

Enabling Smart Manufacturing in Semiconductor Fabs Using Predictive Design and Process Insights

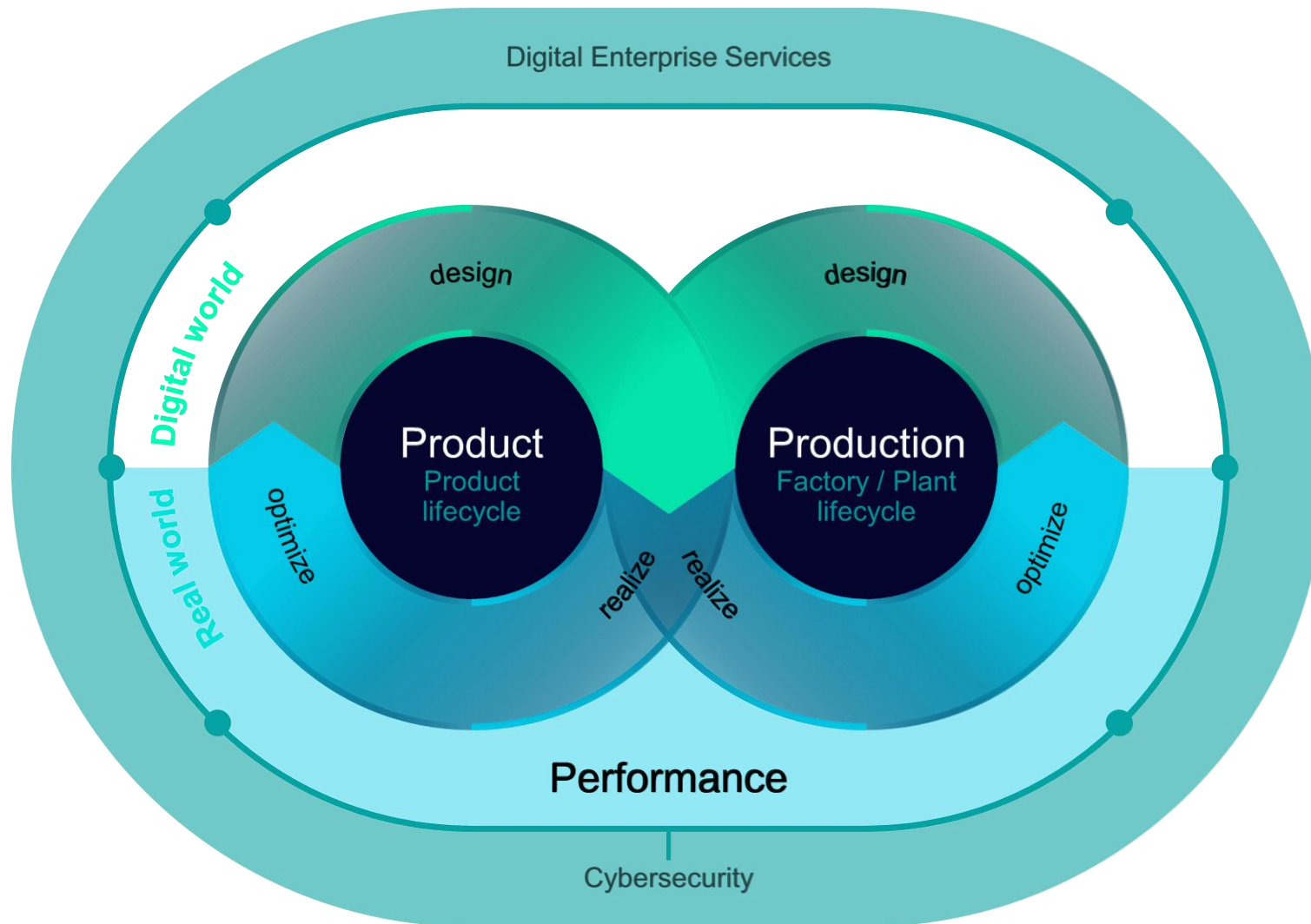
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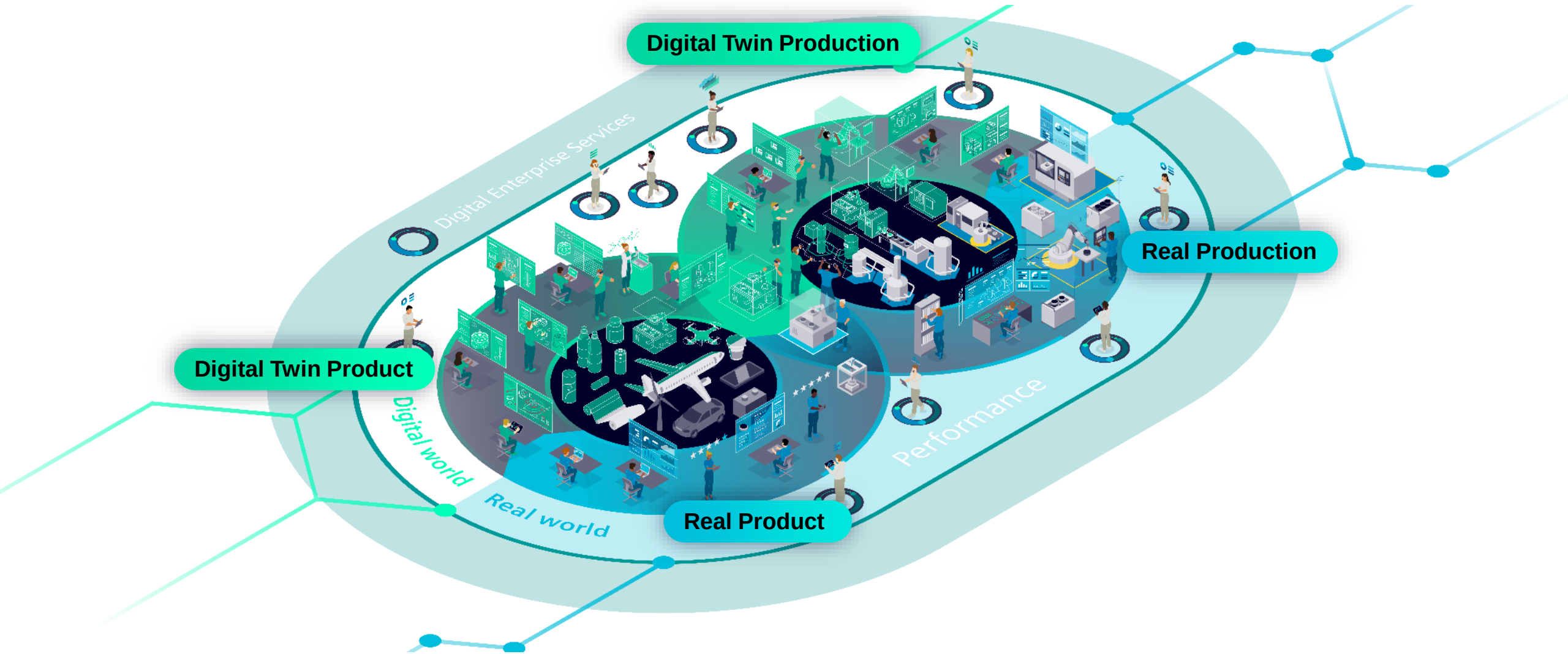
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- Building Digital Twin for Semiconductor Fabs
- Siemens Calibre® Fab Insights Platform
- Digital Twin Production - Combining Product, Process, Metrology
- Digital Threads (Apps)
- Evaluation of solution for HVM (High Volume Manufacturing) implementation
- Conclusion

Smart Manufacturing using the Digital Twin approach: The Goal



Comprehensive Digital Twin approach: The execution



Allows realistic simulations & validation of products, machines, lines and complete plants
Foundation for flexible and efficient manufacturing

Building Digital Twins for Semiconductor Manufacturing

Solving semiconductor fab challenges

- Increase profit margins - Reduce OPEX, CAPEX and increase revenue
- Create product-specific process recipes without test wafers
- Guarantee highest product quality, with minimal measurements across every wafer
- Improve yield curve - Quick diagnosis of the cause of yield limiting issue
- Monitor performance of the fleet and predict future performance, for specific products
- Loss of institutional knowledge with attrition of key engineers



REQUIRED FRAMEWORK AND DEMONSTRATION CAPABILITIES

Semantic Data Integrated Process, Metrology and Product Content

Agnostic framework fitting any computing environment

Methodology to quickly identify, solve and prevent problems

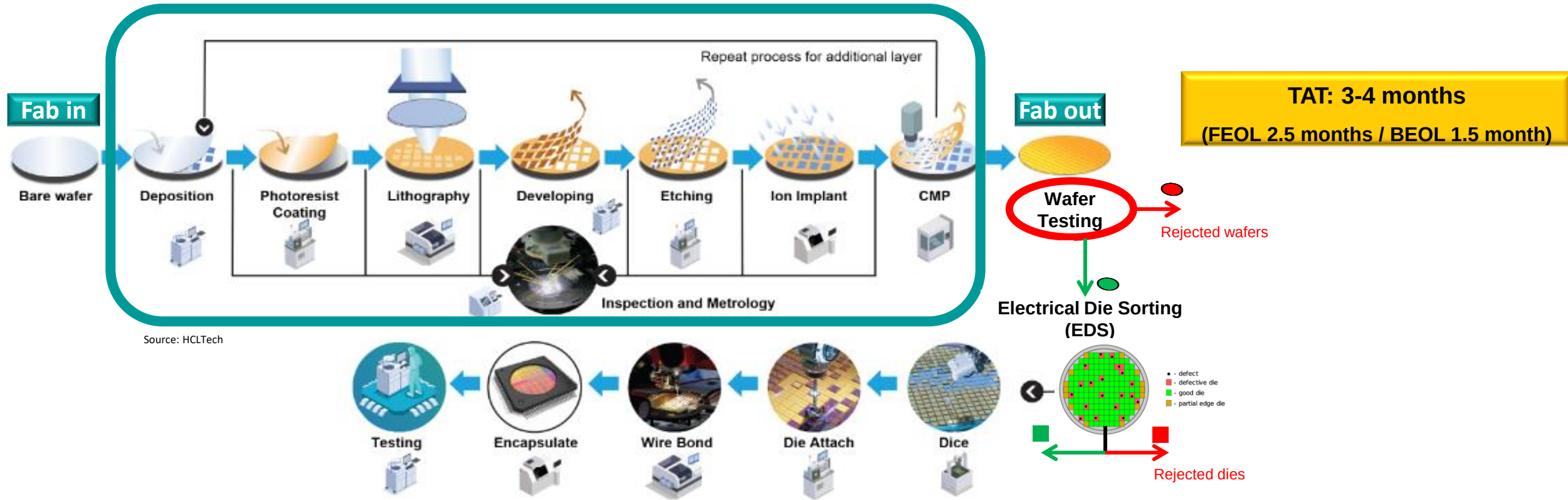
Monitor process drift and differentiate between different processes or product mix

Monitor tool drift and restore nominal operation

Forecast future performance at earlier processing steps in a process sequence

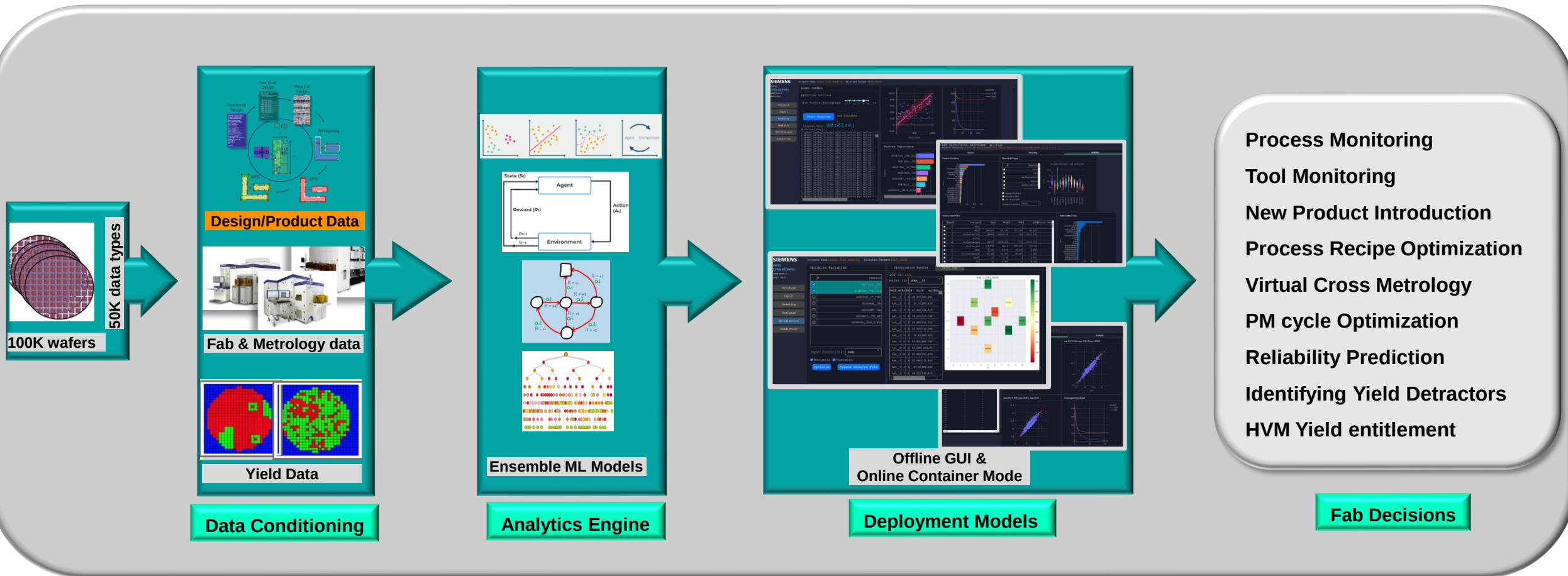
Sample Applications

Yield and Reliability requirements for advanced technology node chips



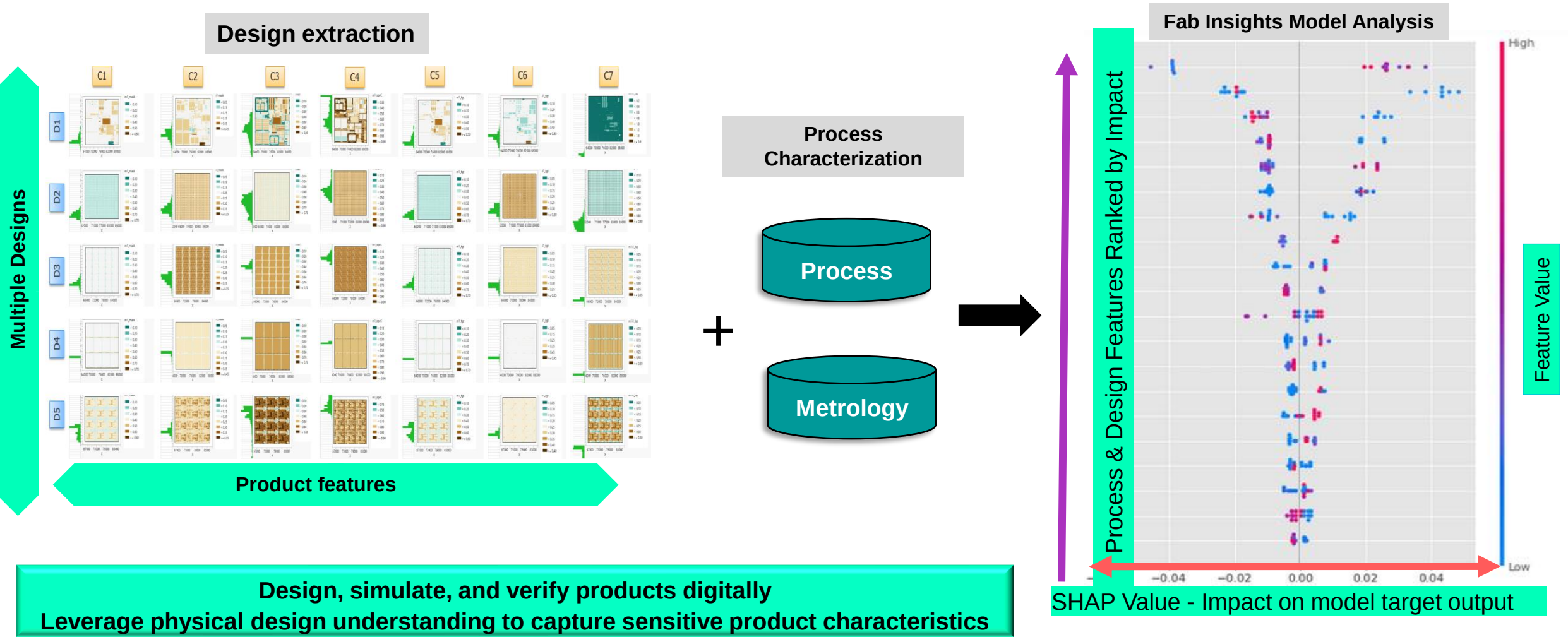
- No real-time monitoring and prediction system to maintain reliability spec
- Electrical testing after Fab-out may not be sufficient for ensuring high reliability standards
- Screening wafers at critical process steps can save significant time and \$\$

Siemens Calibre® Fab Insights Platform



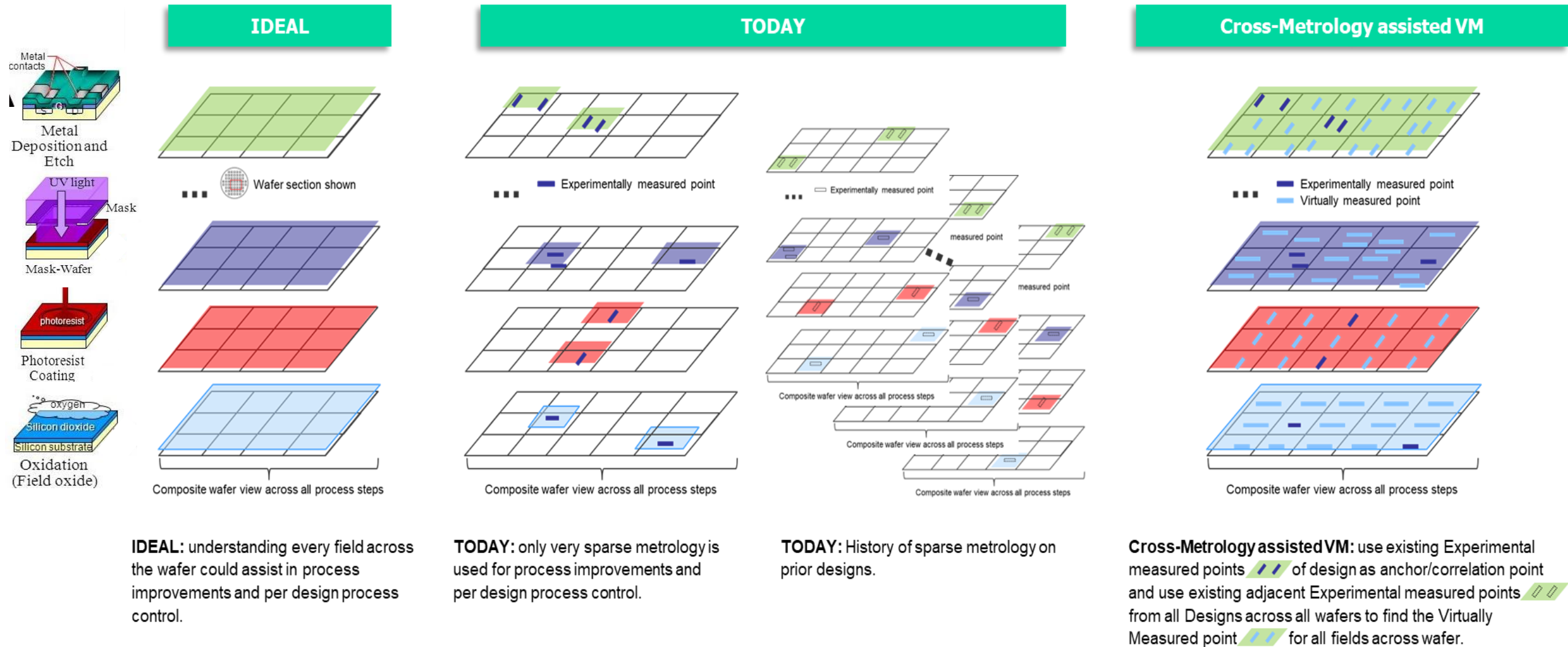
Digital Twin Product: Understanding impact of product design

Visualizing impact of product design features on the model using SHAP analysis



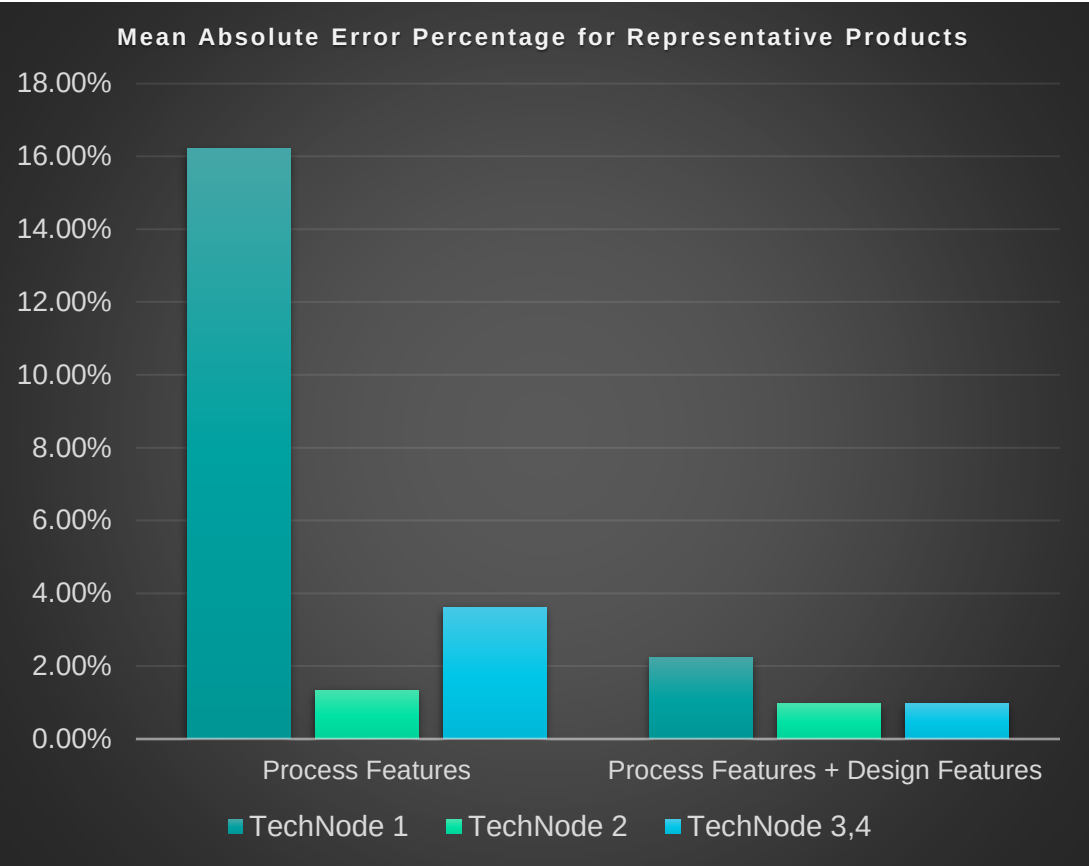
S.Schuler et al, "Virtual metrology: how to build the bridge between the different data sources", Proc. SPIE 11611, Metrology, Inspection, and Process Control for Semiconductor Manufacturing XXXV, 2021

Digital Twin Metrology: Virtual Cross Metrology



Digital Twin Production: Combining Product, Process & Metrology

Combine Process, Product and Metrology data to achieve more physical models

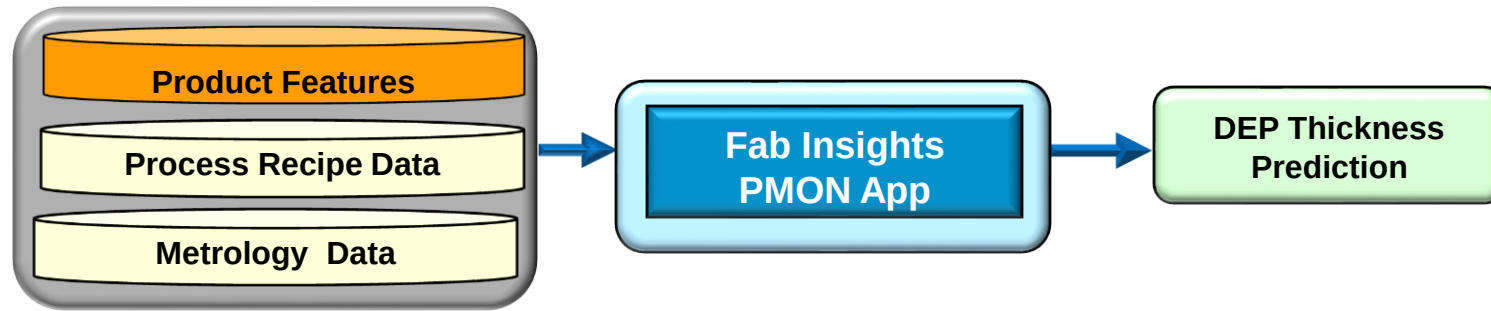


Provides improved process control and wafer dispositioning
Enable solutions to many problems like tool and process drift

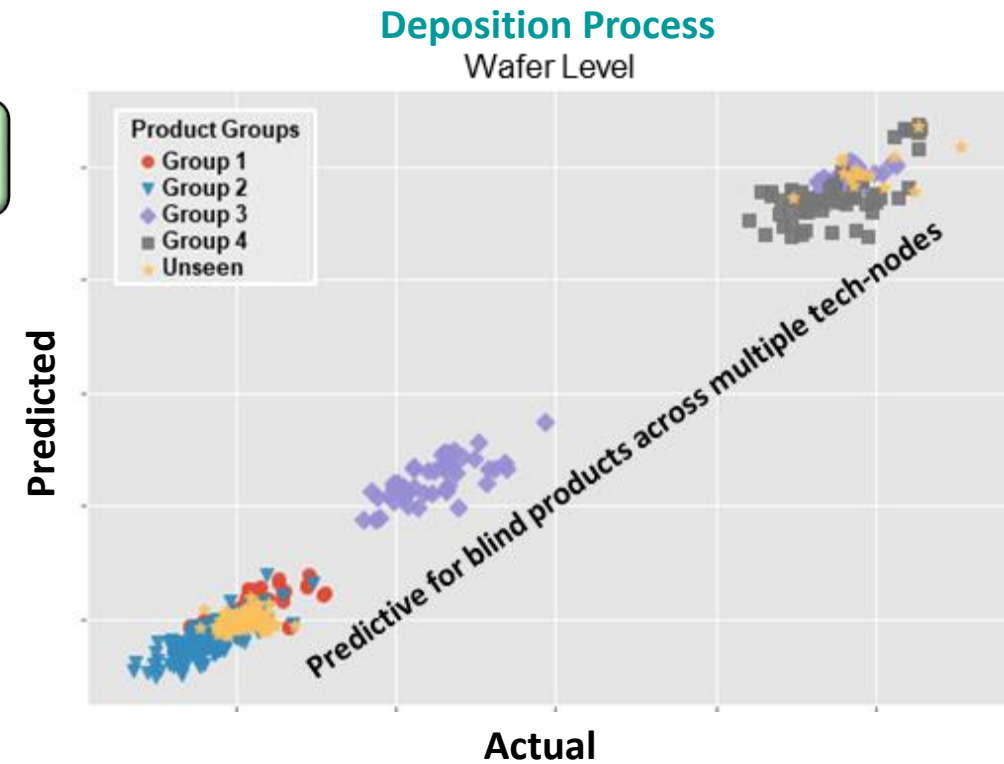


N. Greeneltch, et al "Design-aware virtual metrology and process recipe recommendation",
Proc. SPIE 12495, DTCO and Computational Patterning II, 2023

Applications Results – PMON (Process MONitoring)



- Design features incorporate incoming layout information, including new products
- Process features link empirical data to enable recipe recommendations based on actual measurements

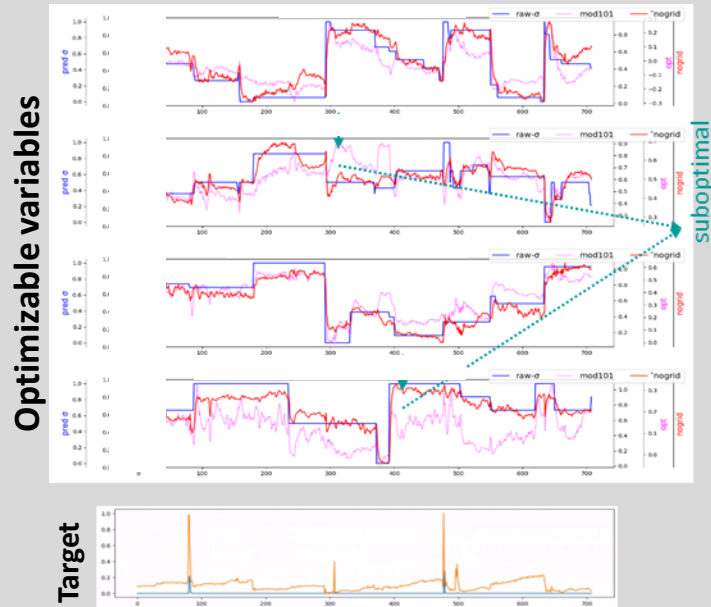


N. Greeneltch, et al "Design-aware virtual metrology and process recipe recommendation", Proc. SPIE 12495, DTIC and Computational Patterning II, 2023

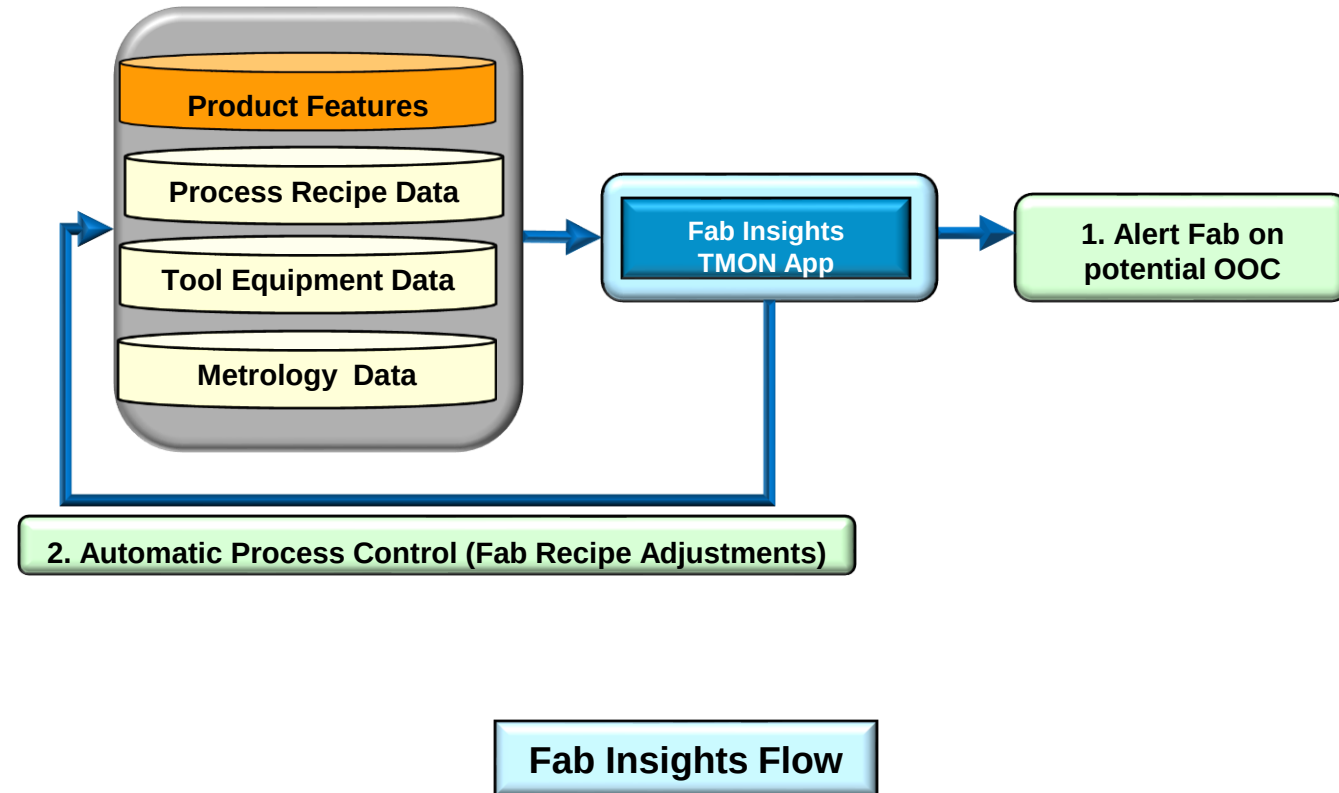
**Monitor process drift and differentiate between product mix or process drift
Reduce monitoring wafers, improve wafer quality.**

Applications Results – TMON (Tool MONitoring)

CVD and Electroplating tools

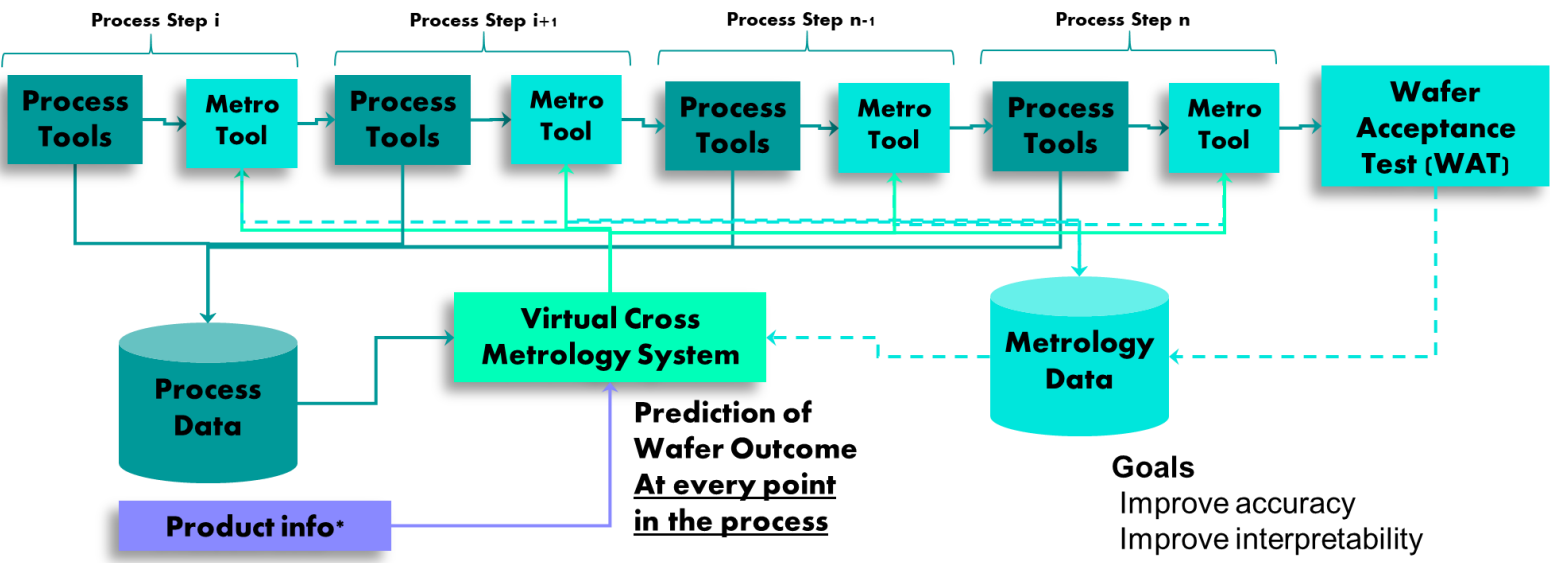


TMON model trained with CVD fleet data to uncover suboptimal process parameter settings



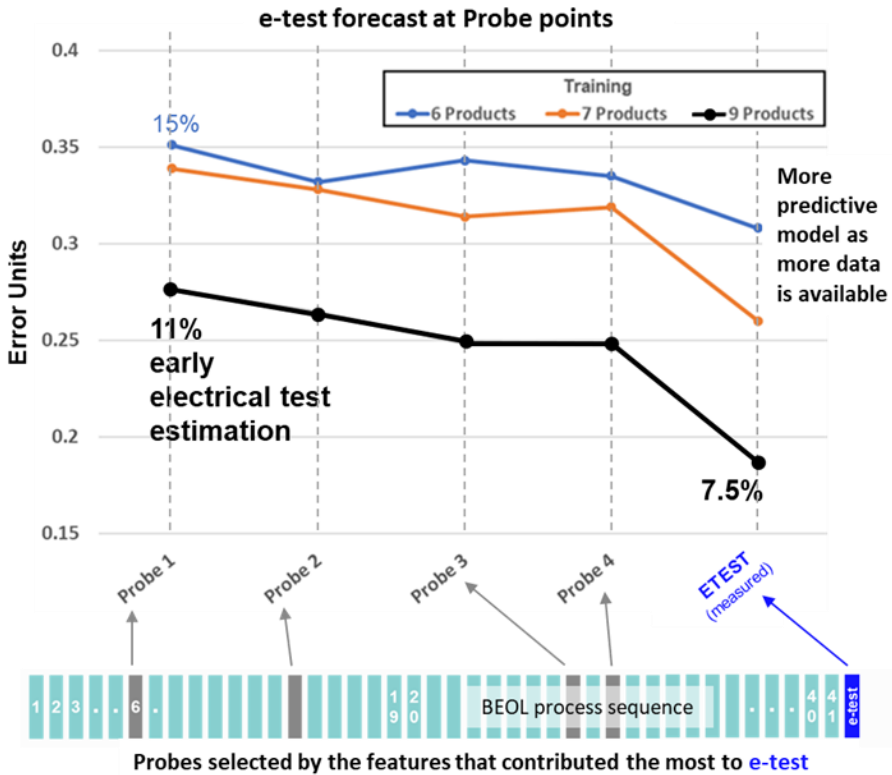
Monitor tool drift across the fleet and detect tool going “Out Of Control” (OOC) early
Restore individual nominal tool performance faster (from days to hours) after PM cycle

Application Results – (Virtual) Cross Metrology



J.Torres,et al "Virtual cross metrology: leveraging process sequence for improved process characterization", Proc. SPIE 12053, Metrology, Inspection, and Process Control XXXVI, 2022

BEOL: E-Test Target

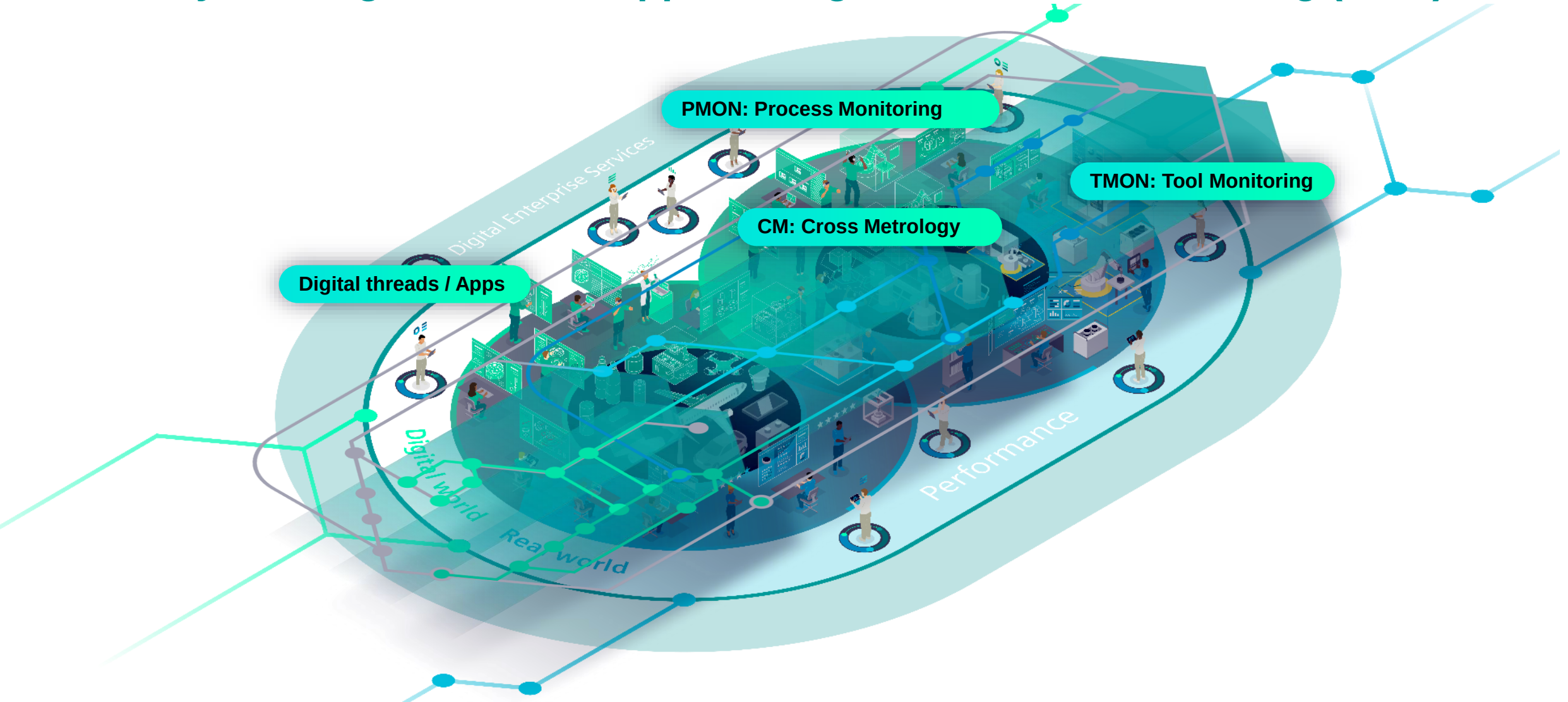


Forecast electrical performance earlier during processing

Model a sequence of 42 individual process and metrology steps to identify most significant contributors to e-test

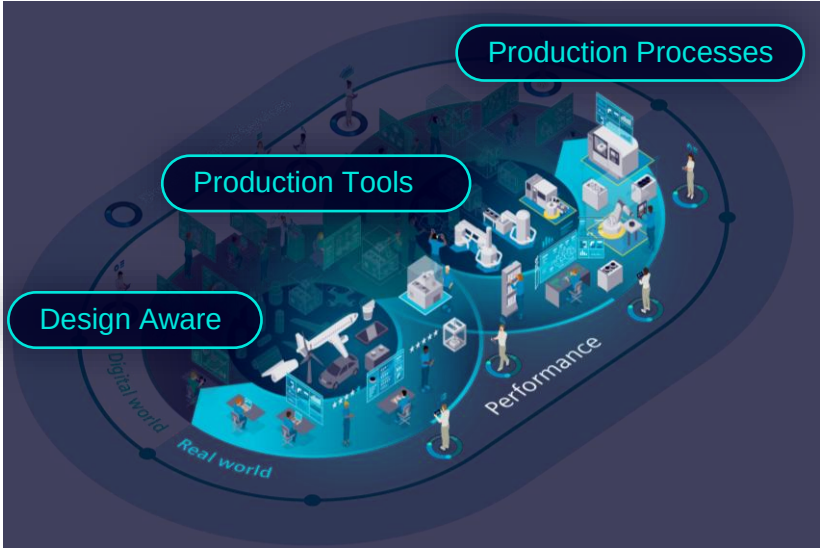
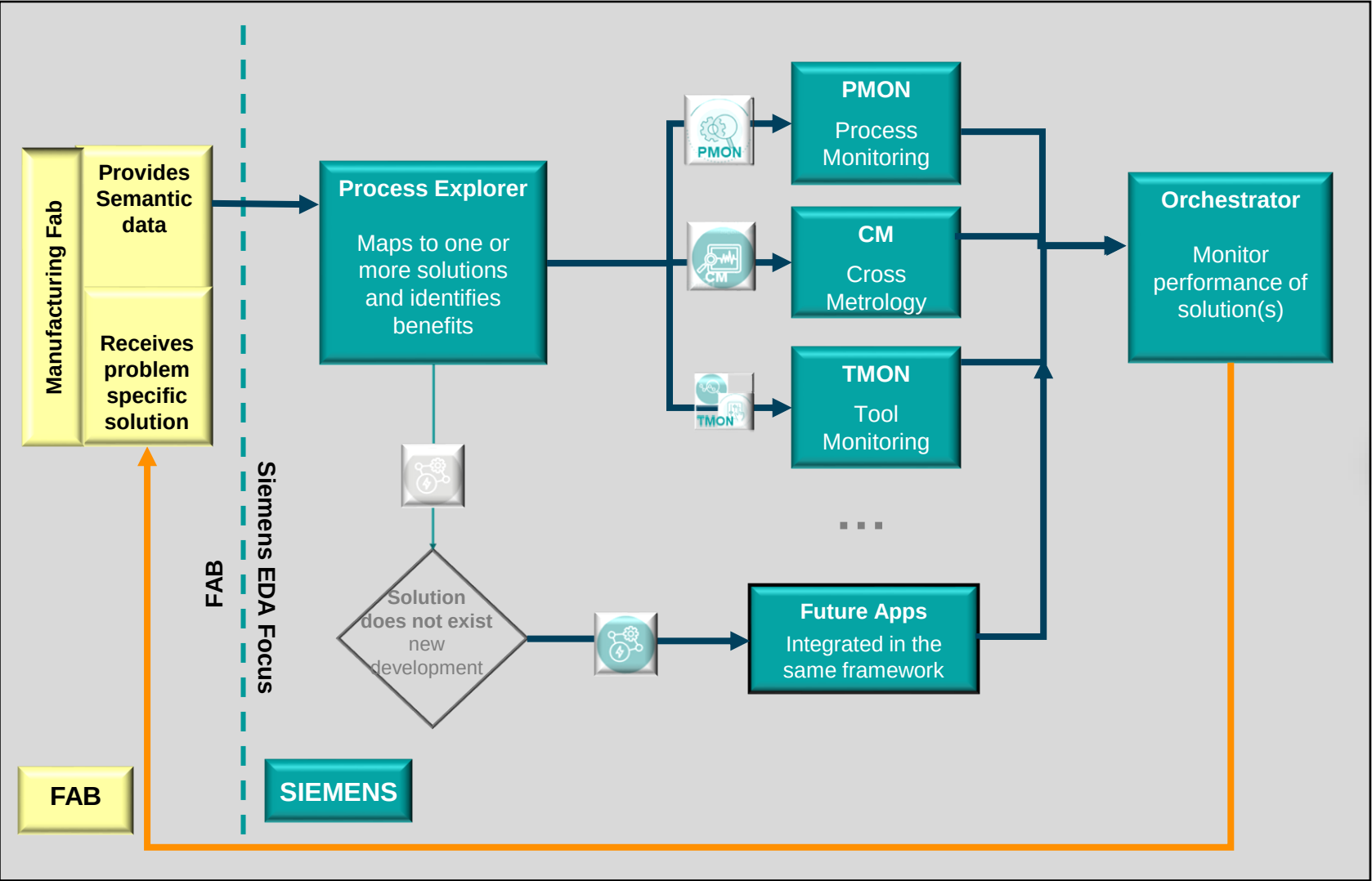
Virtual Cross Metrology to monitor and detect early drift of a process

Flexibility with digital threads/Apps for High Volume Manufacturing (HVM)



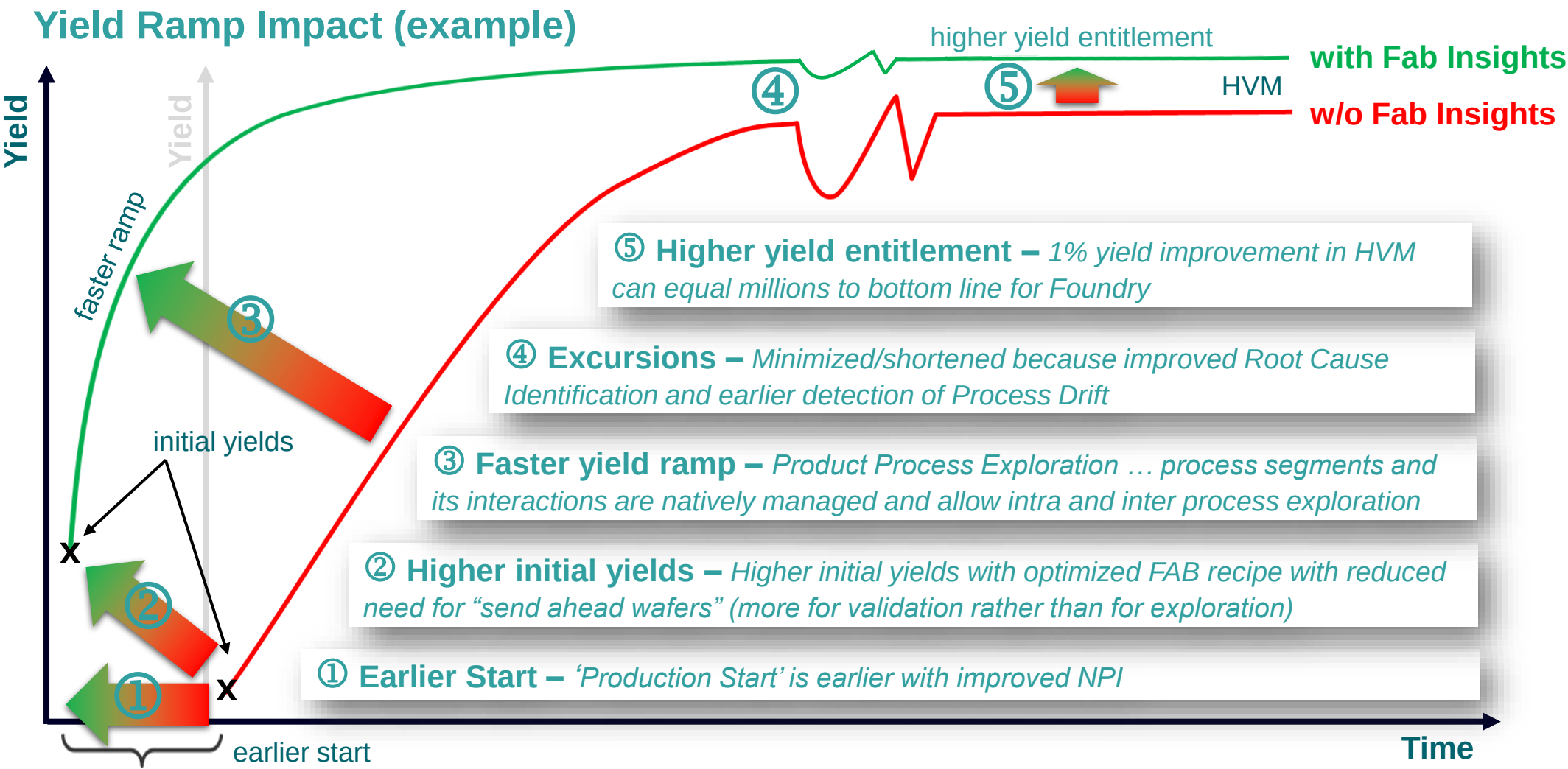
Digital Threads / Apps - Building blocks for the digital journey, based on specific business workflows.

Realizing the full potential of a Digital Twin in HVM



Quickly and securely improve communication between design and production facilities and teams

Fab Insights Unique Business Value (UBV) and Enabling Return Of Investment (ROI)



Digital Transformation for Semi Fabs

- *Data is not enough*: Data needs to be coupled with semantics describing the data
- *Flexible*: Solution must work in cloud and/or on premise
- *Adaptability* of solution to address multiple problems
- *Scalable*: Solution must be trivial to deploy at scale across all relevant manufacturing points.
- *Cost effective*: Solution must easily demonstrate significant benefits over existing processes and tools
- *Fab Insights Solution* incorporates the fab manufacturing history along with new product info and leverages process sequence to achieve fab yield goal
- *Digital Twin capability* provides actionable and predictable insights to improve cost and resource efficiency for HVM



Acknowledgements

Calibre® Fab Insights Team:

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