WHITEPAPER

Modernizing Semiconductor Yield Optimization Through AI-Driven Analytics

Authors

Surjit K Lahiri
Group Practice Head—
Semiconductor Manufacturing &
Data Storage,
Tech Mahindra

Dan Miklovic
Expert Advisor -
Third Eye Advisory

Executive Summary

In semiconductor manufacturing, yield optimization is the primary determinant of profitability that directly impacts production costs and product longevity. As manufacturing demands complex front-end and back-end processing, the risk of process variations causing defects has increased exponentially. While traditional methodologies such as statistical process control (SPC) and failure mode and effects analysis (FMEA) provide stability, they are insufficient for scaling modern data ingestion.

This white paper analyzes the limitations of legacy analytics and proposes an integrated, AI-enabled yield analytics platform as the mandatory solution. With AI-driven predictive modeling, manufacturers can identify root causes with greater precision and automate adaptive process adjustments. The application of these AI-enabled strategies enables rapid yield ramp-up during critical launches of new product information (NPI). As a result, manufacturers can maintain competitive margins and ensure sustained reliability across high-volume production.

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Introduction

Artificial intelligence and large-scale data center deployments are fueling unprecedented demand for advanced semiconductor capabilities. McKinsey estimates that the industry, which was roughly at $630-680 billion in 2024, is expected to surpass $1 trillion by 2030, led by AI workloads and the expansion of computing infrastructure.1 This growth is reshaping competitive dynamics while placing unprecedented pressure on manufacturing efficiency, scalability, and product quality.

At the same time, semiconductor technologies are getting complex. Shrinking geometries, advanced packaging architectures, and tighter process tolerances have significantly reduced defect margins. Even minor variations in materials, equipment performance, or operating conditions can now result in substantial yield loss. Maintaining high yield efficiency has become critical to cost control and time-to-market competitiveness, particularly at advanced process nodes where production costs are exceptionally high.

Modern fabrication environments generate vast volumes of multi-domain data from different areas, including equipment behavior, process parameters, metrology, and test results. While this data holds critical insights into yield drivers, traditional approaches struggle to correlate high-dimensional information at the required speed and scale. Manual investigations and fragmented tools restrict the ability to identify root causes, predict yield trends, and implement corrective actions efficiently.

Addressing these challenges requires a shift toward integrated, AI-enabled yield intelligence approaches that transform large, heterogeneous datasets into actionable insights. Manufacturers can accelerate yield stabilization, improve ramp performance, and sustain long-term manufacturing excellence by combining advanced analytics, automation, and collaborative engineering workflows within unified platforms.

The New Complexity of Yield Optimization

At advanced semiconductor nodes, yield behavior is increasingly governed by tightly coupled interactions across process physics, equipment performance, material variability, and design architecture. As three-dimensional structures and sub-5nm geometries push manufacturing limits, small deviations can cascade into significant yield loss. Identifying root causes now requires a comprehensive view across industry trends, business ROI objectives, manufacturing data complexity, and end-user collaborative workflows:

- **Industry and Technology Drivers:**
  - The semiconductor industry is currently shaped by system complexity, aggressive quality requirements, and advanced packaging architectures such as multi-die systems
  - Shrinking manufacturing geometrics at advanced nodes lowers defect tolerance headroom
  - The complexity of the supply chain introduces new types of subsystem variation that inevitably induce defects
- **Financial Imperative:**
  - Accelerating time-to-market and yield ramp-up from new product introduction (NPI) to high-volume manufacturing (HVM) remains a priority
  - The maintenance and improvement of product yield year-over-year (YoY) ensures long-term profitability
  - The enhancement of product reliability YoY reduces operational risk and warranty liabilities
- **Manufacturing and Data Complexity (IDM, Foundries, Fabless, OSAT/ATMP):**
  - Semiconductor manufacturing analytics follow a reverse-empirical model wherein the critical decisions define required insights, and data collection
  - Manufacturers have to manage big data issues around volume, velocity, variety, veracity, and value
  - Systems process both real-time production data and historical datasets
  - Production data from multiple sources is integrated to provide descriptive, diagnostic, predictive, and prescriptive analytics
  - Complex work-in-process (WIP) routing occurs across the fab equipment
  - Multiple data formats are supported, including standards-based systems such as SECS/GEM, STDF, and RITdb, and proprietary sources
  - Use-case-specific data cleansing and filtering are needed to ensure analytical accuracy

- **End User Workflow and Collaboration Challenge (Product Designer, Process Engineer, Test Engineer, Quality Engineer):**
  - Multiple engineering stakeholders must collaborate across yield analysis workflows
  - Bringing together teams located across the globe to share scenarios, insights, and results remains a challenge
  - Analytics workflow development is necessary for engineering productivity
  - Data governance, provenance, and traceability are a result of regulatory and quality compliance
  - Stakeholder knowledge management is critical for deriving learnings from past analytics problems and solutions to optimize future workflows

The growing structural and process complexity of advanced semiconductor devices is illustrated by an example of 3D NAND memory fabrication below.

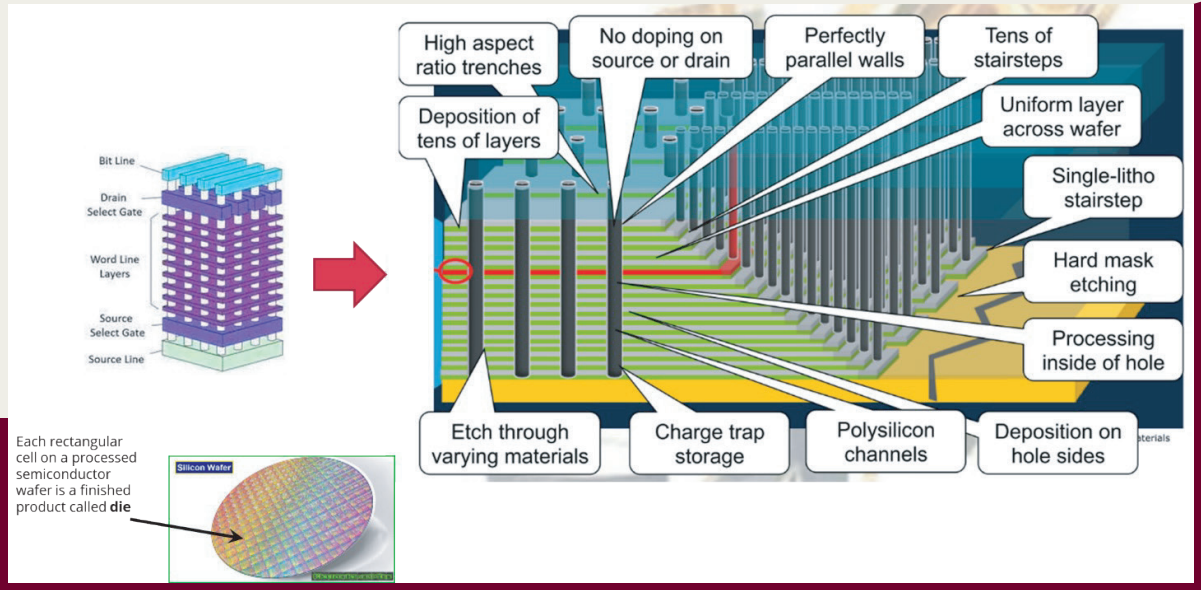

Figure 1: Key Manufacturing Challenges for 3D NAND Memory Fabrication

The impact of manufacturing complexity is reflected in wafer yield performance, defined as follows:

Total wafer yield = Number of good dies/total number of dies

- Yield percentage varies across fabs and product lines; these metrics are tightly controlled corporate secrets
- A fab's objective is to achieve the highest, most consistent yields and optimized production cycles to maximize ROI on billions of dollars invested in facilities

Traditional Yield Management Across FEOL, BEOL, and Packaging

Semiconductor manufacturing involves a sequence of highly controlled processes spanning front-end-of-line (FEOL), back-end-of-line (BEOL), and packaging stages. Each step introduces potential sources of process variation, material contamination, and equipment drift that can lead to manufacturing defects and reduced yield performance.

To monitor and improve yield across these stages, manufacturers apply a combination of statistical, analytical, and inspection-based techniques. Comprehensive data is collected from process equipment, metrology systems, and material characterization to identify yield-impacting trends and anomalies. Methodologies such as failure mode and effects analysis (FMEA) and design of experiments (DOE) commonly support root-cause investigations by helping isolate process sensitivities and optimize operating conditions.

Real-time process stability is typically maintained using statistical process control (SPC), which detects deviations early and provides corrective action before they propagate. Fault detection and classification (FDC) systems further automate the identification of anomalies across equipment and process signals. In parallel, automated optical inspection (AOI) and inline metrology tools provide high-resolution defect detection and critical dimension measurement throughout wafer processing, ensuring compliance with design specifications and minimizing yield risk. However, these traditional approaches are reaching their limits as manufacturing complexity increases.

Market Solutions and Competitive Landscape

The application of analytics in semiconductor manufacturing has matured over decades, shifting from isolated point solutions to specific use-case workflow platforms deployed on premises, at the edge, and in the cloud. Current market offerings consist of a diverse mix of customer homegrown and specialized vendor platforms customized to specific manufacturing use cases.

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Exensio® Analytics Platform:
Provides data acquisition, normalization, semantic, big data cloud management, AI/ML, and data visualizations

Targeting:
-Mfg Analytics
-Process Analytics
-Test Ops
-Assembly Ops

Components:
-Semantic Data Model
-Rules Engine
-Big Data Analytics

Deployment:
-On Premises/Edge
-Cloud

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Silicon.da Analytics Platform:

Can leverage silicon design, monitor, diagnostic, fab and production test data to improve key chip production metrics such as quality, yield and throughput, as well as key silicon operational metrics such as chip power and performance

Targeting:
-Mfg Analytics
-Test Ops

Deployment:
-On premises/Edge
-Cloud

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Run-to-Run Control

Improves process yield by optimizing equipment and process performance

SPC3D®

Combines the power of data transformation with analytics to provide intelligent detection

Fault Detection

Minimizes yield loss and reduces unscheduled equipment downtime

Targeting:
-Mfg Analytics
-Process Analytics

Deployment:
-On premises/Edge
-Private Cloud

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Discover® Yield Software
A complete yield management enterprise platform that combines parametric, defect and yield optimization with data mining and workflow development across all data sources from memory and design to assembly and packaging.

Targeting:
-Mfg Analytics
-Process Analytics
-Assembly Ops

Deployment:
-On premises/Edge

Where Traditional Yield Analytics Fall Short

Modern yield challenges have exposed critical gaps in analytics integration, workflow automation, and collaborative knowledge reuse:

- **Integrated Analytics Platform Across the Yield Lifecycle:**
  - Supporting descriptive, diagnostic, predictive, and prescriptive analytics within a unified environment
  - Ingesting data from non-standard and heterogeneous sources
  - Enabling custom algorithm development with out-of-the-box analytical models
  - Automating data flows
  - Supporting AI/ML model development, testing, and deployment
  - Performing cost-benefit analysis
- **Collaborative Data and Analytics Workflow Management:**
  - Integrating data through messaging, event processing, virtualization, and centralized managementEnabling collaborative review of workflows and visualization results across global teams
  - Supporting version control of workflows, including the creation of standardized ‘golden sets’ by product
  - Leveraging GenAI co-pilots to create new analytics workflow
- **User Collaboration and Knowledge Management:**
  - Enabling real-time communication to share problems and results across teams
  - Maintaining searchable knowledge repositories for analytics insights and solutions
  - Encouraging adoption through usage gamification
  - Supporting reuse of validated analytics workflows
  - Promoting consistent sharing of best practices across the organization

Beyond Predictive Modeling: Tech Mahindra's Integrated Yield Intelligence Solution

To bridge these gaps in the analytical landscape, Tech Mahindra has developed an AI-led semiconductor yield analytics platform. The platform enables a continuous flow from heterogeneous data ingestion to prescriptive action. It integrates predictive machine learning with collaborative engineering workflows to accelerate the transition from NPI to HVM.

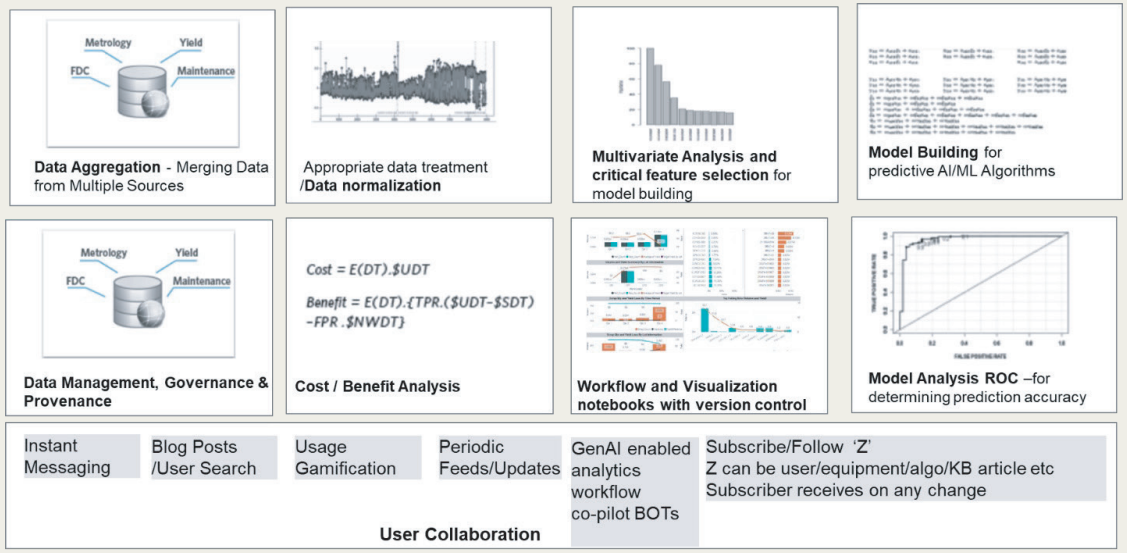

Figure 2: Platform Capability Overview

The solution is built on three foundational capabilities that address analytics integration, workflow orchestration, and knowledge sharing across the yield lifecycle:

- Integrated AI-Enabled Yield Analytics Platform: A unified analytics environment that ingests multi-source manufacturing data and applies statistical methods and AI/ML models to identify root causes and predict yield outcomes
- Collaborative Data and Analytics Workflow Management: Automated and version-controlled analytics workflows that standardize data preparation, modeling, and visualization across engineering teams
- User Collaboration and Knowledge Management: Built-in communication, knowledge-sharing, and workflow reuse capabilities to support cross-team collaboration, institutional learning, and continuous yield improvement

Solution Benefits

Faster Time to Market & yield ramp up from NPI to HVM	Maintain and improve product yield YoY	Faster Time to Market & Improve product reliability YoY

Manufacturing Analytics

- Automatically data collection
- data visualization --Data Table, Yield Trend by lot, Zone Stats, Heatmap, Zone Stats with WEH, Commonality, Indicator data, Zone Stats vs Indicator corelations
- Alerts and Warnings
- Online and offline rules
- yield management environment
- Automated data cleaning
- Complete lot and wafer genealogy
- Automatic historical data mining
- Defect source analysis
- Physical failure analysis
- Guided Analytics
- NPI product rapid characterization and root cause analysis tools

Process Control

Setup/config, Matching Table, Outlier data delete, Sensor Summary,

FDC Raw trace by Chamber

- Chamber/Tool Matching
- Quick Highlights of Process Control
- Conventional FDC (Fault Diagnostics Classification) capabilities
- Offline model creation and simulation
- Configuration versioning
- Real-time interactive reporting
- OCAP (out of control action plan) alarms
- Online SPC(Statistical Process Control)
- Approval loop
- Combine summary and real-time FDC data

Testing Ops

- Multi Algo Support for Part Average Test (PAT) such as GDBN, NNR, DPAT, SPAT and Clustering
- Quick Highlights of Test Operations
- Broad support for current and legacy testers
- Bi-directional tester control
- Detailed analysis per test
- Real time tester data
- Automated data collection and cleaning
- Big data analytics (Cassandra and R)
- Test-specific analytics and charting
- Inkless wafer map editing/merging/exporting
- Online and offline rules for quality and reliability

Assembly Ops

- Single Device Traceability
- Instant and precise reports on work in progress (WIP) to identify process defects quickly
- Quick Highlights of Assembly Operations
- Compatible with and complementary to existing electronic chip IDs (ECIDs)
- Maintains die handling location maps and location transformations through every step of the test and assembly processes
- Every package is linked to ALL die in the package (e.g. MCMs or SiPs)
- Fully integrated to all manufacturing data streams: Test data, Manufacturing data, Process control data

Conclusion

The semiconductor industry operates in a winner-takes-all environment where yield performance defines market survival. With leading-edge 3nm wafers costing around **$22,000** each,[2] even a marginal **1%** yield [3] fluctuation can have a massive impact, easily exceeding $100 million in annual profitability. Integrated AI yield solutions can help manufacturers harness production data to streamline processes, cut costs, and ensure reliability for next-generation electronics.

At the same time, ongoing innovation continues to push technological boundaries, driving smaller geometries and tighter manufacturing tolerances. This rising complexity is stretching traditional, human-driven analysis methods to their practical limits. As a result, deploying state-of-the-art AI-enabled yield management and enhancement solutions is becoming crucial to sustaining competitive, scalable, and profitable semiconductor manufacturing operations.

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About the Authors

Surjit K Lahiri

Group Practice Head—
Semiconductor Manufacturing & Data Storage,
Tech Mahindra

With over three decades of experience across industrial automation, cyber-physical systems, high-tech manufacturing, machine vision, cloud, data storage, and IoT, Surjit has built and scaled semiconductor and data-storage services businesses from the ground up. He has driven multi-million-dollar deals with global OEMs, fabs, OSATs, hyperscalers, and ISVs through consulting-led solution architecture and AI/ML-driven engineering. Before Tech Mahindra, Surjit held leadership roles at Mindteck, Novellus Systems, and Siemens, shaping portfolio-level innovation and complex capital-equipment software programs.

Dan Miklovic

Expert Advisor - Third Eye Advisory

Dan is recognized as a thought leader and one of the top market place influencers in the Asset Performance Management and Manufacturing Operations sectors. His coverage spans across all forms of heavy industry from A&D to Utilities and covering topics such as MES, EAM, QMS, PLM, EH&S, and Al/ML as applied to industrial operations. Dan is involved in both professional and amateur auto sports as an emergency services official and race operations director. He is heavily involved In the start-uc community as a mentor and advisor for entrepreneurship programs at Lindenwood University, Washington University, University of Missouri - St. Louis and the eFactory program at Southwest Missouri University helping clients to validate product strategies and develop business plans to entice investors.

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