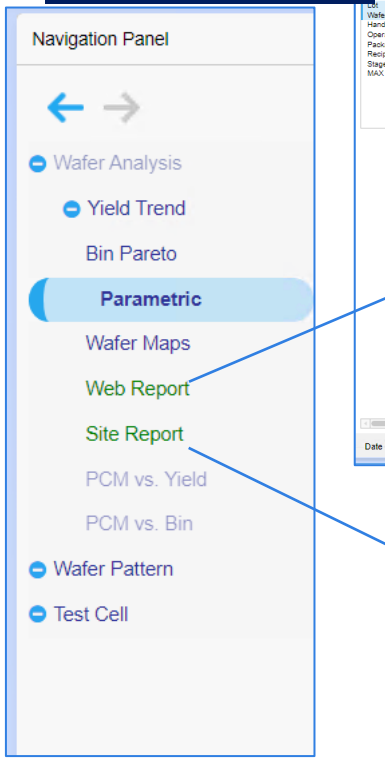
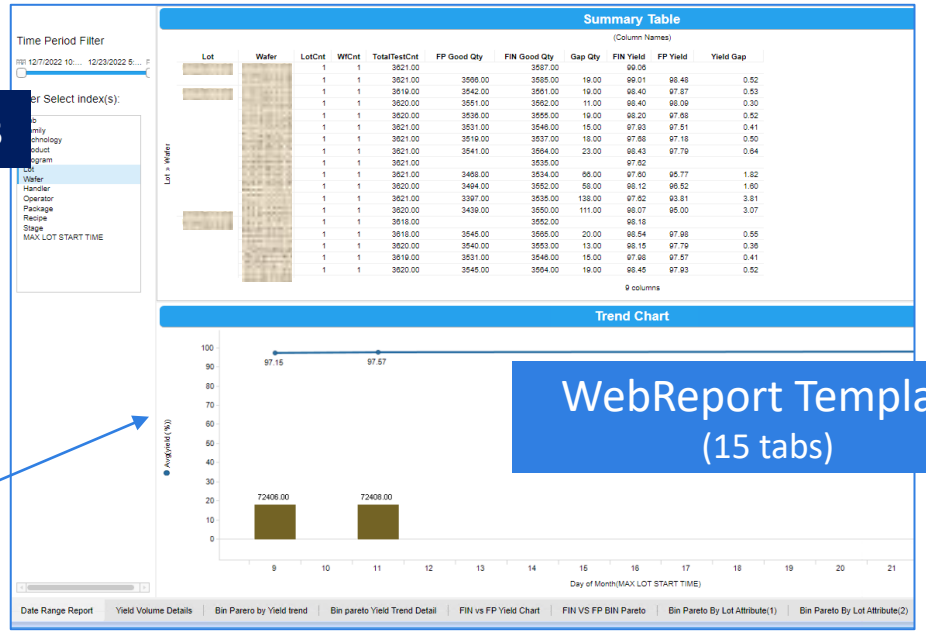
Flexibility to link customized templates in Guided Analytics (GA)

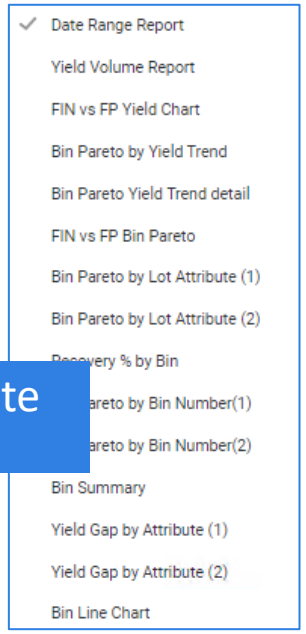
- Use the power and simplicity of Guided Analytics to speed your Characterization analysis

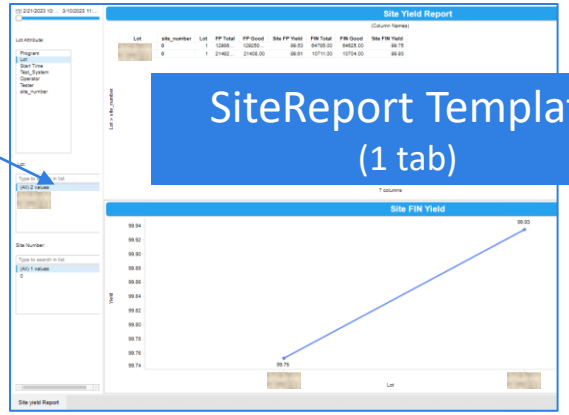
GA Templates





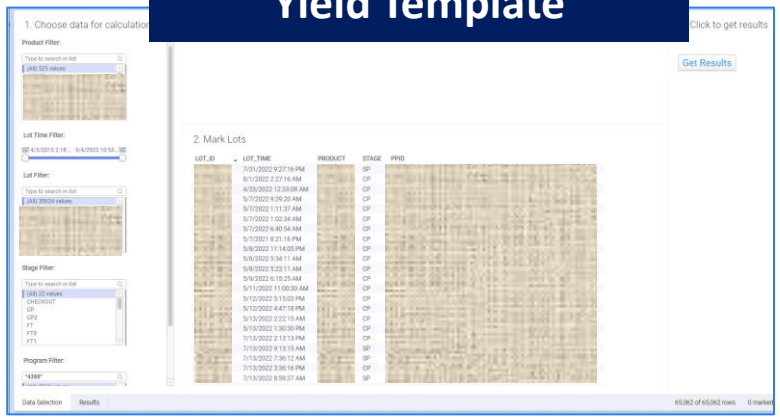
WebReport Template
(15 tabs)





SiteReport Template
(1 tab)

Wafer Sort Combined Yield Template



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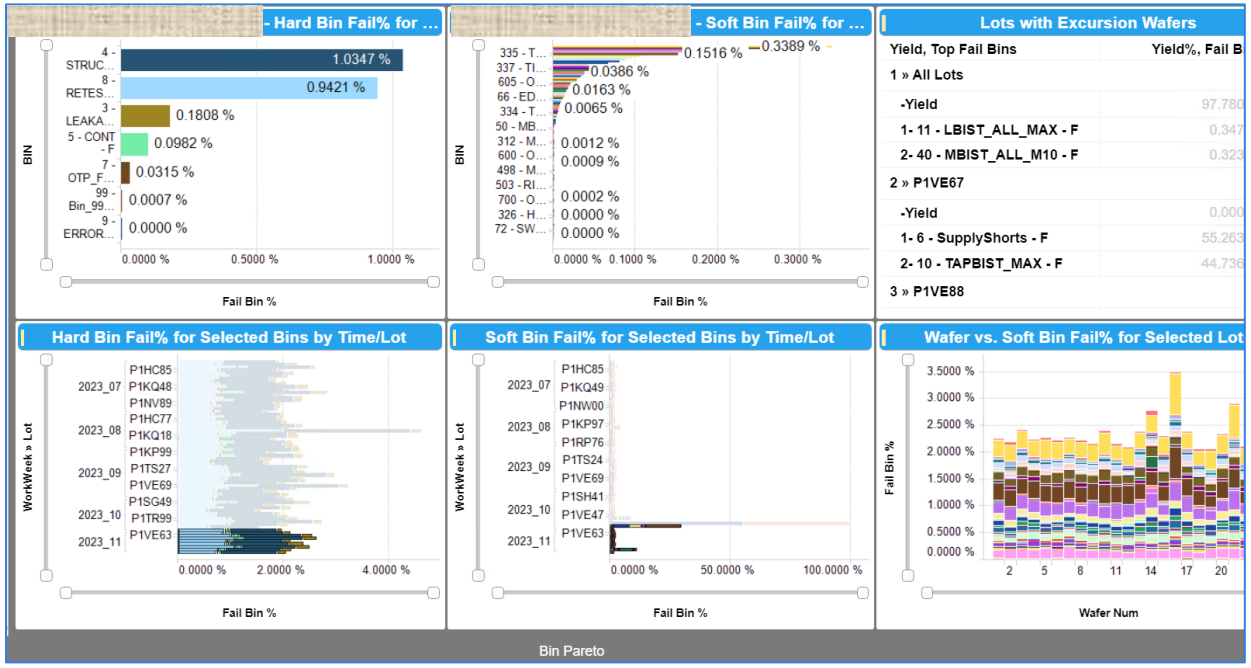
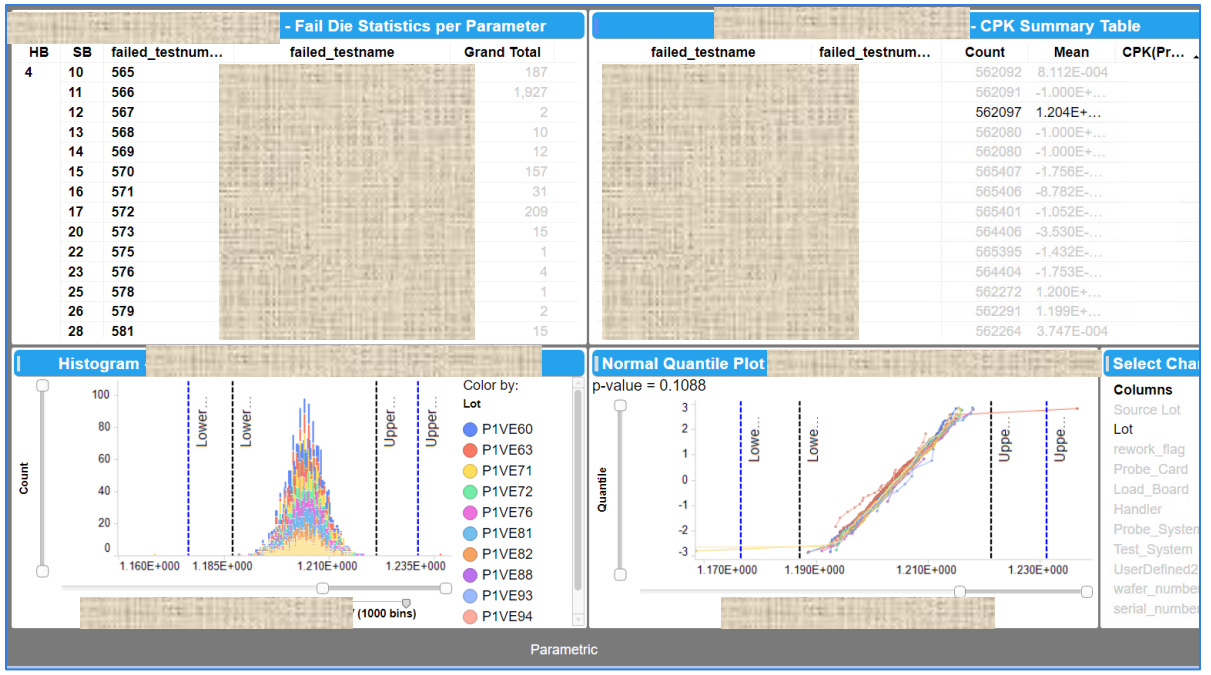
Characterization Features for the Way You Work

- Bin pareto view – where are the losses?
- Parametric view – are limits appropriate for results?
- Toggle switching between the two views

Bin Pareto



Parametric



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Yield Ramp Challenges & Solutions

- Accelerating Yield Analysis
- Machine Learning for Optimized Test
- Adaptive Test

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PDF Solutions and Siemens EDA accelerating yield

See Siemens technical presentation on Day 2 afternoon

- **How to get to high yield faster?**
- **Integrate diagnostics to FIRE/DirectScan**
- **Combine Fault Diagnostics with all your data sources**
  - WAT
  - Sort Yield
  - Sort Maps
  - Etc.
- **Get to root cause faster**
  - Find layout dependency
  - Help the foundry to know where to look for PFA

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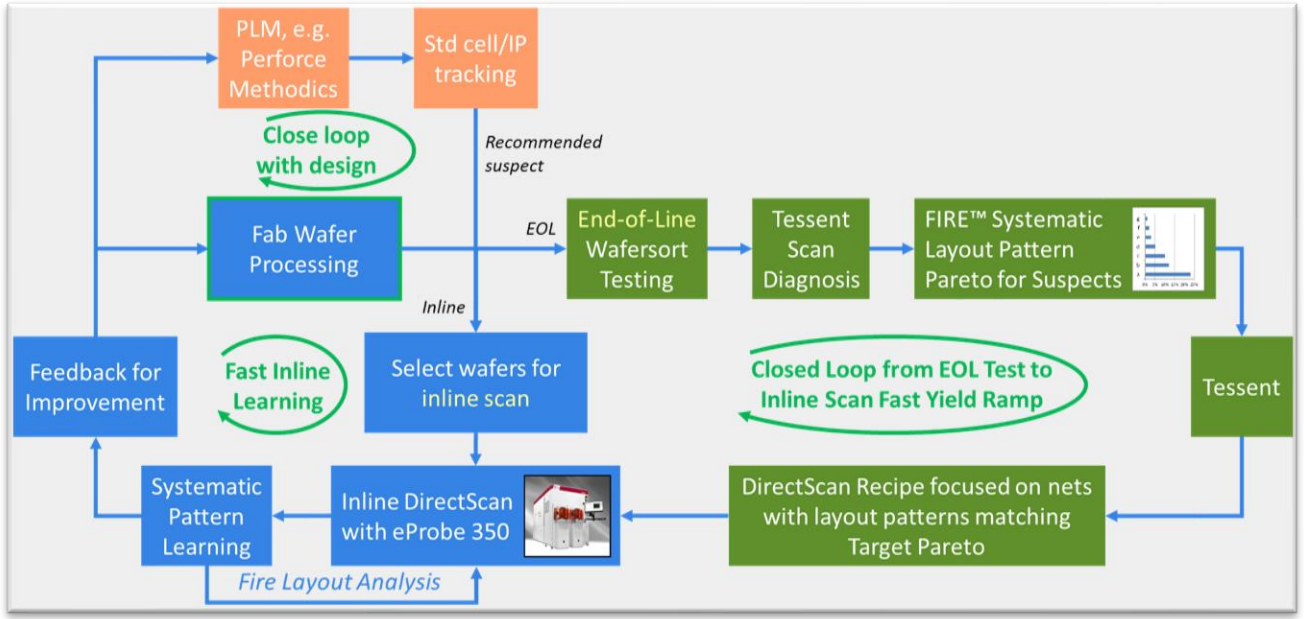
Tessent and Exensio/FIRE working together



Customer Benefit

For an HVM product at advanced node:

- **7x improvement in inspection and/or PFA efficiency**
- **ID'd root causes for ~90% of measured failure**

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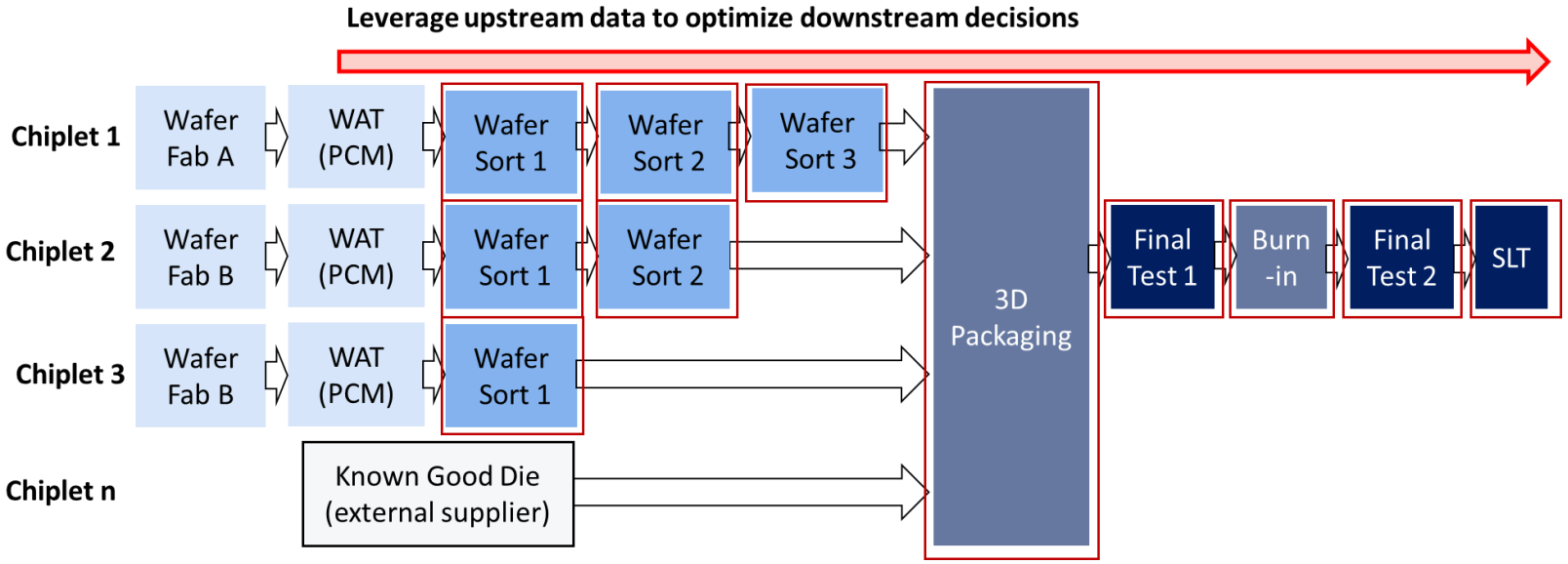
The system in package (SiP) testing challenge



For SiP

- P/F is not enough
- Rules are not enough
  → Move to models
- Pass info to downstream tests

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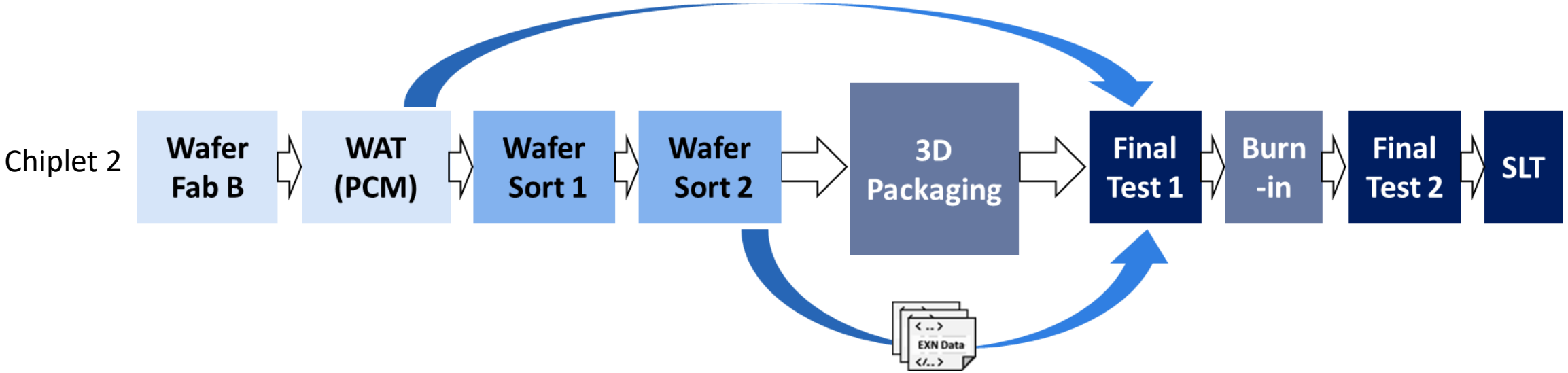
Feed Forward, Model-Based Testing



- **Deploy a feed-forward-loop test operation for a multi-chip device**
  - Reliable and timely capture of wafer sort test operation data
  - Automate feature extraction from PCM/WAT & WS to produce feed-forward data
  - Mechanism to train & periodically retrain models on current data
  - Deploy models across supply chain to the package test operation
  - Monitor test data and model performance

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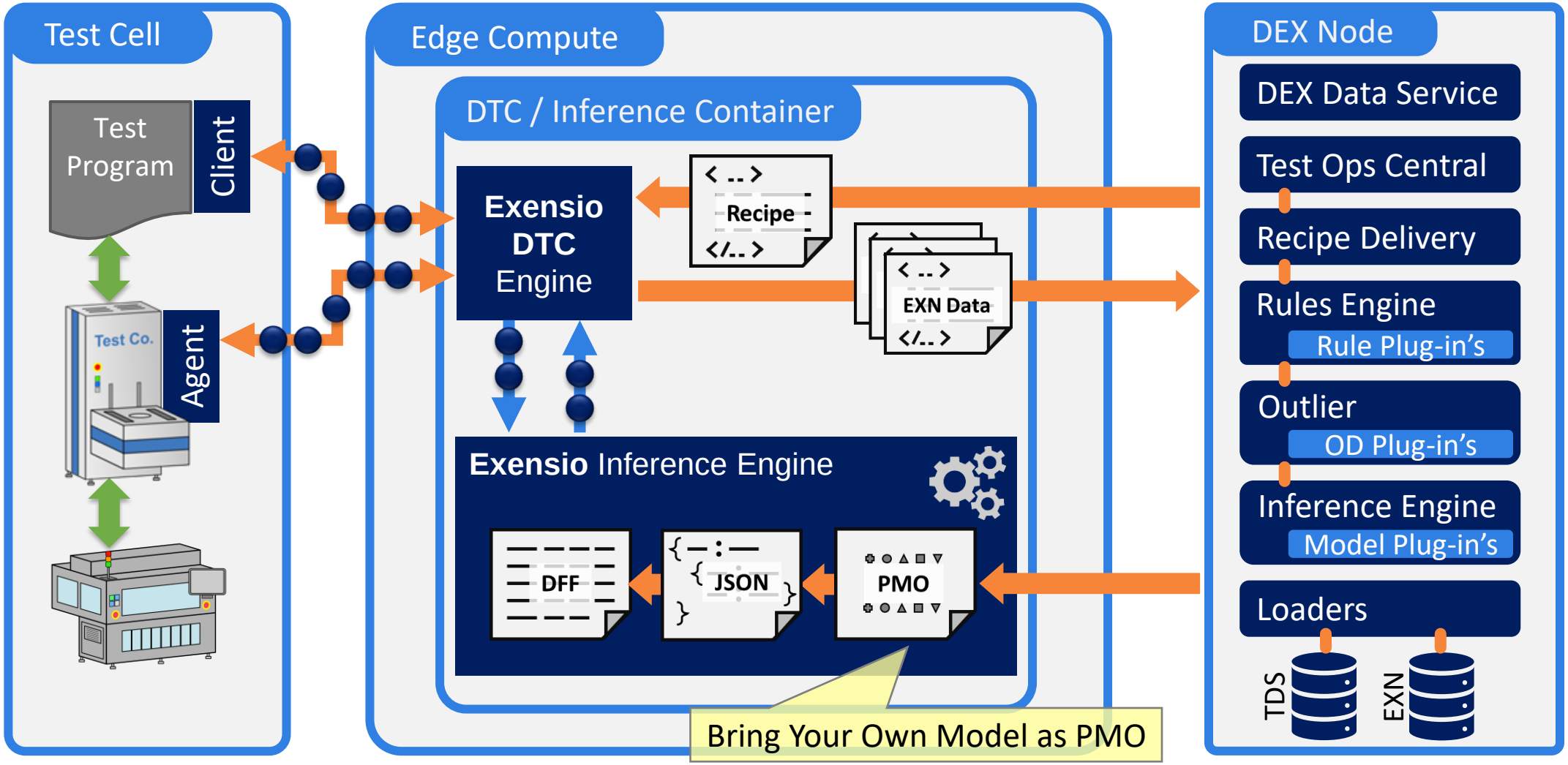
Edge Integrated Inference Container

Your model with Exensio rules & model management deployed to the edge



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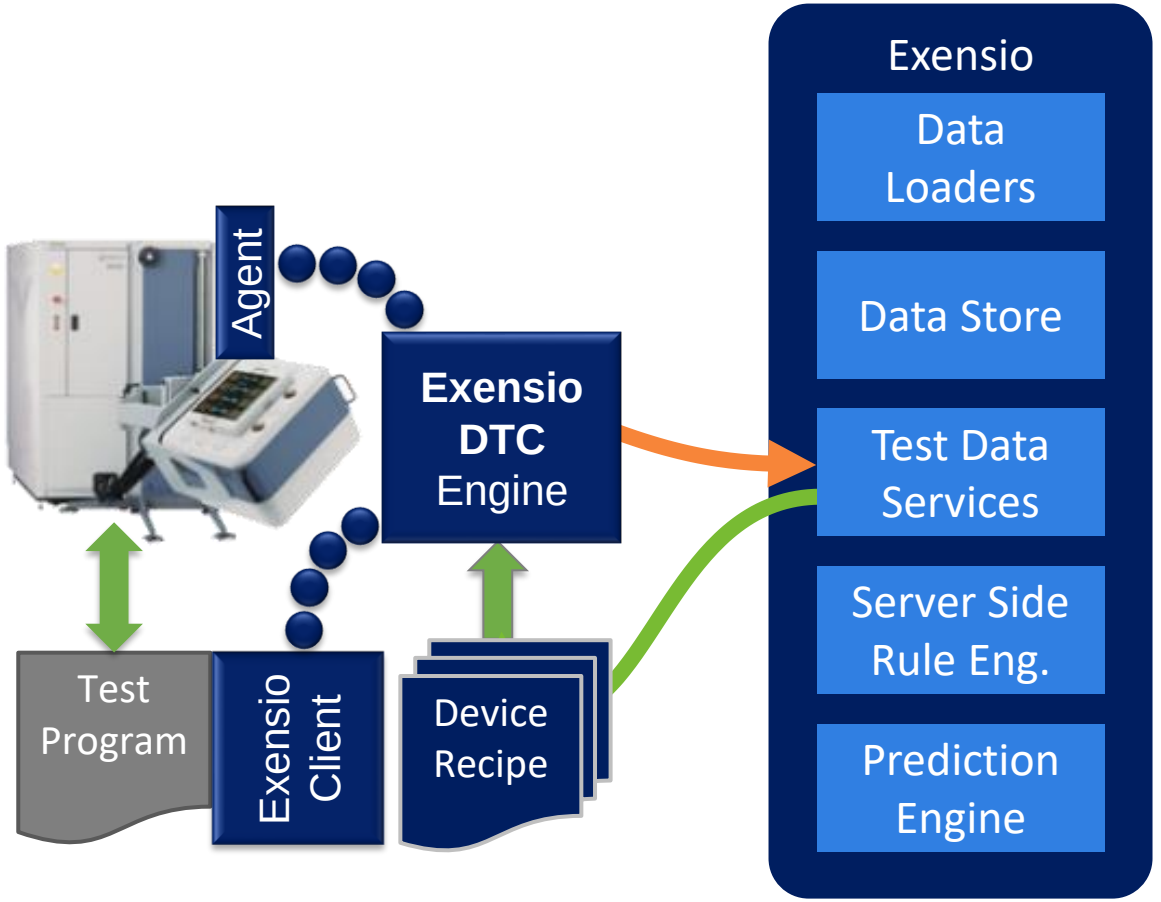
Adaptive Test Architecture

- **Test flow switching controlled by Customer recipe**
  - Short flow when conditions nominal
  - Increase test coverage when conditions abnormal
  - Sample monitor all tests for quality and analytic



DTC	**Dynamic Test Controller** *test control / data reporting / rule engine*
Agent	**Tester Agent** *tester specific / data capture / TOS interface*
Client	**Test Program Client** *flow switching / dynamic limits / Exensio APIs*

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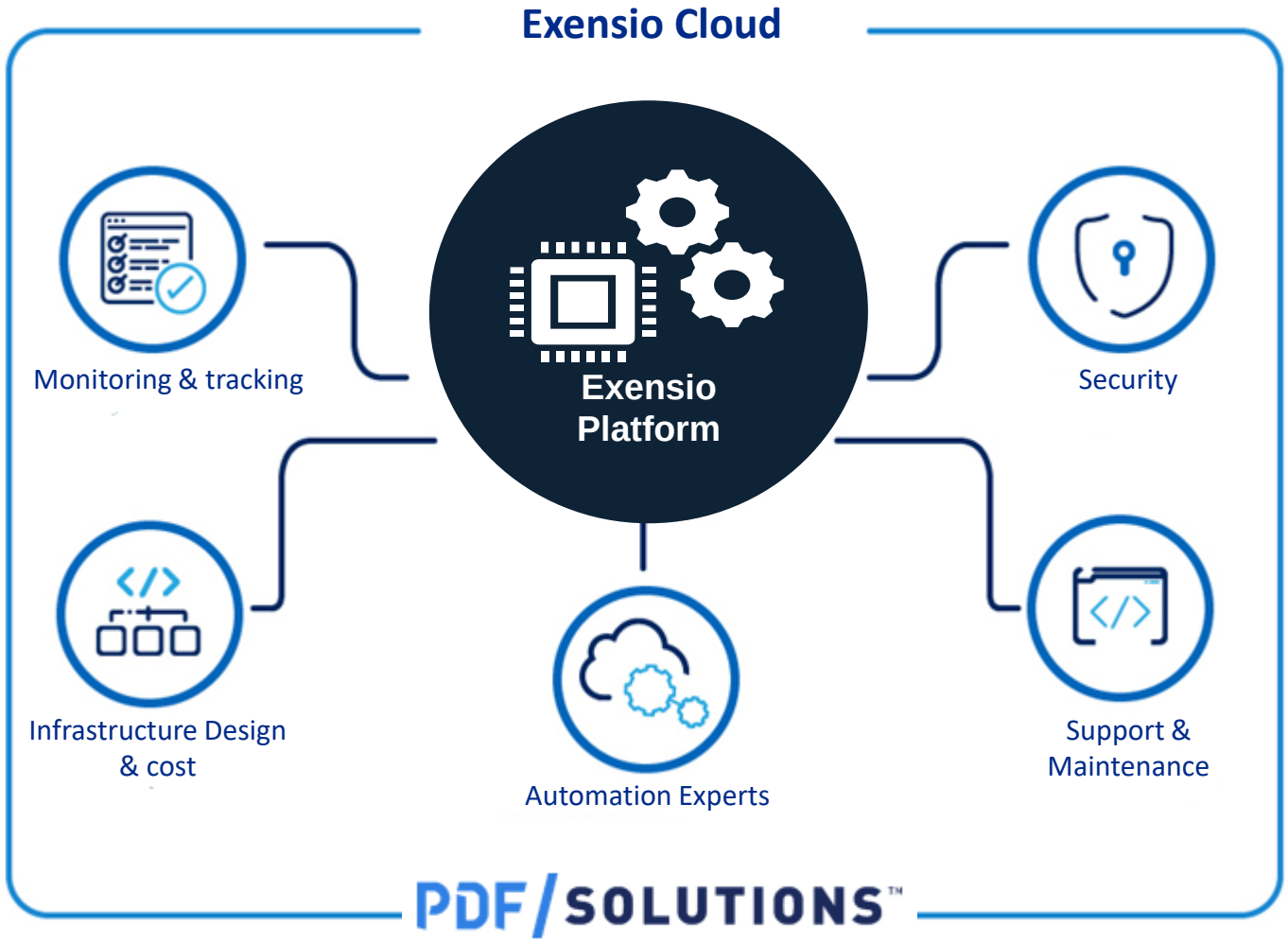
Cloud for Scalability

- **Use Exensio in the Cloud to manage your scaling**
  - Focus on your ramp
  - Not your data management
- **Automated Node Expansion for data scalability**
- **High Availability and Disaster Recovery**



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HVM Challenges & Solutions

- Best in Class Operations at Test
- Supply Chain Visibility & Security
- Leveling Up Your Engineers

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Exensio Advanced Quality & Ops Path

Offline Reporting
- *Floor Monitoring*
- *OEE reporting*
- *Stoppages / RE losses*

Real Time Rules
- *Outlier Screens (DPAT, GDBN)*
- *Escape Prevention (eg Test count)*

Operational Visibility | **Operations Shield** | **Quality Shield** | **Machine Learning**

Real Time Rules
- *Site2Site Yield*
- *UPH Limit*

Model Based Prediction
Model Based Screening
- *Predictive Binning*
- *ML Outlier Screening*
- *"Bring Your Own Model"*

BiC Ops

OEE Overall Equipment Effectiveness
RE Rate Efficiency
UPH Units per Hour
DPAT Dynamic Part Average Test
GDBN Good Die Bad Neighborhood
BiC Best in Class

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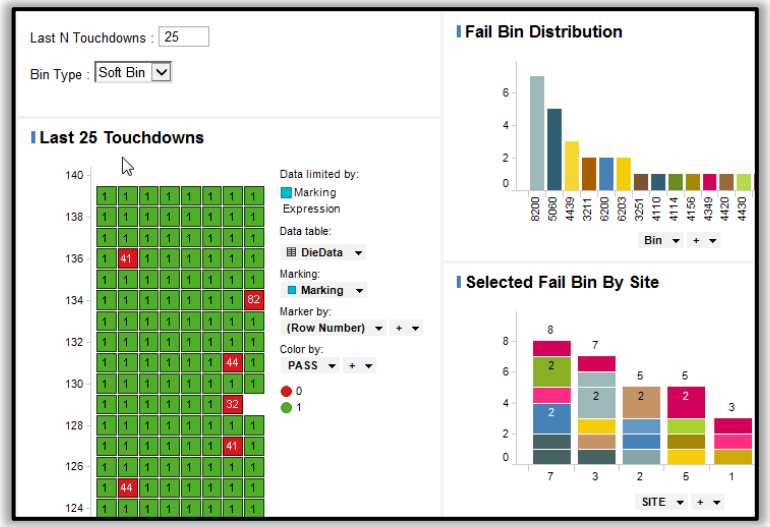
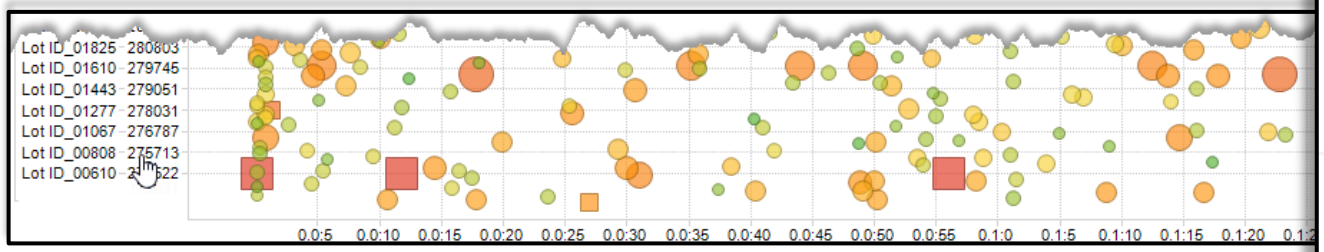
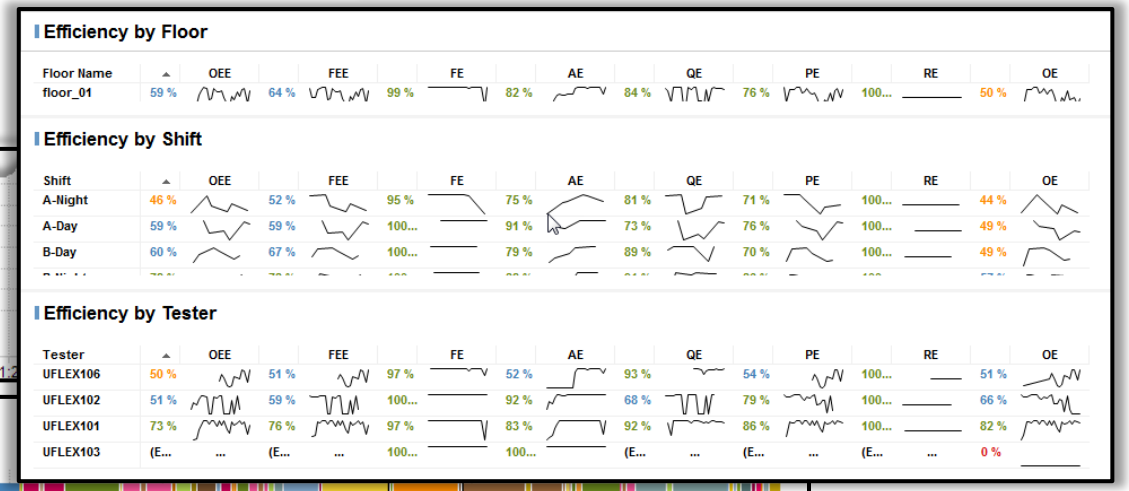
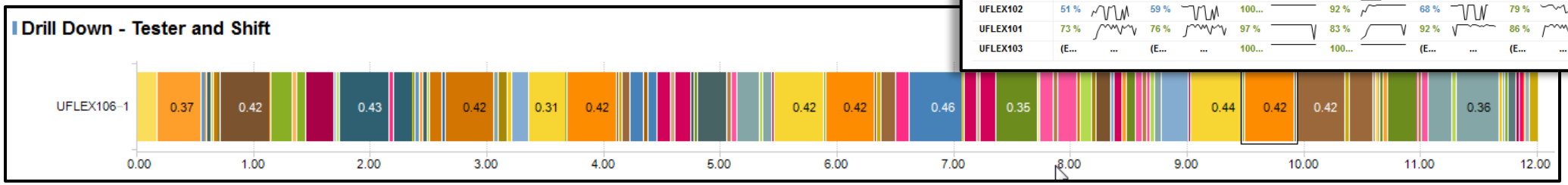
Drive Operational Efficiency Improvement

- **Real-Time Test Status**
- **Throughput (UPH) Analysis**
  - Actual UPH vs target UPH by Product / Tester / Test Program
- **Overall Equipment Efficiency (OEE) Analysis**
  - Efficiency by Floor / Shift / Tester
  - Measure Setup and Intra-Lot Idle Time









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Powerful Rules for OSATs and Fabless

Operations Shield

Process Control Rules

- Fab & Packaging Problems
- Test Floor Problems

Quality Shield

Escape Prevention Rules

- Stop errors from shipping

Quality Shield

Outlier Detection Rules

- Catch discrepant units

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Powerful Rules for OSATs and Fabless: Detailed Rule Catalog

Process Control

- Yield
- Bin Percent / Count
- Lot Begin / End
- Parametric Test Statistic
- Parametric Test Yield
- Site-to-Site
  - Yield
  - Percent Delta
  - Test Statistic Delta
- Parametric Test SPC (WECO)
  - Oscillating / Outlier / Trend / Zone

Escape Prevention

- Consecutive Bin
- Stuck Unit (parametric)
- Test Count
- Bad Device Good Bin
- Good Device Bad Bin
- Limit Fail Good Bin
- Measurement Exception
- Limit Exception
- Device Test Time
- Retest Limit
- Mixed Lot Limit
- Units per Hour Limit
- Valid ECID

Outlier Detection

- DPAT
- GDBN
- Cluster Detection
- NNR
- Univariate / Multivariate

- Custom rules by equations

WECO Western Electric Co
SPC Statistical process Control
ECID Electronic/Exclusive Chip ID
DPAT Dynamic Part Average Test
GDBN Good Die Bad Neighborhood
NNR Nearest Neighbor Residual

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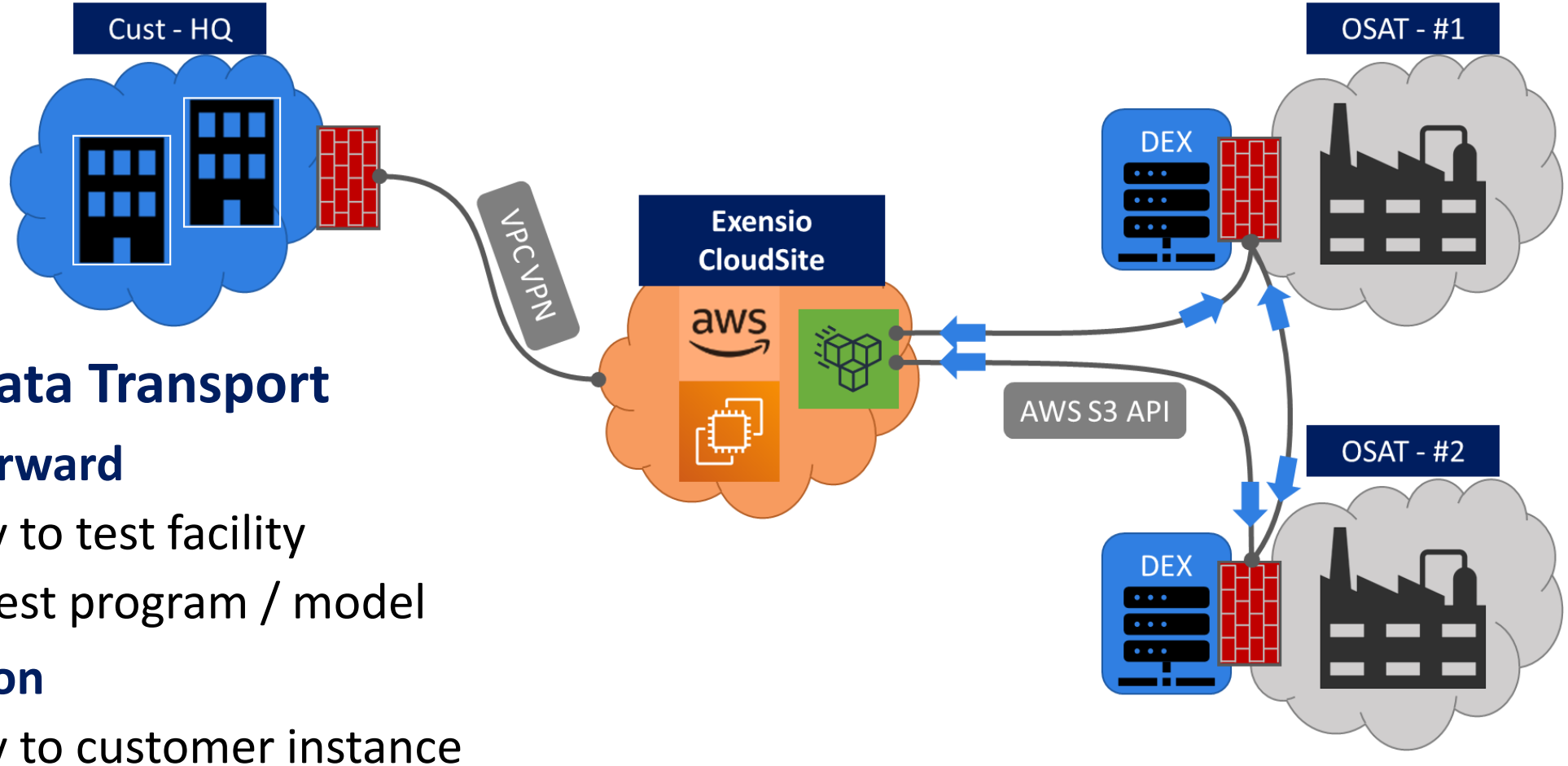
Data Exchange Connects You & Your Suppliers

High-performance managed Exensio deployment with OSAT integration



Automated Data Transport

- **Data Feed Forward**
  - Test facility to test facility
  - Server to test program / model
- **Data Collection**
  - Test facility to customer instance

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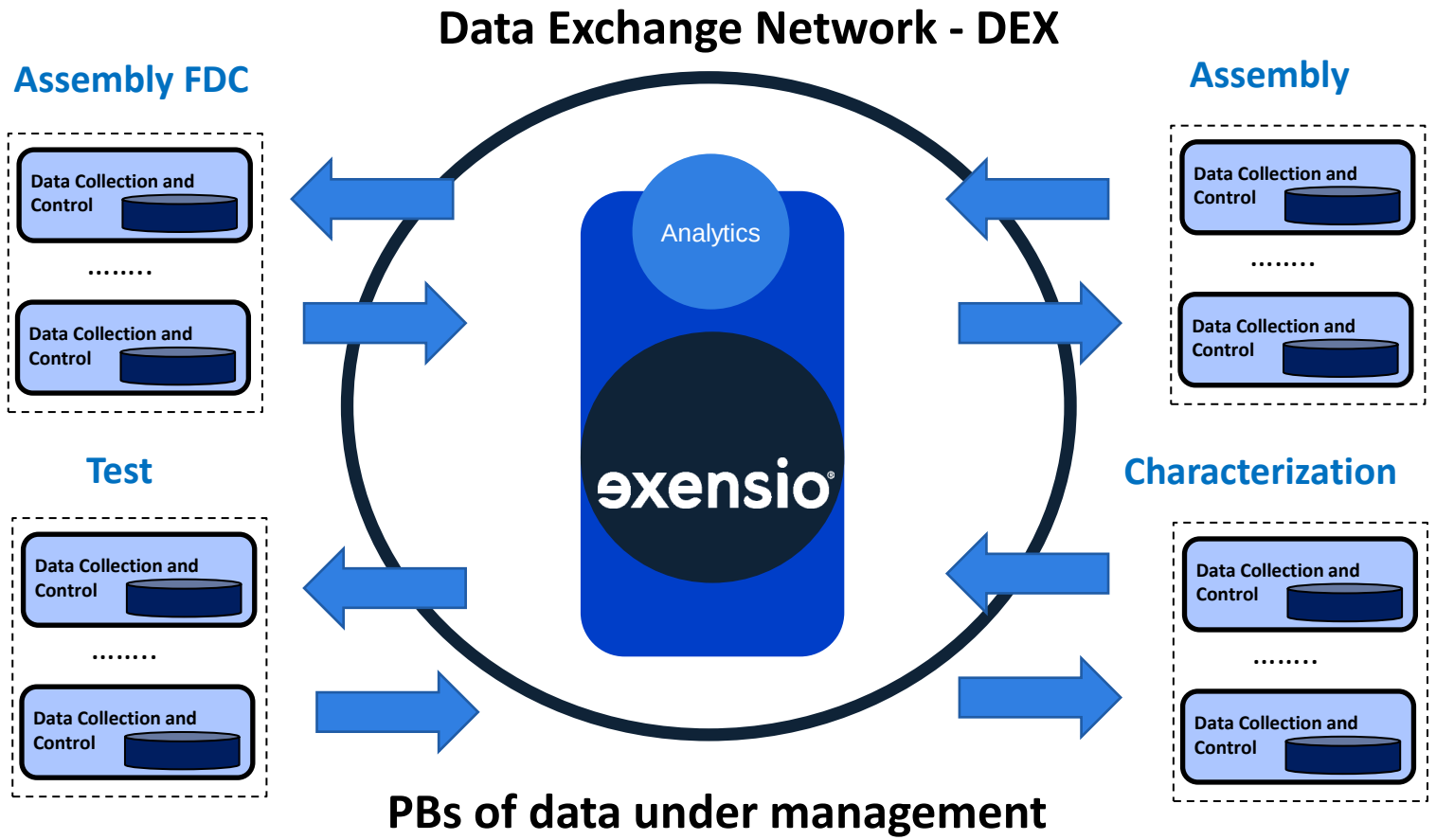
Exensio Data Exchange via DEX



Exensio DEX

- Local test data collection and tester integration
- Bidirectional secure data transport
- Customer data routing
- End-to-end encryption
- Secure containerized model execution

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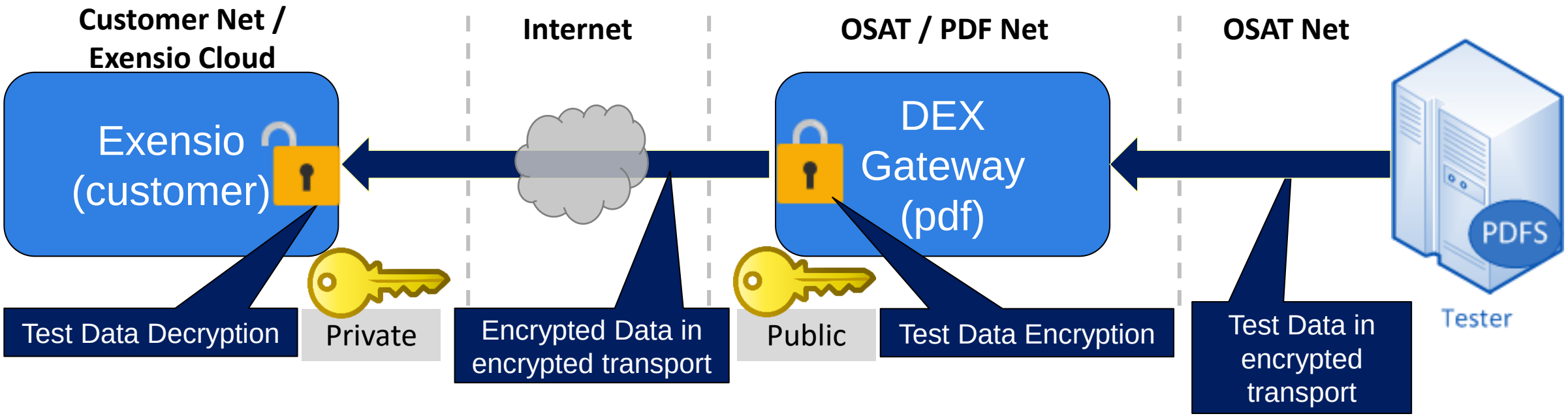
Security : Encrypted Data Transport (Example: OSAT to Customer)



- **Encrypted Transport Across Public Networks**
  - Transport between DEX and Exensio nodes is encrypted and private
  - Data is transmitted over encrypted tunnel
  - Only intended destination server can decrypt transport payloads
    - Node-unique private encryption key required to decrypt payloads
    - Bulk payload encrypted with AES-256

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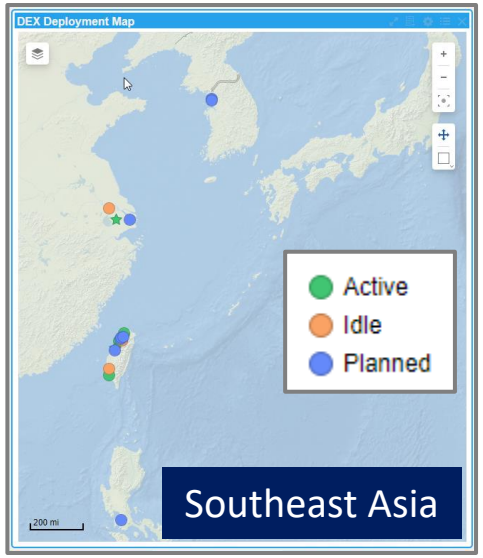
Oct 2023 DEX Deployment Locations (OSATs)

DEX ID	Site Name
AMKOR-P3/4	Amkor Philippines
AMKOR-TW	Amkor Taiwan
ASE-CL	**ASE Chungli**
ASE-KH	ASE Kaohsiung
Carsem-S	Carsem Malaysia S-Site
FOX-TW	Foxconn Taiwan/Ingrasys
GIGA-TW	Giga Taiwan
iTEST	iTest Milpitas
JCET-SG	JCET Singapore/STATS ChipPAC
JSET-CN	JCET China

DEX ID	Site Name
KYEC-ZN	KYEC ZhuNan
SPIL-CS	**SPIL Chung Shan**
SPIL-HC	**SPIL Hsinchu**
SPIL-SZ	**SPIL SuZhou**
SPIL-ZK	**SPIL Zhong Ke**
UTAC-SG	UTAC Singapore
UTAC-TH	UTAC Thailand
KYEC-LFT	KYEC Tunlou
GIGA-TW	ChipBond Taiwan
UNISEM	Unisem Malaysia



Exensio User and/or DEX DEX New in Q3/Q4 ‘23

10 new sites added / in-process since Q2 ‘23

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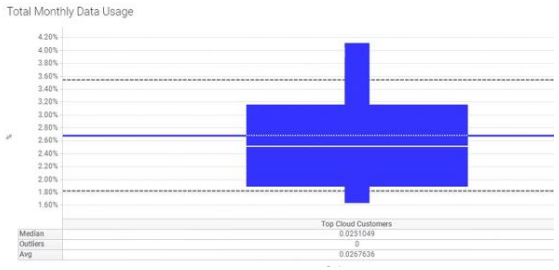
Guided Analytics: *Continuous Data Mining on 100% of data*

- **Manual analysis typically evaluates monthly 3-5% of the data**
  - Significant time spent aligning data types
  - Focus on obvious excursions and low yields
  - Harder to analyze wafer patterns, correlations across data types



- **Guided Analytics systematically analyzes 100% of the aligned data* and highlights issues**
  - Single database with aligned data allows for consistent results and more sophisticated analysis
  - Structured GA flow provides consistency in analysis across the organization

Processes all data every day

**Data types: Yield, Hard/Soft Bins, failing test parameters, PCM/WAT, test equipment, UPH*

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Guided Analytics for Fabless Companies

- **Automates up to 90% of analysis; Quickly review with few clicks**
  - High level dashboard
  - At-a-glance prioritization across products
- **Ultra-fast performance**
- **Analyze all your data types**
  - Seamless integration of data types: Hard Bin, Soft Bin, parametric, WAT/PCM, test tools, UPH, etc.
- **Easy to customize analysis**
  - Tailor for how your company works
- **Jump off for detailed analysis**

GA-Manufacturing Analytics

GA-MA
Yield, Bins, Parametric
Wafer Patterns
PCM/WAT OOS
PCM correlations

GA-Test Operations

GA-TO
Yield, Bins, Parametric
Wafer Patterns
Bin Review, First & Last Fail
Retest, Site-Site
Efficiency (UPH)

Not only does GA make it easy to use the software, it makes it easy for engineers to do their jobs

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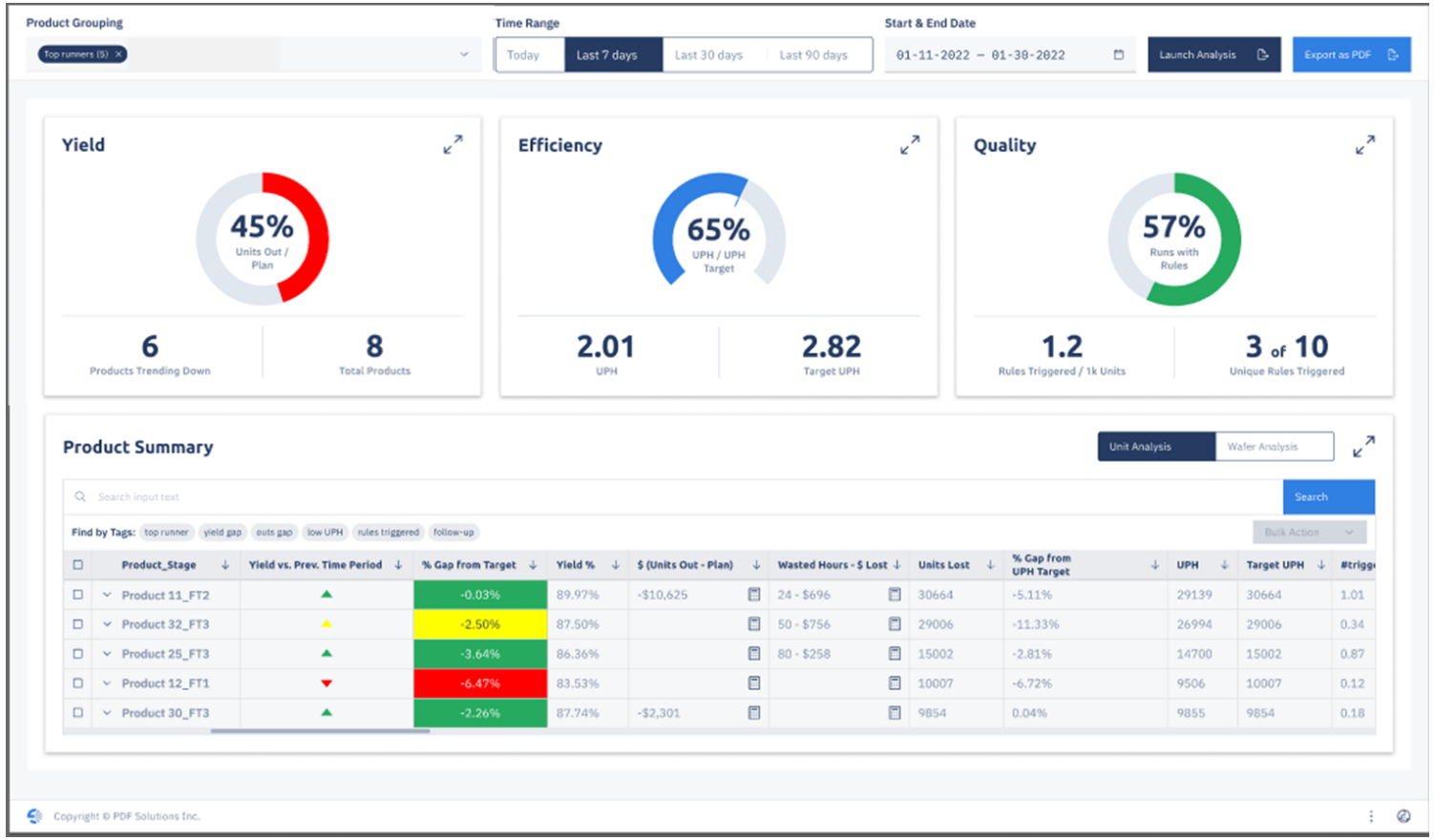
Guided Analytics for Execs: *Look Across Your Business*

- **Higher level summarization**
  - View by factory, product line, etc
- **Overall view**
  - Yield
  - Efficiency
  - Quality
- **Know where to look**
- **Know where to delegate**



Executive View

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Exec View: Loss Calculator

- Calculator function to translate losses into dollars.
- Both unit losses & wasted tester hours

Dollarize Yield and Efficiency Gaps

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In Field Challenges & Solutions

- **Containment & Root Cause of Complex FAs**

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Containment & Root Cause of Complex FAs

- **Despite all your teams' good efforts, you *will* get FAs**

- **Modern products are complex**
  - Chiplets & 2.5D/3D packages
  - Advanced process nodes
  - Complex supply chains
- **But your customers don't care**
- **They want the answers, *now***

Traceability & End-to-End Data Analytics make FA easier

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End to End Analytics & Traceability for Better FA/RMA

WAT (aka PCM, E-Test)

- Parametric data

Wafer Sort (aka EWS, CP)

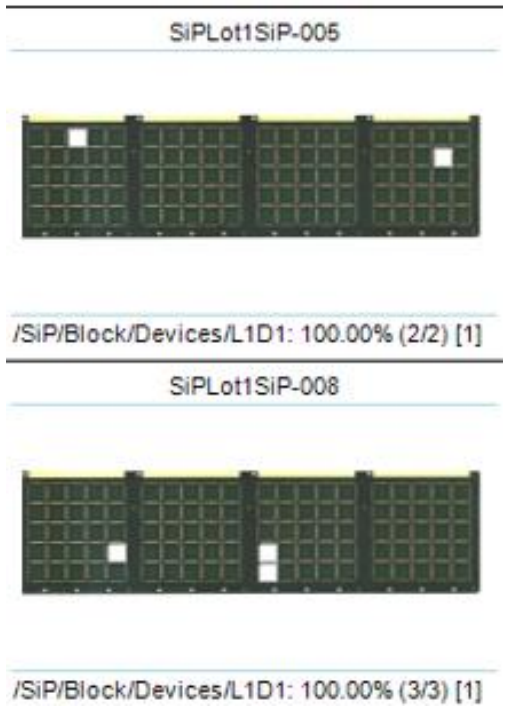
- Yield, binning
- Wafermaps
- Parametric data
- Equipment Details

Final Test (aka Class)

- Yield, binning
- Parametric Data
- Equipment Details

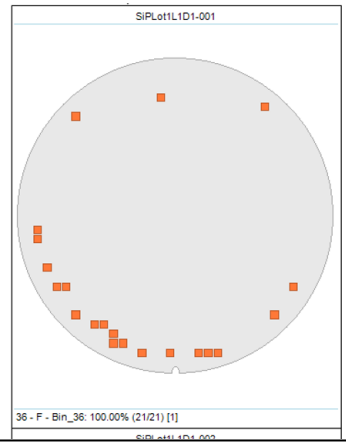
Packaging

- Substrate Maps



Reconstituted Wafer Maps

- ✓ Use traceability to see failures at each of previous steps
- ✓ ECID or Exensio Assembly Ops



Defect Localization

- Logic using Scan Fault Diags
- Memory using Bitmap
- Both → Siemens Tessent collaboration

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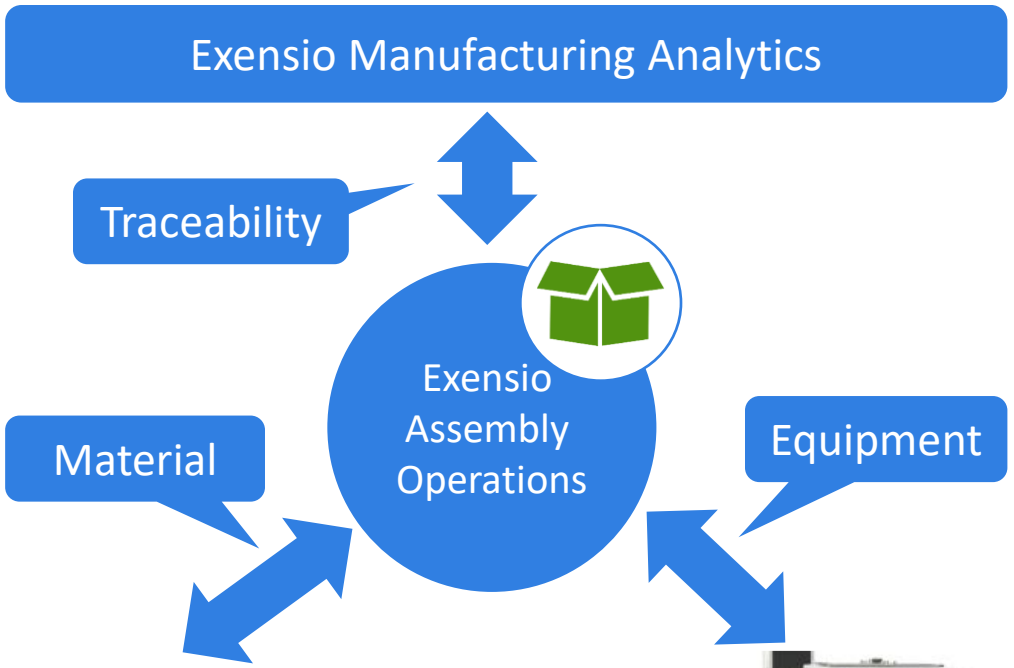
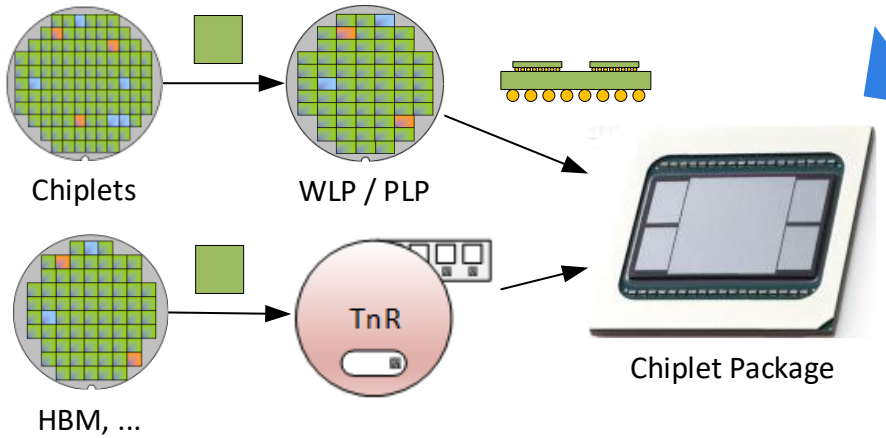
Exensio Assembly Operations Overview

- Reduce yield loss by up to 10%
- Up to 5x faster RMA response & root cause analysis
- Up to 10x reduction in recall volume
- Integrated with Exensio® Manufacturing Analytics






Wafer Sort


Packaging


Final Test

- Traceability through assembly and final test
- With or without ECIDs
- Enables NPI, yield ramp, device matching, RMA, …
- Equipment integration via SECS GEM and Cimetrix® Sapience
- Full SEMI E142 support

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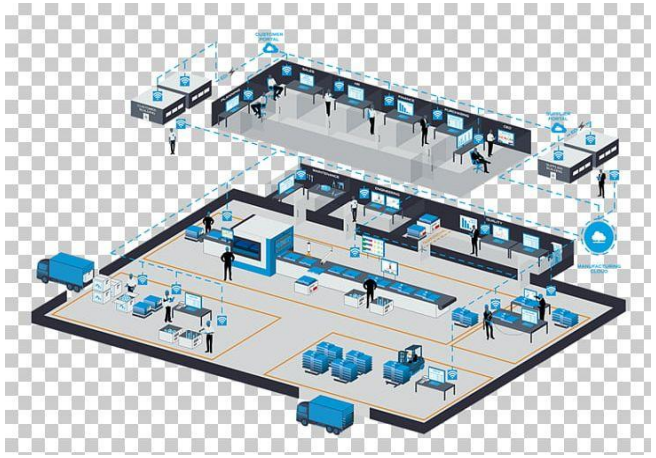
Summary: PDF is solving real challenges with analytics-driven outlook

Common Challenges

- Manufacturing Efficiency
- Yield Management
- Outlier Identification
- Data Assimilation
- Supply and Demand

Digital Manufacturing Powered by



End to End Data connectivity enabling Digital Twin and Semiconductors Innovation with AI

20%

Improved Efficiency

- ↑ *Labor*
- ↑ *Sourcing*
- ↓ *Maintenance*
- ↓ *Warranty*

10%

Improved Utilization

- ↓ *Invalid Activities*
- ↑ *Equipment Efficiency*
- ↑ *Sustainable Practices*
- ↓ *Integration Time*

6-mo faster

Time to Value & volume

- ↓ *Defects*
- ↑ *New Product*
- ↑ *Qualification*
- ↑ *Mfg Efficiency*
- ↓ *Asset downtime*

PDF SOLUTIONS™

30%

Improved Quality

- ↓ *Scrap Rate*
- ↑ *Fill Rate*
- ↑ *Yield*
- ↓ *Lead Time*

30%

Reduced Cost

- ↓ *Optimized Capacity*
- ↓ *Asset Utilization*
- ↓ *Change over Time*
- ↓ *Downtime*

PDF's Mission: Provide innovative solutions to create, access, and organize data to enable analysis and control for semiconductor and electronics companies to achieve better time-to-market, yields, quality, and operational efficiencies

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Thank You

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