



# NI Product Analytics

NI Connect 2023  
O+ Introduction

Ron Chaffee, Sr. Director of Applications Engr.

May 2023

# O+ Intro

O+ Overview : Life Cycle Analytics

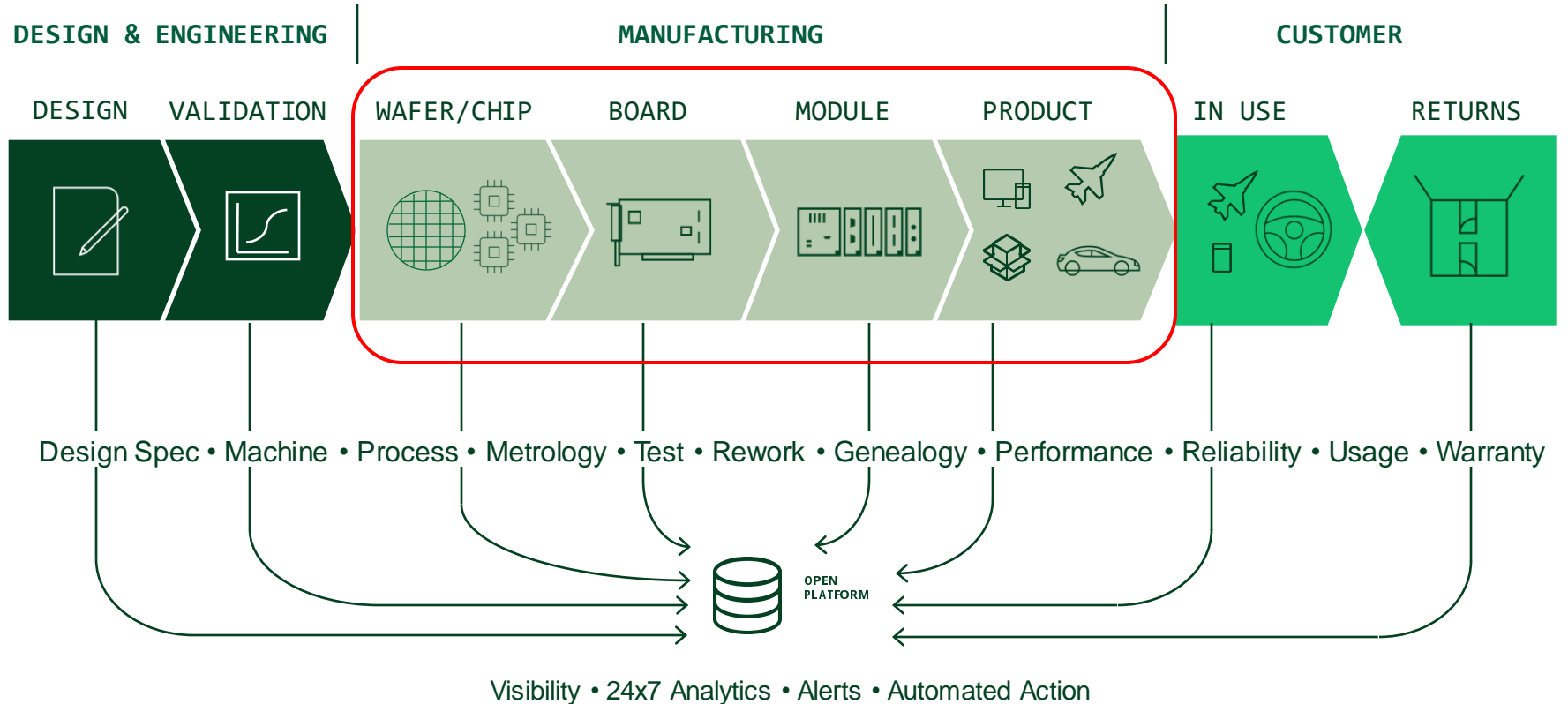
O+ for Semi Manufacturing

- ML Apps : Wafer Classification

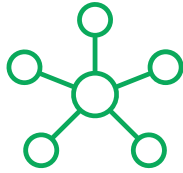
O+ for Electronics Manufacturing

- ML Apps : Crack Detection

# Lifecycle analytics – following the product journey



# Complete end-to-end solution



## Collect

Data **security & encryption**

**Accuracy, Completeness** and **integrity**

Data **harmonization & standardization**

**Any data type** (Product, machine, process)



## Detect

**Prescriptive** analytics

**AI / machine learning**

**24 x 7** analytics engine

**Real-time**



## Act

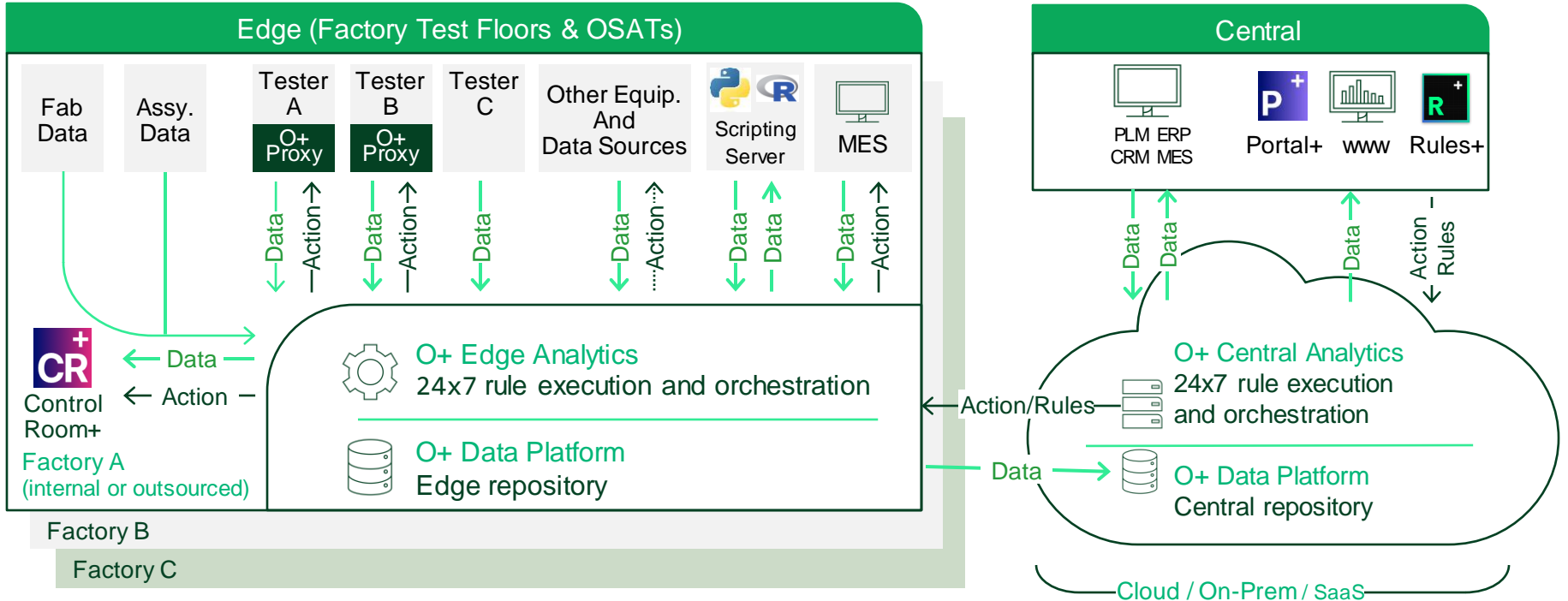
**Automatic**

**Distributed**

**Controlled**






A unique, automated and proactive integrated solution

# Semiconductor System Architecture



Actionable Insights Across All Manufacturing And Test Processes

# How do we benefit Semi direct and end customers?

	 Yield Analysis and Reclamation	 Efficiency	 Quality, Reliability and Brand Protection	 Time To Market	 Supplier Transparency
Capabilities	<ul style="list-style-type: none"> <li>Tester to Tester Correlation</li> <li>Improve overall yields</li> <li>Minimize site-to-site variations</li> <li>Optimize re-test policies</li> <li>Identify equipment performance issues</li> </ul>	<ul style="list-style-type: none"> <li>Enable consistent tester availability and utilization</li> <li>Avoid excessive index and pause times</li> <li>Industry leading test time reduction capabilities</li> <li>Ensure efficient test &amp; retest policies.</li> </ul>	<ul style="list-style-type: none"> <li>Minimize excursions.</li> <li>Minimize RMAs.</li> <li>Analyze root cause.</li> <li>Protect your brand.</li> <li>Comply with industry standards.</li> </ul>	<ul style="list-style-type: none"> <li>Shorten NPI time.</li> <li>Optimize balance between time, cost, and quality .</li> <li>Facilitate multi-team collaboration.</li> <li>Share learnings from NPI to HVM and back.</li> </ul>	<ul style="list-style-type: none"> <li>Benchmark suppliers.</li> <li>Ensure supplier compliance with flows for every chip.</li> <li>Real Time Monitoring and Feedback.</li> </ul>
Direct Benefits	Increase up to 10% NPI, 2% HVM	Up to 25% cost savings	50% case avoidance	From weeks to days NPI	Supply chain consistency
End Cust. Benefits	Stability and predictability of supply Improved yield tracks with improved quality		Accelerating new products using latest technologies		Compliance with MIL/Aero standards Improved installed quality & reliability

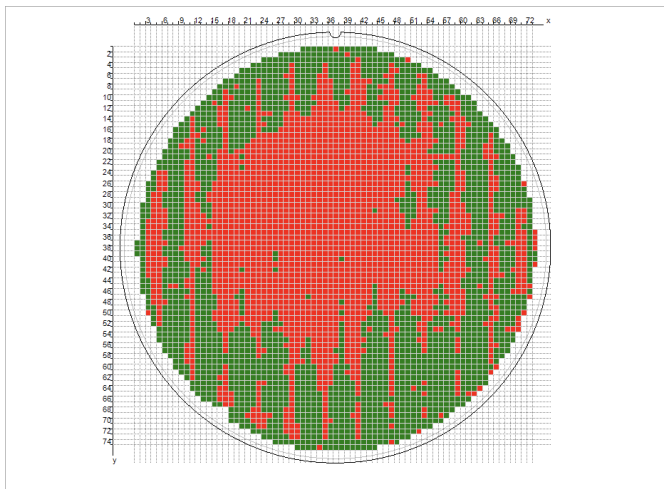


## Yield

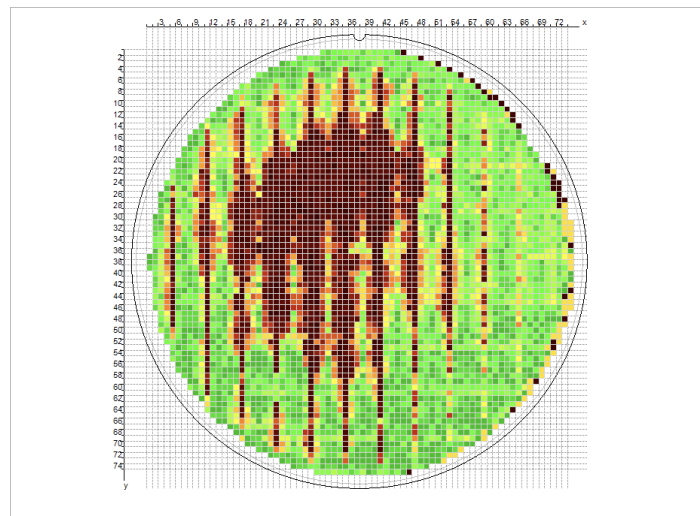
---

- Overall yield
  - Site-to-site yield
  - Re-test policy
  - Equipment & H/W performance issues
- Baseline yield & SBL monitoring
  - Test equipment performance
  - Test and retest policies and execution
  - Tests limits validation
  - Cross-operation correlation
  - Targets against any measure/KPI

# Wafer Maps : Single and Stacked



Individual Bin Yield Maps



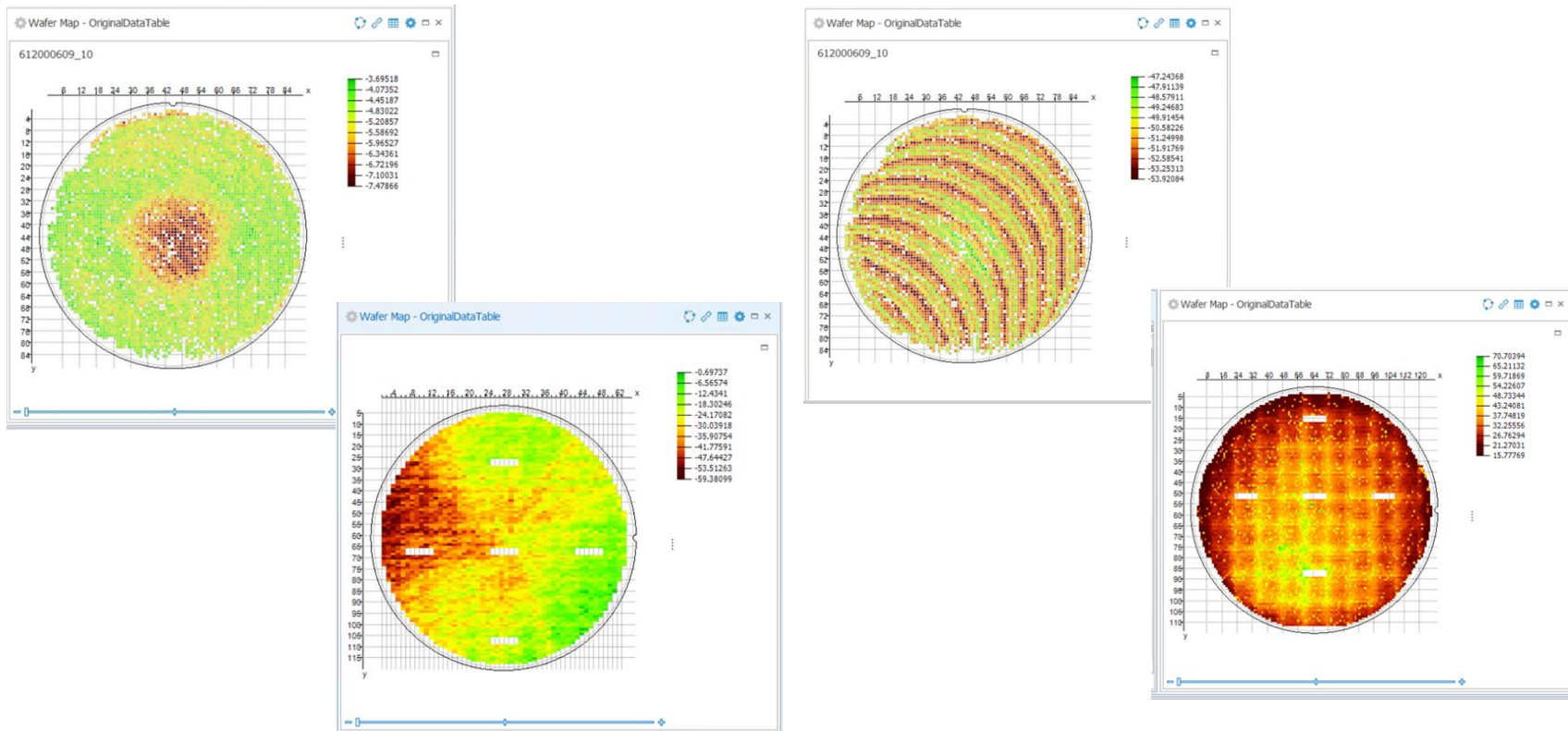
Stacked Bin Yield Maps





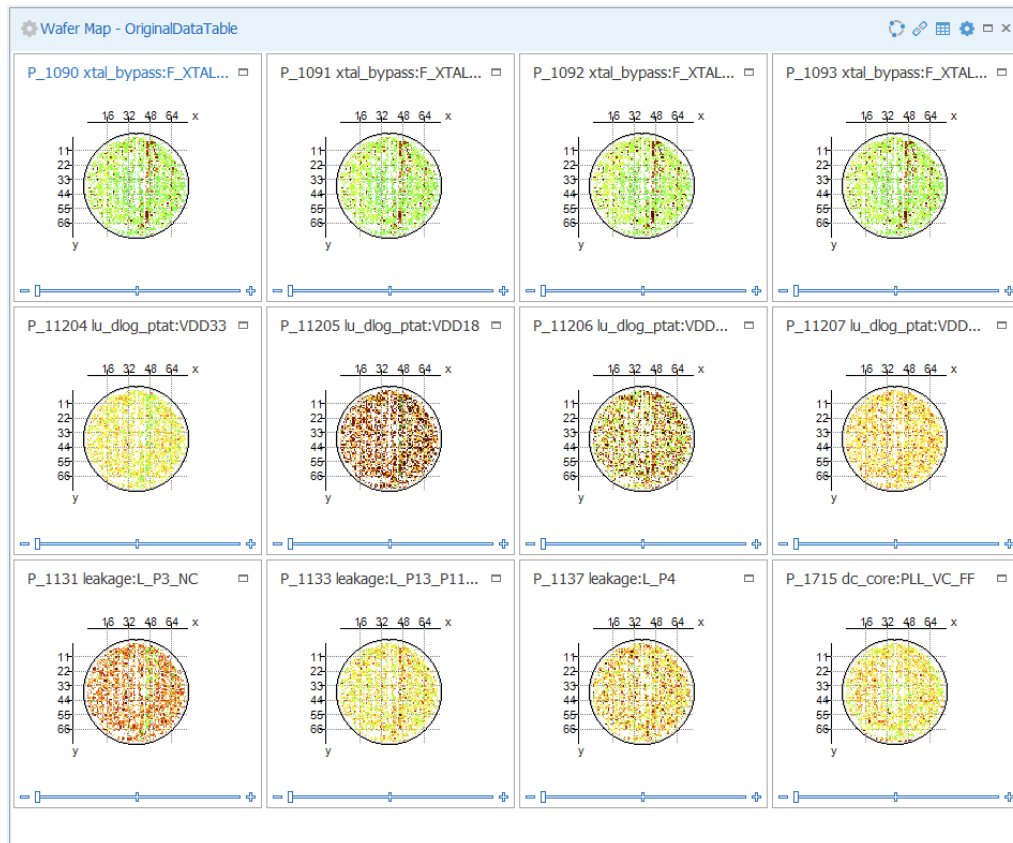
NI Enterprise Software Solutions

# Parametric Wafer Maps



# Reconstructed FT Maps

FT Parametric Wafer maps  
based on product ECID



# Advanced & Predictive Analytics

## O+ Open Architecture

### AI/Machine Learning Support

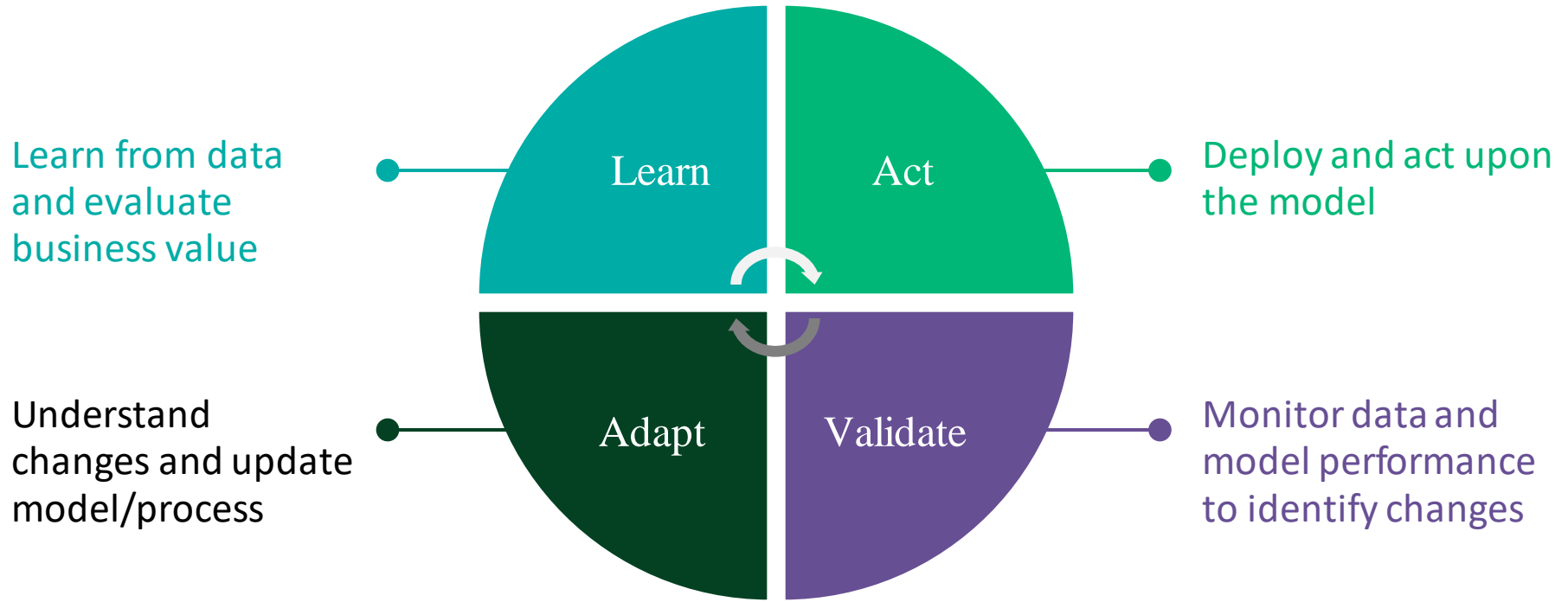
#### Model Development

- Data Extraction

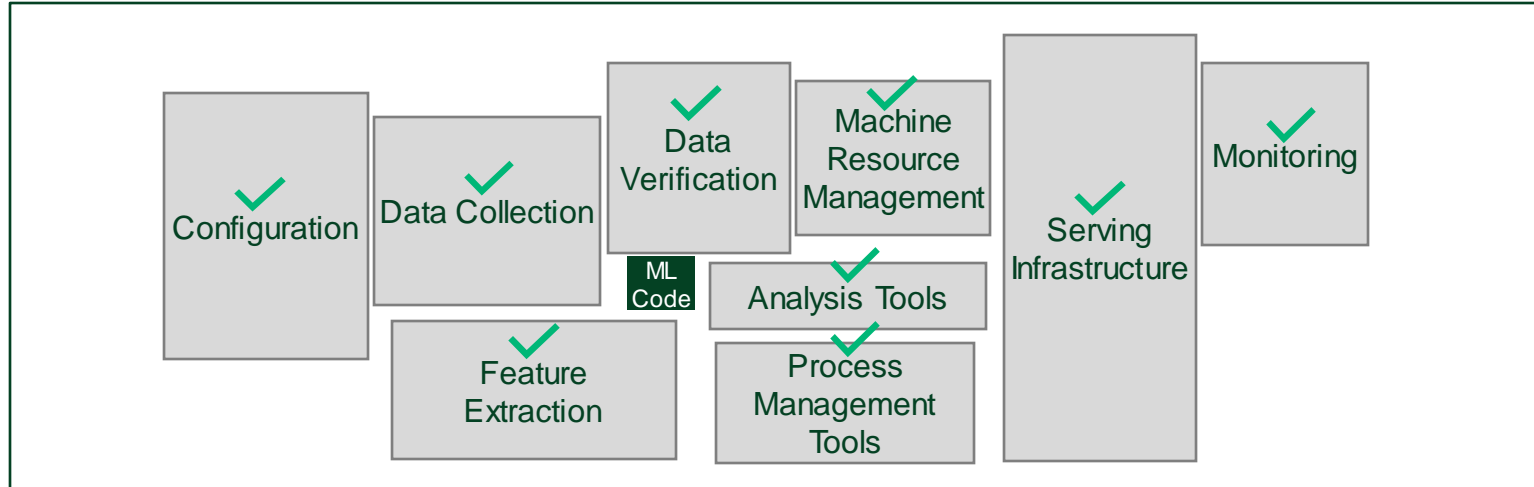
#### Model Deployment

- Virtual Operation (VOR)

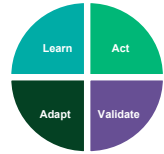
# The full machine learning lifecycle



# NI O+ supports end-to-end machine learning



Machine Learning applications can scale across products and across the supply chain



## Programmatic Large Data Extract

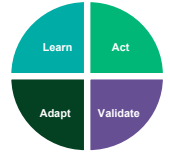
- Data extract template created from O+
- R & Python supported
- Enables external extract parameter modifications
- Invoked using 3<sup>rd</sup> party tools
  - Jupyter, Spyder, Pycharm, Cloud9, etc.
- Extraction status reporting:
  - In Progress / Failed / Completed
- Data exported in Parquet format

The image displays three overlapping screenshots from a data management tool:

- Top Left:** A main interface window showing a flow diagram with steps like 'Load O+ Job Data', 'Load from O+ Data Source', 'Field Mapping', and 'Merge Tables'. A 'Step Properties' panel is visible on the right.
- Top Right:** A 'Level Data Wizard' dialog box, 'Step 1 of 6 - Population'. It allows selecting a date range (e.g., 'Last 30 days') and population. It includes checkboxes for 'Include current period' and 'Final result per operation'.
- Bottom Right:** A Jupyter Notebook window titled 'Example\_dataimport\_toPython\_dataframe'. It contains Python code for a function that reads a Parquet file from a path and returns its contents as a pandas DataFrame. The output shows the file was successfully read and converted.

Green curved arrows indicate the flow of data from the main tool to the wizard, and then to the Jupyter notebook.

# Machine Learning : Deployment & Execution



## Built-in support for Python and R

- Enables state-of-the-art ML Models
- Supports third-party libraries :
  - TensorFlow
  - PyTorch
  - Python Libraries :
    - Pykrig (Smoothing)
    - SciPy (Statistics)
- Containerized for easy deployment
- DIY Models deployed in production at OSAT's or internal test floors

```

jupyter Example_dataimport_toPython_dataframe Last Checkpoint: 3 minutes ago (autosaved)

print('Total Tables Found: ', cnt)

# Auxiliary function to load a parquet path into a dataframe
# Takes a single path and the root path of the data as required inputs
# The function adds the missing columns if partitioning exists

def get_dataframe_from_path(path, rootPath):
    part_names = path.replace(rootPath + '/', '').split('/')
    part_names = [x for x in part_names if "-" in x]

    part_name_dict = {}
    for pname in part_names:
        col_name, col_value = pname.split("-")
        part_name_dict.update({col_name: col_value})

    if len(part_name_dict) == 0:
        df = pq.read_table(path).to_pandas()
    else:
        df = pq.read_table(path).to_pandas()
        for key, val in part_name_dict.items():
            df[key] = val
    return df

In [4]: main_df = get_dataframe_from_paths(paths["@ig1valData"])

In [ ]: print(main_df.head())
  
```



Packaged  
step

The screenshot shows the Orange3 workflow editor with a 'Python Script' node. The configuration window for this node is open, showing the following Python code:

```

# Now run the DL calculation
unique_id = get_uid_from_filename(front_image)
response = infer_population(pred, unique_id)
image_path = Path(front_image)

image = create_tf_serving_message(front_image)
prediction = tensorflow_client.predict(model, image)
logging.debug('Received response from TF server: %s' % str(prediction))
response = populate_response_with_model_results(prediction, image_path, response)
  
```

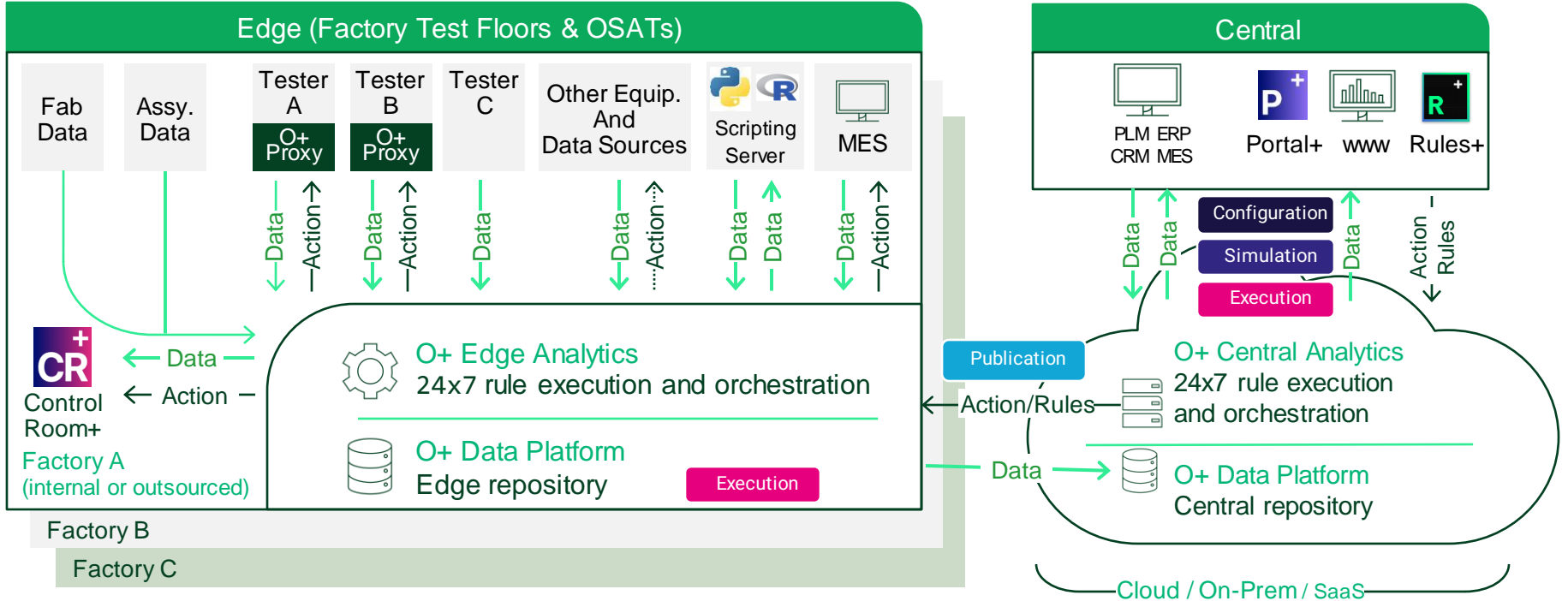
The configuration window also shows input and output parameters:

Type	Name	Source	Additional Selections
Model	model	d:\data\selection_jcr1	tensorflow/2.3.6
Input File	front_image		
Input File	back_image		

Type	Output Table	Column/Variable Name
Table	response	

# Model Deployment

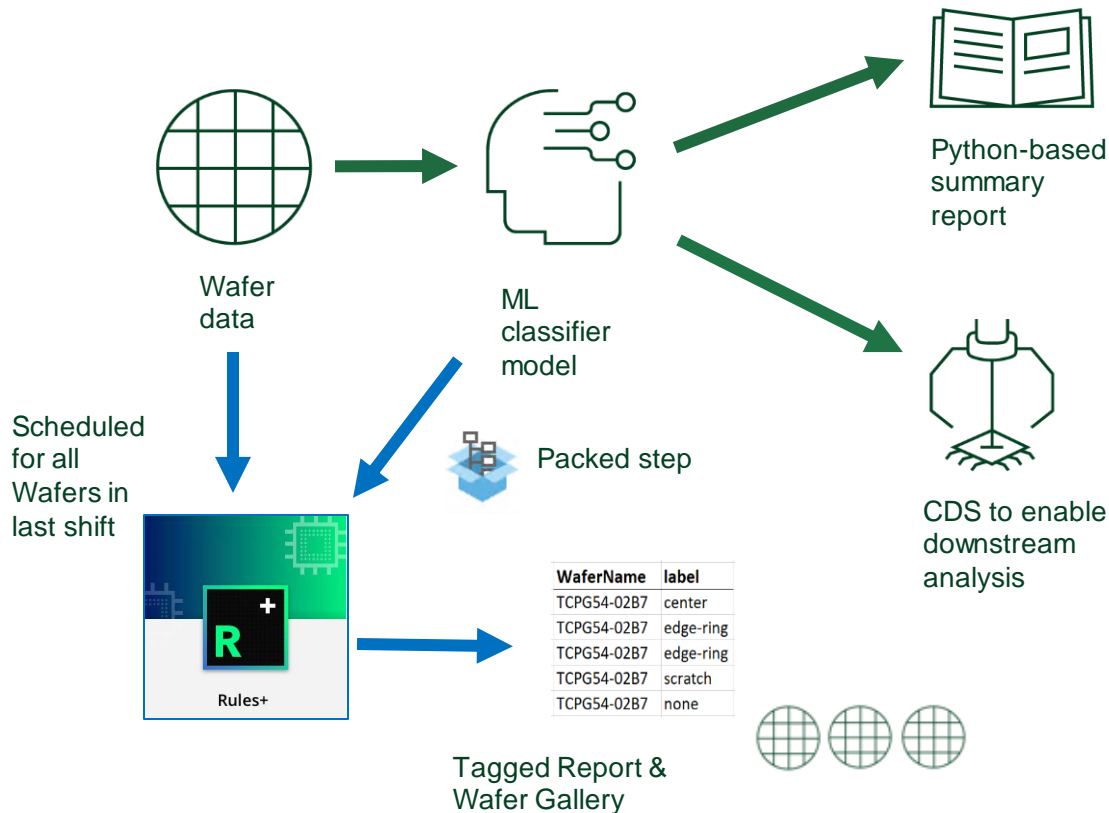




Actionable Insights Across All Manufacturing And Test Processes



# Wafer Classification Process Example

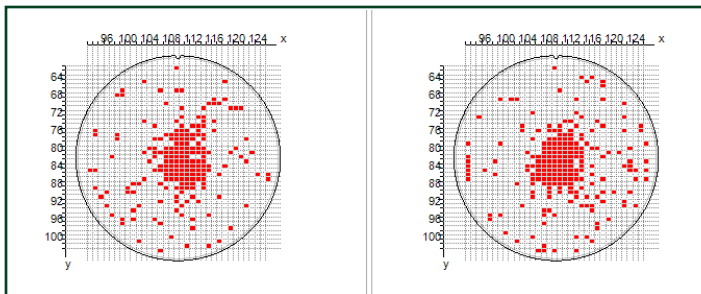
Patent Application : Filed 11/21/2022 (63/426,952)


 Alerts for certain classes appearing  
 Trends for each Product and feature class over time

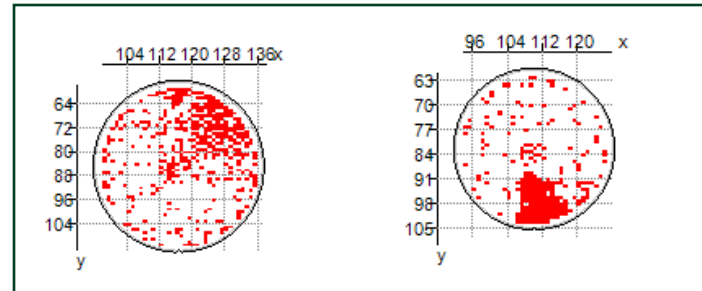
 Wafer quality prediction, GPAT rule for inkless map change  
 Cross operational Insights, Parametric data relationships

# Wafer Classification Model Execution V1.0\*

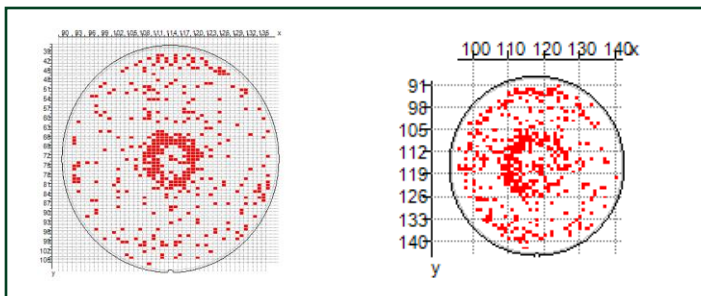
## Center



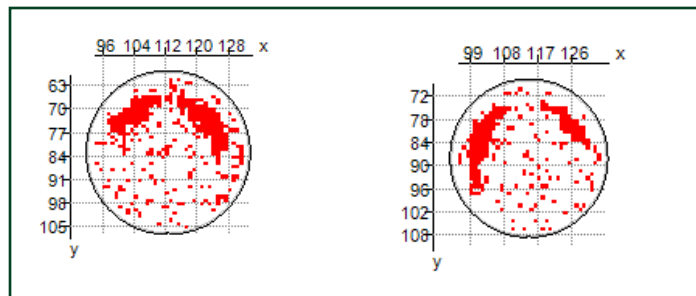
## Edge Local



## Ring

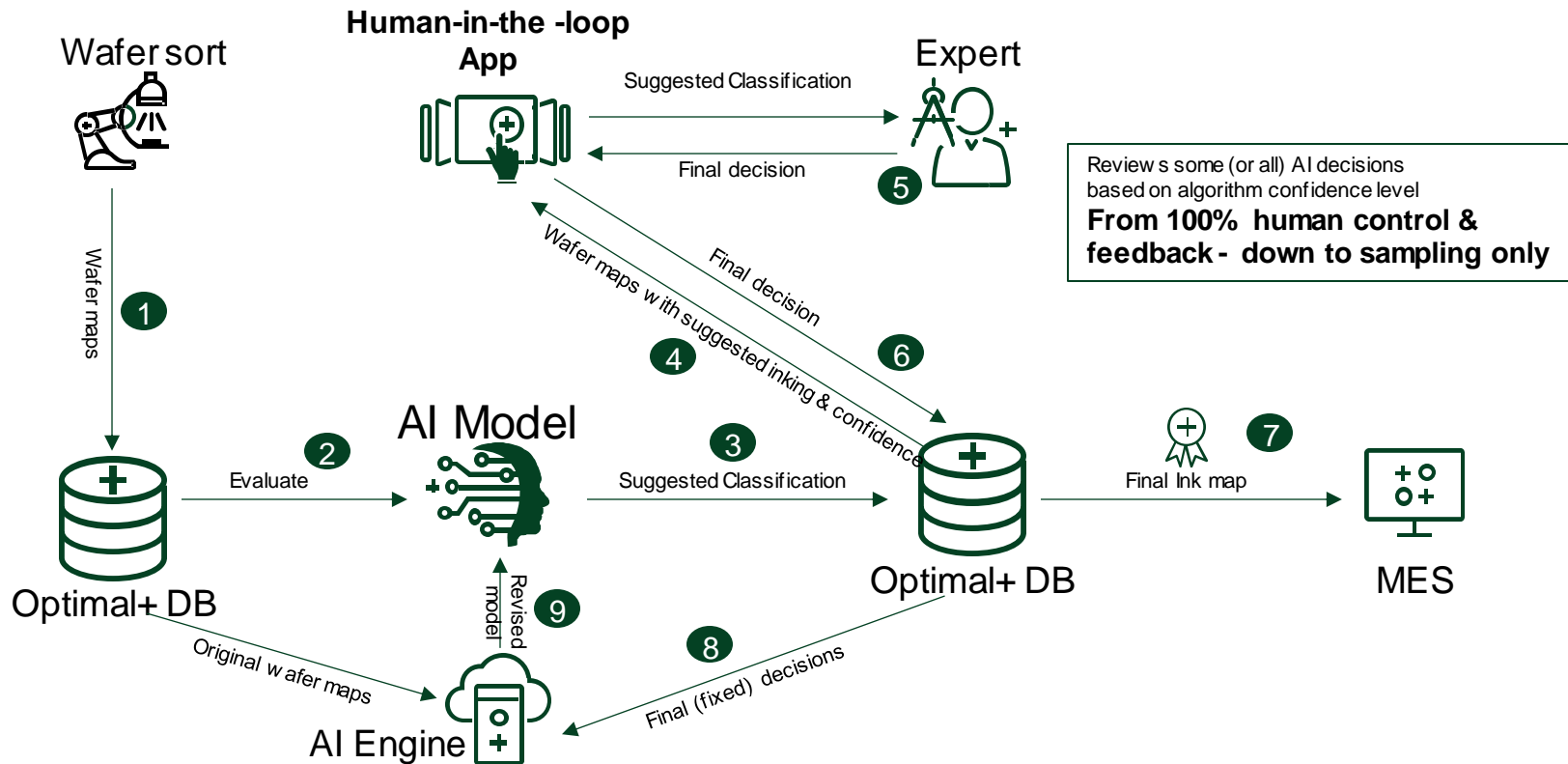


## Arc / Partial Ring



\*Based on 60K Customer Production Wafers

# Human-in-the-Loop; improve model while gaining user confidence

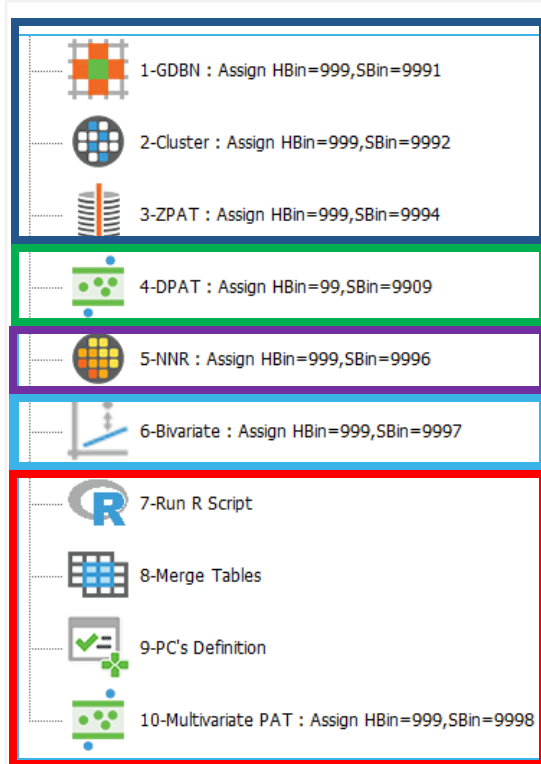




## Quality & Reliability

- 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-binning (via MES)
  - Data Feed Forward and Test Program API

# Outlier recipe using multiple methods & embedded R



**Geographic**

**Parametric Univariate**

**NNR**

**Parametric Bivariate**

**Multivariate:**

- **PCA performed in R**
- **PAT performed on the output**

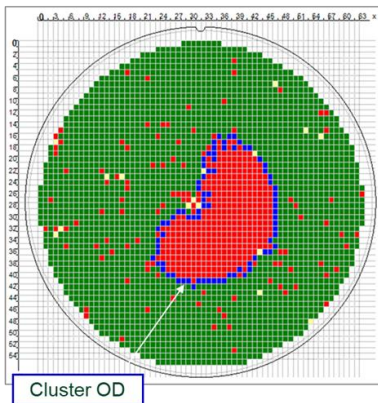
Optimal+ customer best practices implement multi-step OD recipes

Each step has appropriate settings to adjust sensitivity

Embedded R is used here for orthogonal transformation (PCA)

# Geographic Outlier Detection (Cluster, GDBN, & ZPAT)

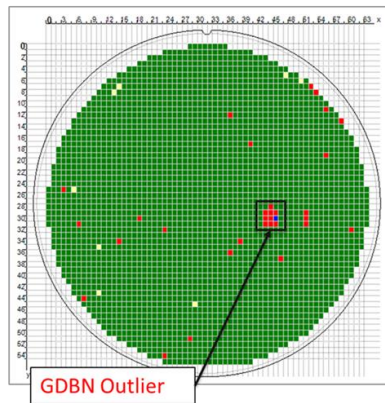
Wafer 82VTC076SEB0 Cluster Outlier Detection



## Cluster

Use historical results and statistical settings to expand boundary of bad-die clusters

Wafer 23TVC152SEB4 GDBN Outlier Detection



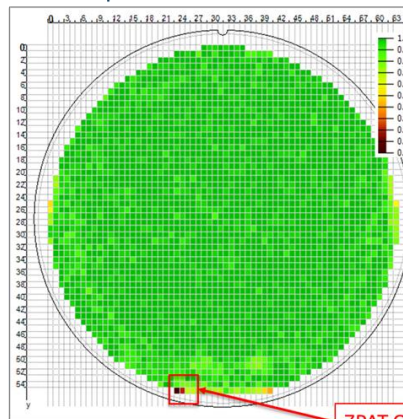
## Good Die Bad Neighbor (GDBN)

Calculate the # of bad die around each die, and recategorize any with more than a preset threshold

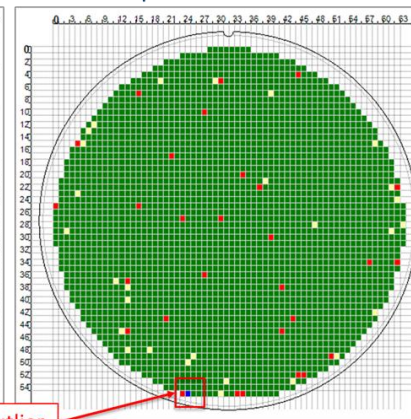
## ZPAT

Use lot results to identify high-probability bad die locations, and push through all wafers

Lot Yield Map

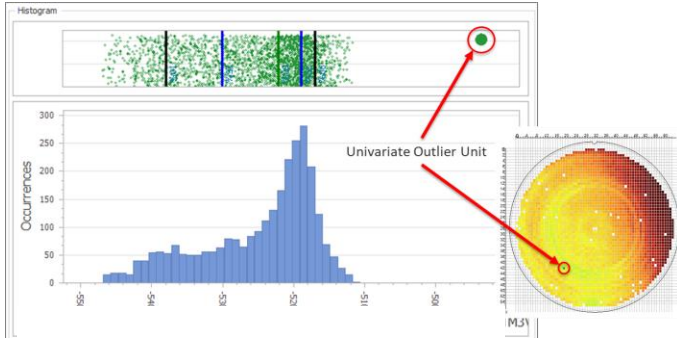


Wafer Bin Map

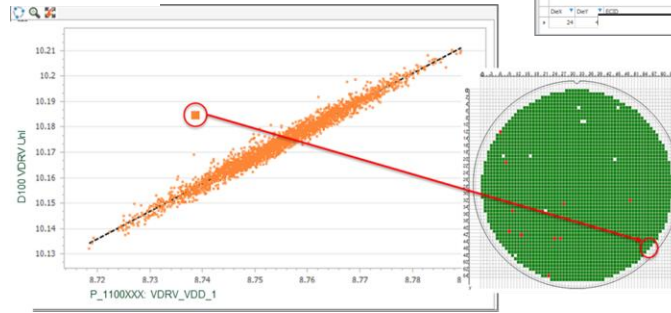


ZPAT Outlier

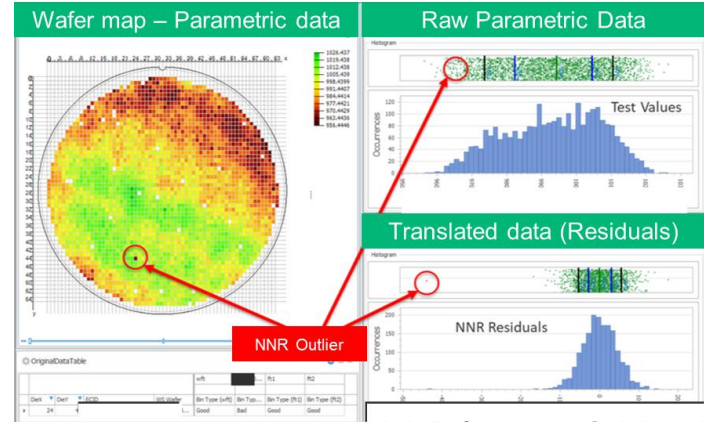
# Univariate, Bivariate & NNR PAT



**Univariate**  
Studies each parametric result distribution individually



**Bivariate**  
Studies pairs of parametric results and their combined distributions and correlations



**NNR (Near Neighbor Residual)**  
Only compare die to PAT limits calculated using test results from nearby die locations (not the entire wafer)

## PAT & DPAT Options

**Static PAT:** Maintain limits over some period

**Dynamic PAT:** Regularly update limits (e.g. after each wafer)



## Efficiency

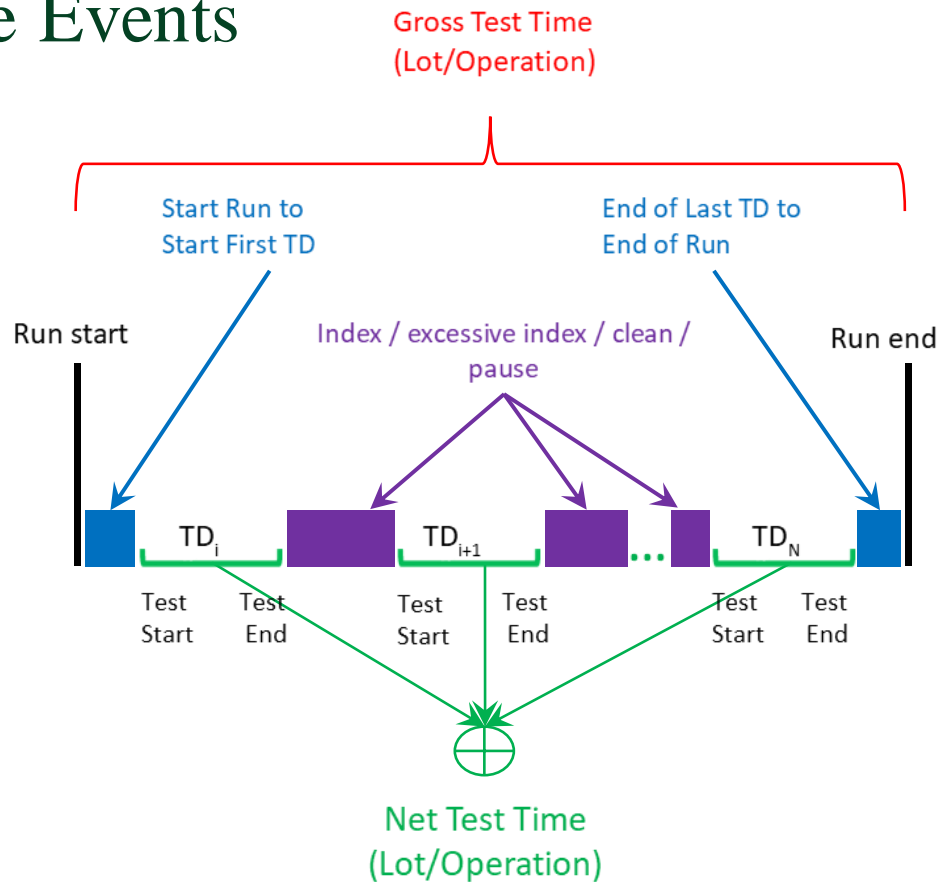
- Inconsistent tester availability & utilization
- Excessive index & pause times
- Test time variations per tester
- Inefficient retest policies & execution
- Adaptive Testing using Machine Learning
- Test equipment performance
- Test and retest policies and execution
- Tester availability & utilization (OEE analysis)
- Classical Test Time Reduction (TTR analysis, ROA)
- Adaptive Test Time Reduction (ATTR)
- Cross-operation correlations
- Shop Floor Control



# Utilization : Run Time Events

Pre and Post Testing Events :  
 Start Run to 1<sup>st</sup> TD  
 Last TD to End of Run

Non-Testing Events :  
 Index : <90 Sec  
 Clean : 90 to 120 sec (WS)  
 Pause : >120 sec during a run



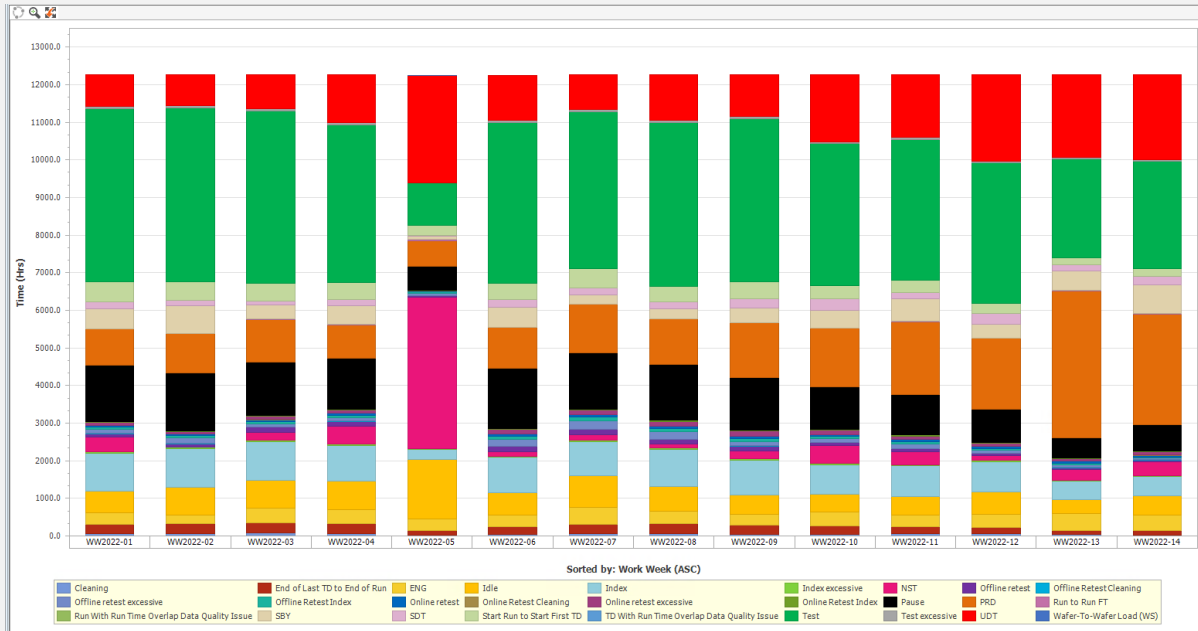


# Utilization : Run Time Events in Touchdown Reports



# Customer use case: Efficiency problem – Understanding Time

## Tester usage breakdown by E10 time categories



- 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

# Smart-Retest Dashboard

Identifies potential die & yield gain by product & bin

Determine the rightwafers for retest

Determine the rightHbins, Sbins to retest

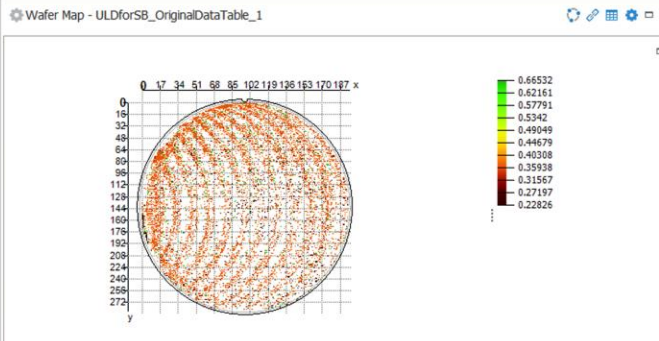
Product	Wafer	First Pass Yield	Total Units	Yield	Yield_BL	Yield Gap	Recoverable 5 Bins	PotDesGain	PotDie
WS00A001	A:DRF12HWG63	75.95 %	43,983	75.95 %	73.78 %	2.17 %	4	3,870	3
WS00A001	A:DRF11SWG63	66.99 %	43,983	71.61 %	73.78 %	-2.17 %	3	3,853	4
WS00A001	A:DRF10SWG63	77.12 %	43,983	77.12 %	73.78 %	3.33 %	5	3,534	5
WS00A...	PGY3001361_23	89.47 %	56,280	89.47 %	97.95 %	-8.48 %	2	3,381	2
WS00A...	PGY3001361_23	91.99 %	57,137	91.99 %	93.76 %	-1.76 %	4	2,165	4
WS00A...	PGY3001361_19	97.89 %	57,137	92.90 %	95.59 %	-2.69 %	5	2,100	5
WS00A...	PGY3001361_17	93.73 %	57,137	93.73 %	99.29 %	-5.56 %	5	2,041	5
WS00A...	PGY3001361_15	97.24 %	81,584	97.24 %	98.02 %	-0.77 %	8	1,806	8
WS00A...	PGY3001361_13	97.28 %	81,584	97.28 %	98.02 %	-0.74 %	8	1,656	8
WS00A...	PGY3001361_11	95.23 %	57,137	95.23 %	99.29 %	-4.06 %	5	1,643	5
WS00A...	PGY3001361_9	87.49 %	17,381	87.49 %	98.87 %	-11.38 %	7	1,636	7
WS00A...	PGY3001361_7	95.99 %	57,142	95.30 %	95.30 %	0.00 %	5	1,611	5
WS00A...	PGY3001361_5	96.40 %	57,137	96.40 %	96.40 %	0.00 %	5	1,584	5
WS00A...	PGY3001361_3	67.91 %	6,562	67.91 %	98.75 %	-30.84 %	6	1,580	6
WS00A...	PGY3001361_1	96.62 %	57,137	96.62 %	96.62 %	0.00 %	6	1,486	6

Total Records : 26266 Selected Count : 1 Sum : 0 AVG : N/A

Operation	Soft Bin	Wafer	Bin Count	Bin %	Online_History_Gain	PotentialGain
ws1	15	A:DRF12HWG63	8,865	20.16 %	36.33 %	3,221
ws1	5	A:DRF12HWG63	604	1.37 %	66.53 %	402
ws1	15	A:DRF12HWG63	1,022	2.32 %	23.10 %	236
ws1	2	A:DRF12HWG63	48	0.11 %	22.83 %	11

Total Records : 4 Selected Count : 7 Sum : 12104.6589046684 AVG : 2420.93178093368

Product	Operation	Num Of Wafers	Potential die Gain	Total Tested	Potential Yield Gain	Avg	Min	Max
WS00A001	WS	95	56,663	672,515	8.43 %	596.5	194.8	1356
WS00A001	WS	175	36,017	1,017,069	3.54 %	205.8	0	721
WS00A001	WS	164	29,538	2,931,938	1.01 %	180.1	0	620.5
WS00A001	WS	326	29,293	2,820,179	1.04 %	89.86	0	662.6
WS00A001	WS	297	18,494	1,427,997	1.30 %	62.27	0	438.3
WS00A001	ws1	1332	17,811	6,142,356	0.29 %	13.37	0	323.1
WS00A001	WS	445	17,664	2,120,099	0.83 %	39.7	0	203.4
WS00A001	WS	223	17,373	1,069,214	1.62 %	77.91	0	407.7
WS00A001	WS	228	16,416	2,122,677	0.77 %	72	0	621.9
WS00A001	WS	239	15,566	624,912	2.49 %	65.13	0	596.7
WS00A001	WS	13	14,557	979,008	1.49 %	1120	0	1806
WS00A001	WS	99	12,192	247,988	4.92 %	123.2	0	1245
WS00A001	ws1	4	11,507	133,206	8.64 %	2877	232.7	3870
WS00A001	ws1	618	11,261	5,409,822	0.21 %	18.22	0	598.4
WS00A001	WS	272	11,203	1,349,308	0.83 %	41.19	2	549

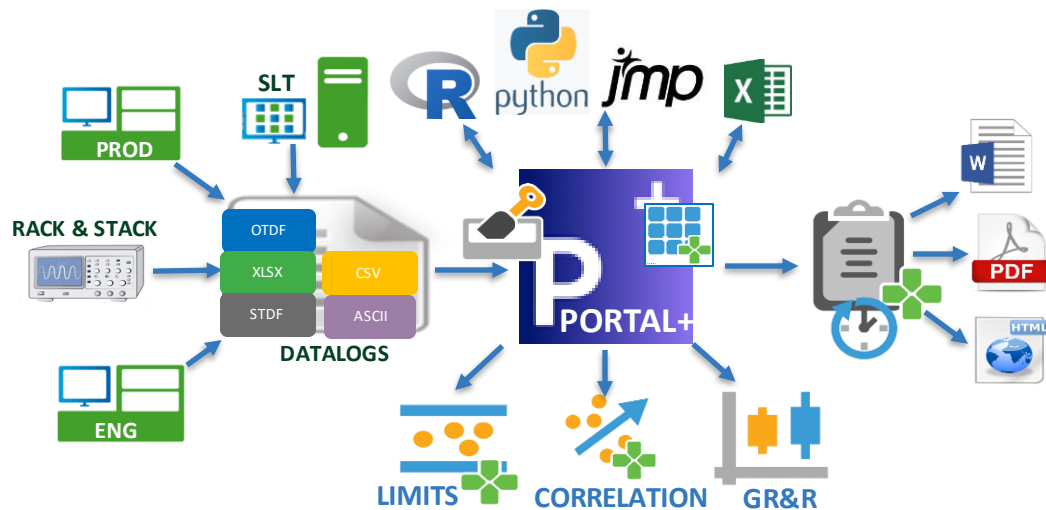




## Time to Market

- Shorten NPI time
  - Optimize balance between time, cost, and quality
  - Facilitate multi-team collaboration
  - Share learnings from NPI to HVM and back
- 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 & GR&R Applications
  - Report generation
  - Adaptive test (reduction or augmentation) and smart ramp

# Advanced analytics introduction



## Components:







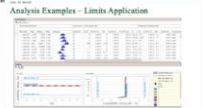


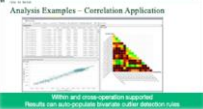

- Conditions
- Datasets\*
  - Saved Analyses
  - Attribute mgr.
- Sandbox:
  - Cleansing rules
  - Validation rules
- Correlation App.\*
  - Heat maps\*
  - Shmoo plots
  - Layout plots
- Limits App.
- GR&R App.

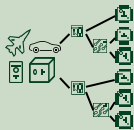
\*Also available with OD

Components of Advanced Analytics for NPI available at Central



# Use cases / Examples

<p>Dataset View</p> 	<p>Adv. Split Analysis</p> 	<p>WAT Summary</p> 
<p>PVT Charts</p> 	<p>Gage R&amp;R App</p> 	<p>WAT to Sort Correlations</p> 
<p>Limits App</p> 	<p>Dataset Summary</p> 	<p>Parametric Health</p> 
<p>Correlation App</p> 		<p>Sub-Die Mapping</p> 

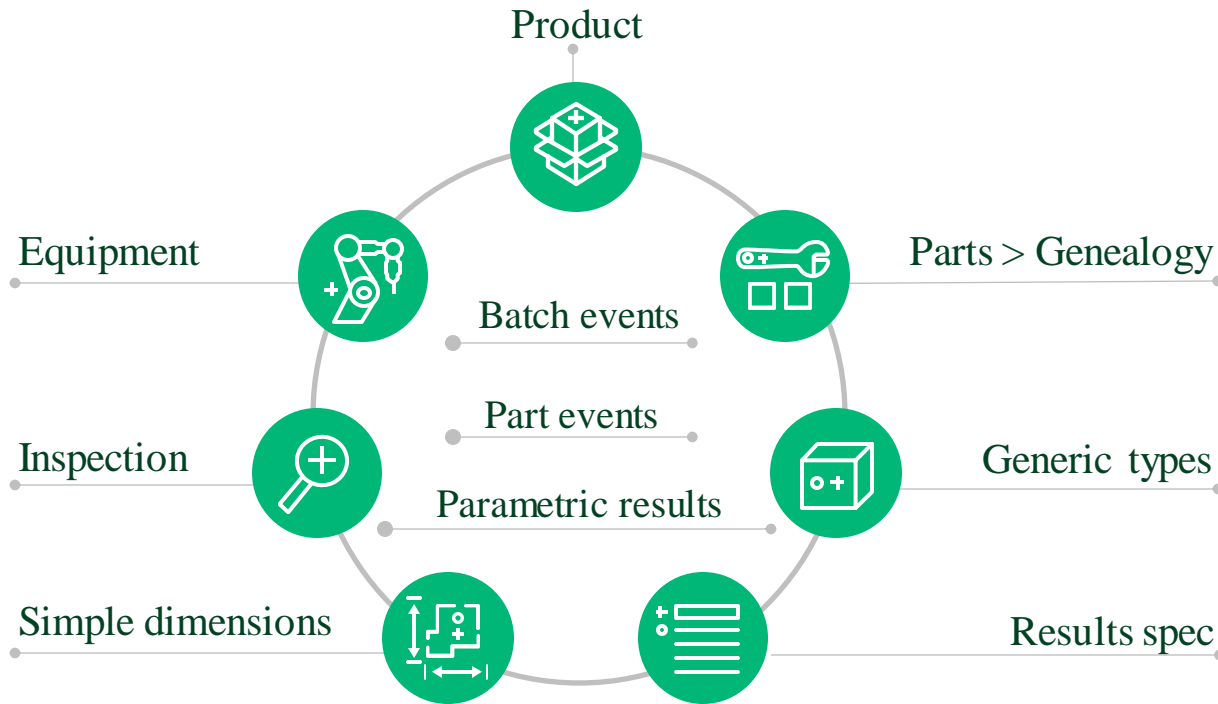


## Genealogy & Assembly

- Asynchronous loading & connecting
  - Unit traceability across all levels
  - Efficient analyses
  - Containment
- Connects all levels
  - BOM datasheet info
  - Parametric data correlations across any operation
  - Group or analyze data from any level
  - Cross operation heat map analyses
  - Wafer map reconstruction based on any level results



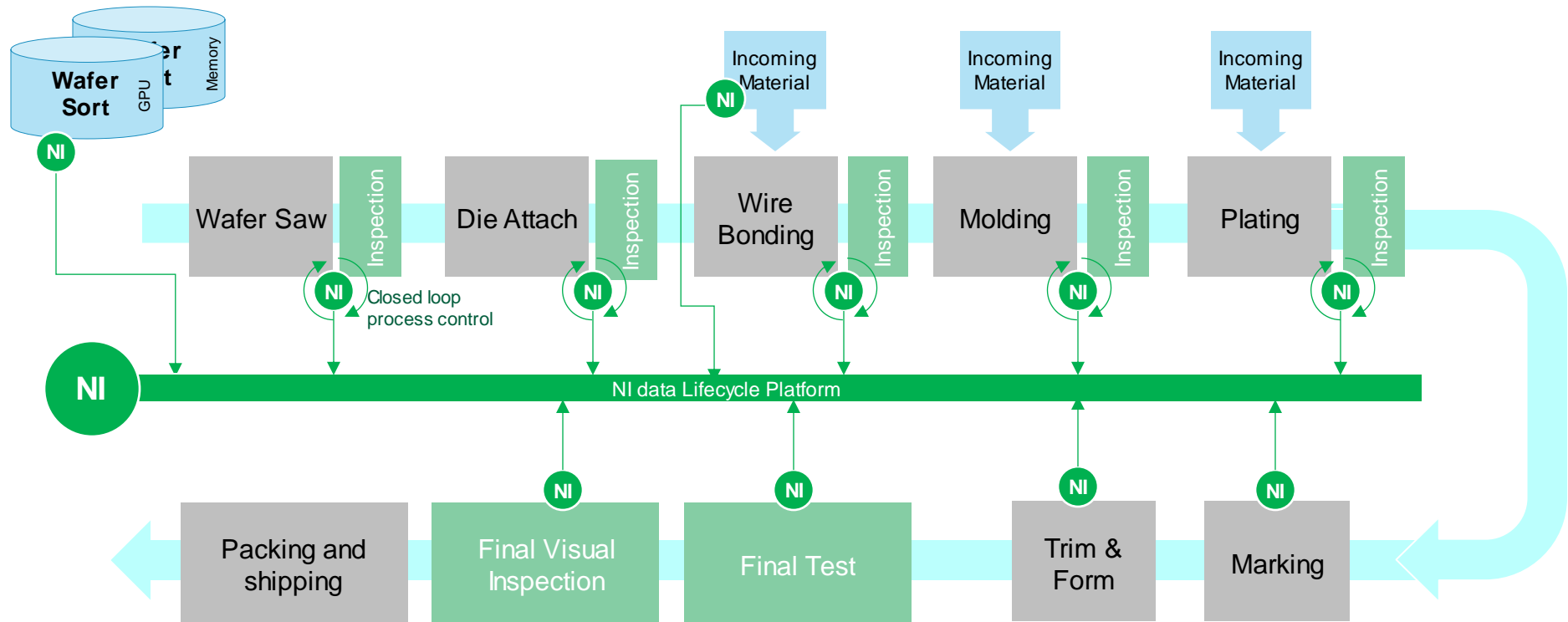
# Dynamic unified data model (UDM)



- Generalization of events
- Generalization of parts
- Virtual batching
- Genealogy and traceability
- Asynchronous loading

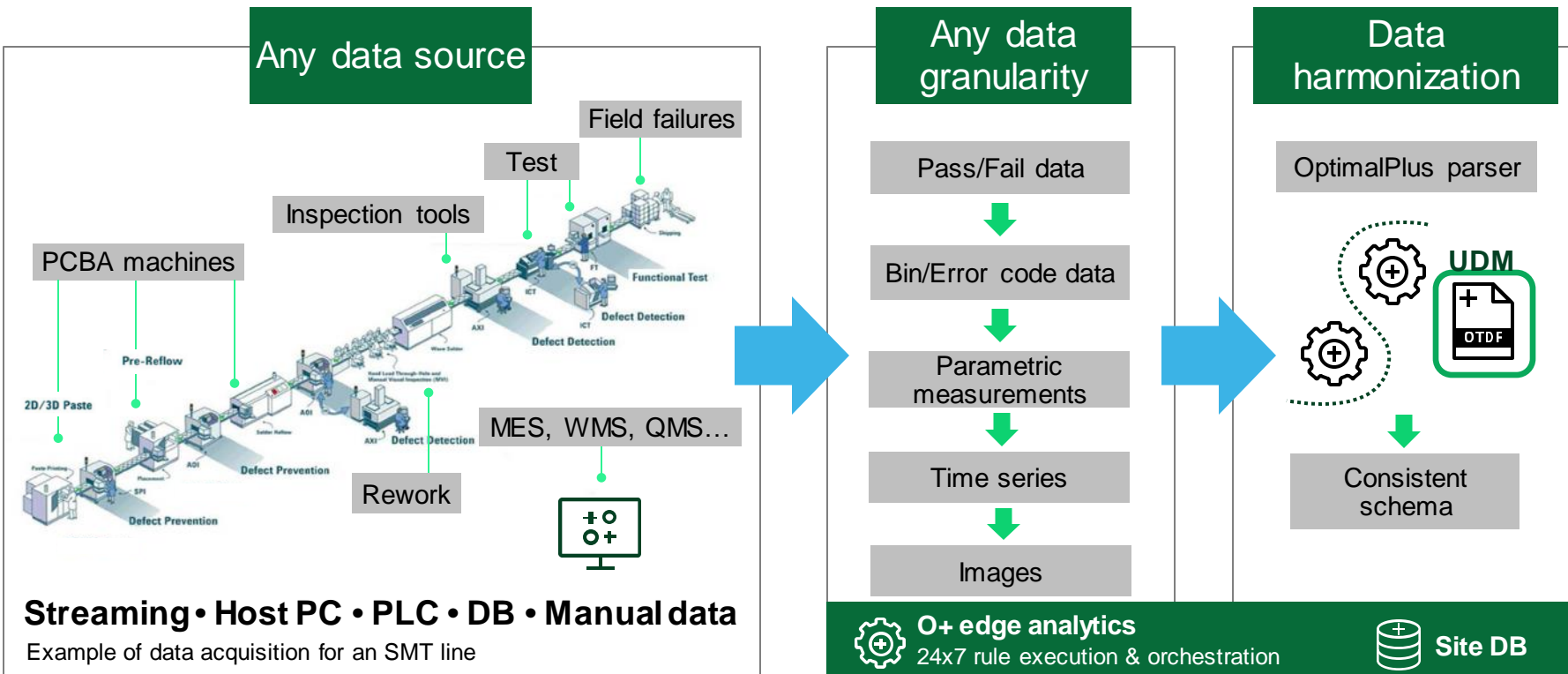
# Chip Assembly and Test operation covered by O+ Solutions

■ "Work"  
■ "Verify"  
→ Data Flow



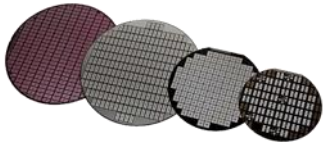
O+ provides unified data platform that enables Closed Loop Process Controls analytics across the assembly line and the supply chain

# We collect and harmonize data into a consistent data model

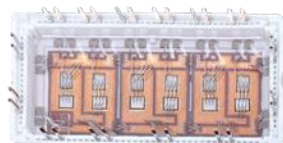


# Power Module – reducing scrap at every step

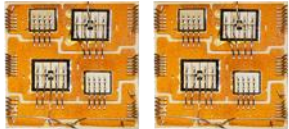
Power IC



Cooler module



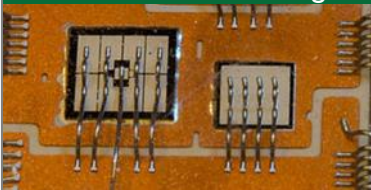
Substrate module



Inverter bridge



Power wire bonding



EV inverter



## We tackle industry challenges

Complex & highly intertwined processes

Overall Yield is low with significant scrap

Process is key to good thermal performance

Direct material & consumables  
influence quality

Field failures are costly & cause  
safety liability

Root-cause of process mishaps is difficult

## We close the loop

Data feed forward, Data feed backward

Adaptive manufacturing in Bonding  
& Welding

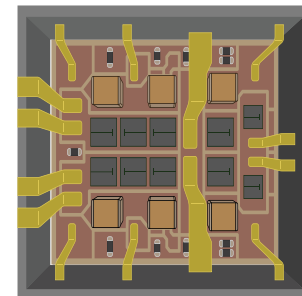
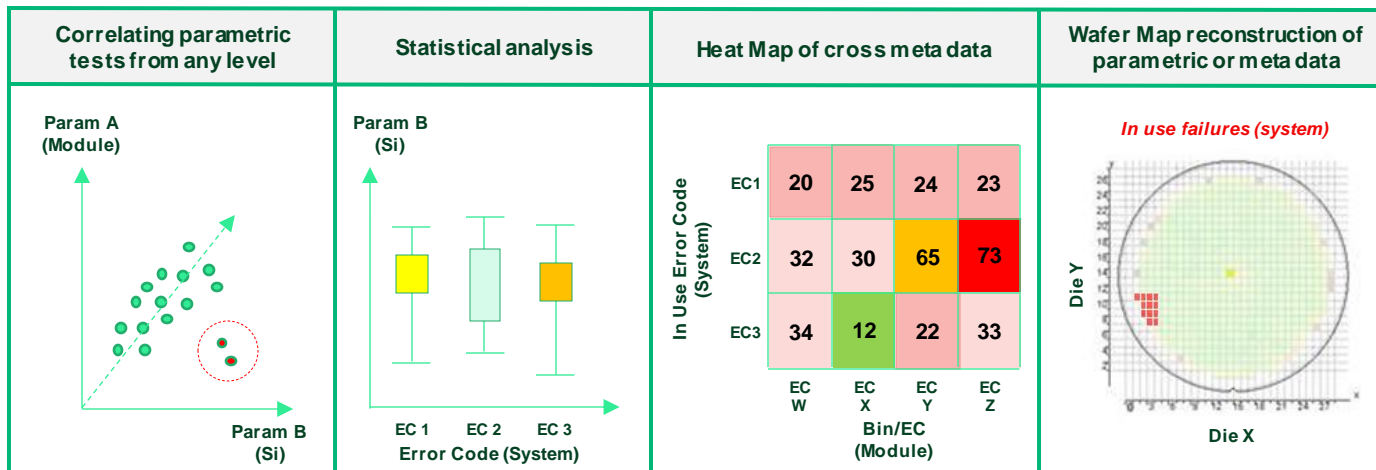
# Genealogy enabling cross operation with full unit traceability

## Capabilities

- Cross operations analysis on events from different levels
- Ability to load N levels of units with full unit traceability
- Cross Operations on any retest level (not only shell)



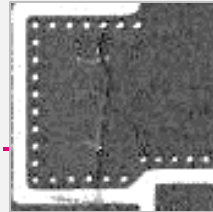
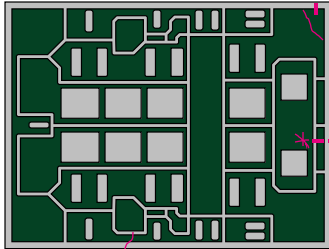
## Use case examples:



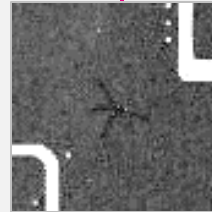
# Inspection solution for Inaccurate defect detection at SAM

## Crack detection

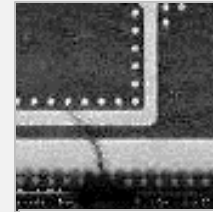
Back side



Line cracks occur under the weld joint and are contained in the ceramic



Star cracks occur under the weld joint and are contained in the ceramic area



Line+ cracks occur outside the weld joint and propagate through ceramic across copper

# Welding – doing it right the first time, every time

Ultrasonic welding



Wire bonding



Laser welding



Spot welding



Arc welding



Magnetic pulse welding



We tackle industry challenges

- Irreversible process, scrap is costly

- Difficult to assess quality in-line

- Tooling “wear” affecting quality

- Mating parts & consumables influence quality

- Field failures can cause safety liability

- Defects are time consuming to root-cause

We close the loop

- Real-time feedback throughout

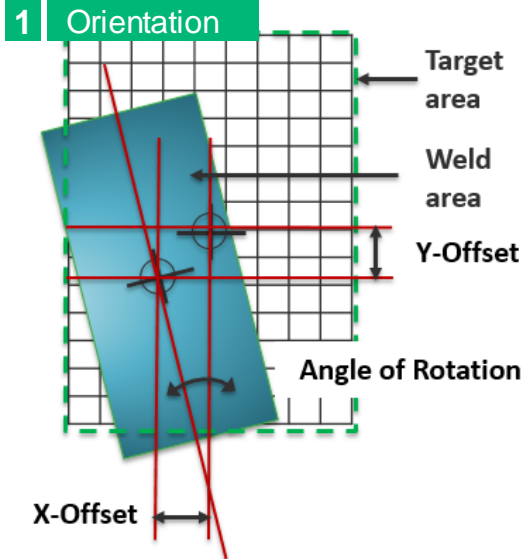
- Adaptive manufacturing

# Feature extraction

O+ solution processes images from SAM to create a highly aggregated set of parametric insights

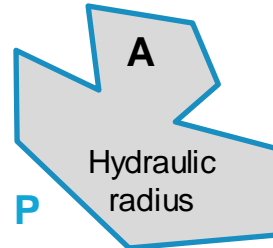
**Expected statistical behavior per parameter is a baseline for evaluation of new parts**

- 15-17 welds
- ~50 parameters per weld



**3 Attributes**

$$R_h = A/P$$

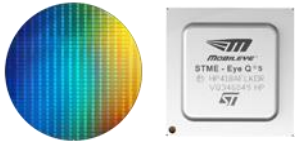


Parametric Test Name	Histogram
M_ :Area@2	
M_ :AspectRatio@2	
M_ :CentriodY@2	
M_ :CentroidX@2	
M_ :EllipseRatio@2	
M_ :EqEllipseMajor@2	
M_ :EqEllipseMinor@2	
M_ :Height@2	
M_ :HeywoodCircularity@2	
M_ :HolesArea@2	
M_ :HydraulicR@2	
M_ :NumberOfHoles@2	
M_ :OrientationDeg@2	
M_ :Perimeter@2	
M_ :RectRatio@2	
M_ :WeldCoveragePers@2	
M_ :WeldObjectCount@2	
M_ :Width@2	



# ADAS – cameras with the best eyesight

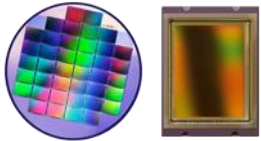
Processor



Lens module assembly



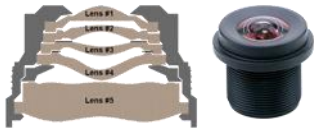
CMOS image sensor



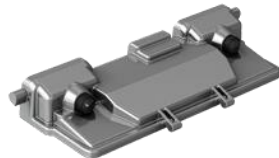
Mono cameras



Lens modules



Stereo cameras



We tackle industry challenges

High scrap after active alignment of LMAs

Camera performance only @ EOL

Incoming components affect performance

Equipment (AIT) need high degree of precision

Field failures can cause safety liability

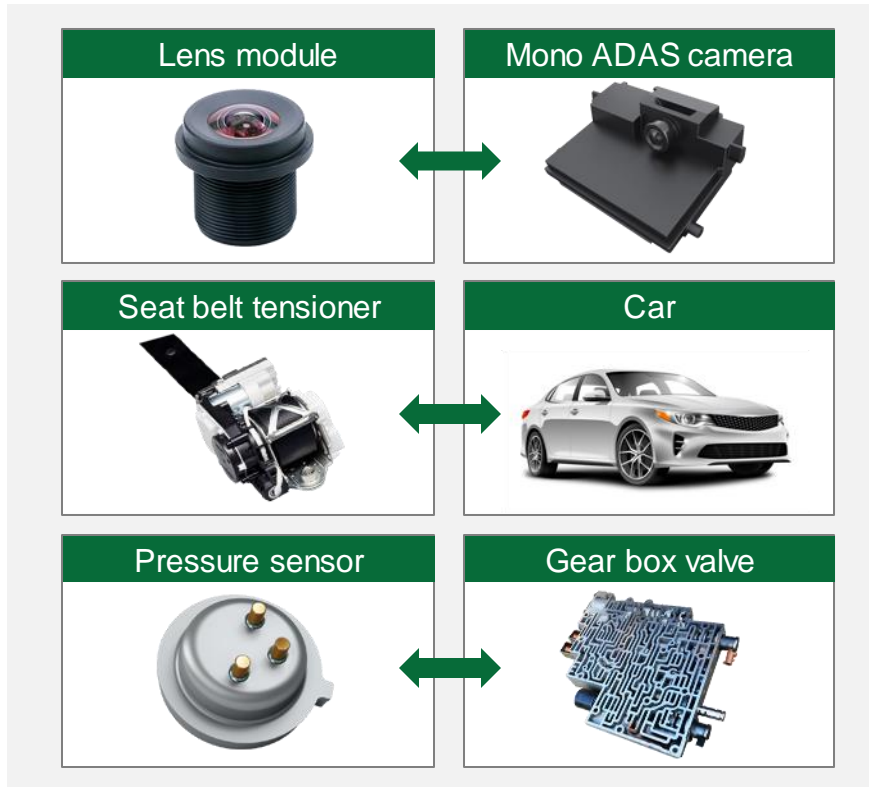
Root causing failures and issuing recall

We close the loop

Real-time feedback from In-line to In-coming

Adaptive manufacturing in CMAT

# Supply chain – connect companies & produce win-win



## We tackle industry challenges

Lens modules for ADAS cameras are not consistent even though they meet spec.

Seat Belt tensioners fail in the field and supplier can not readily root cause failures

Pressure sensors fail in the field making automobiles inoperable on the roads

## We close the loop

Facilitate data flow and centralization

Facilitate data driven conversation

# Thank You

A large, thin white arc that starts near the bottom center and curves upwards and to the right, ending near the top right corner of the slide.