LineWorks Solution

Transform and digitize your manufacturing line

Software Solutions
for Manufacturing
Excellence

Machine Learning Solving the Puzzle in Wafer Anomaly Detection

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[1] camLine GmbH
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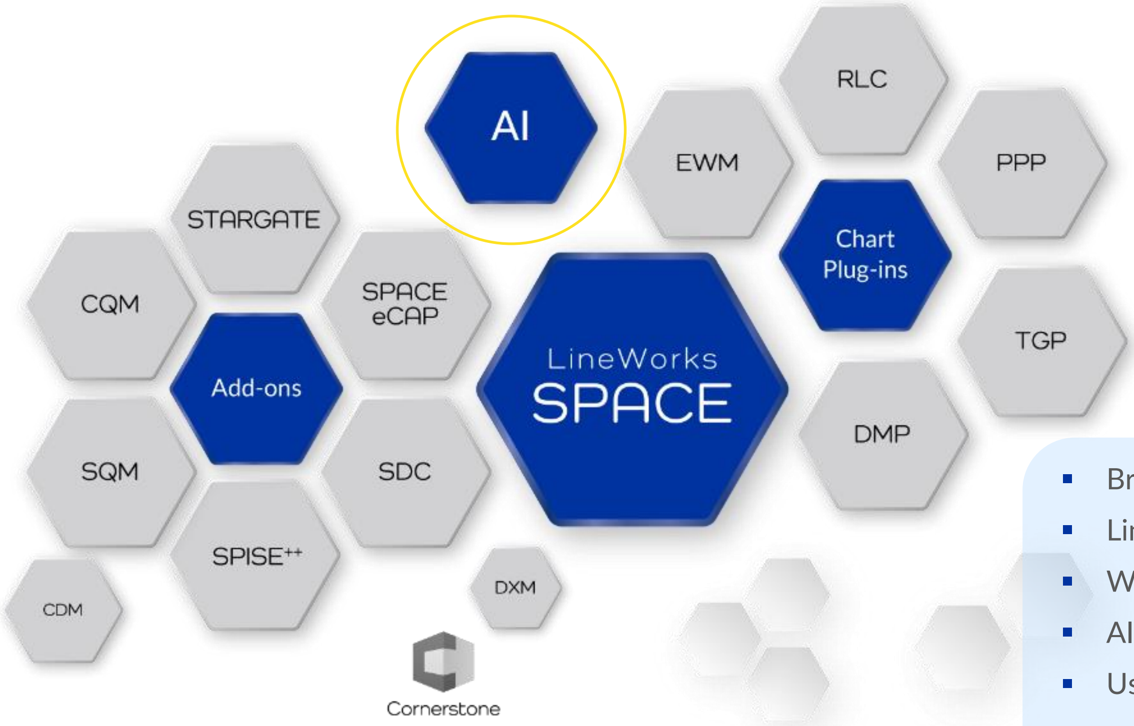
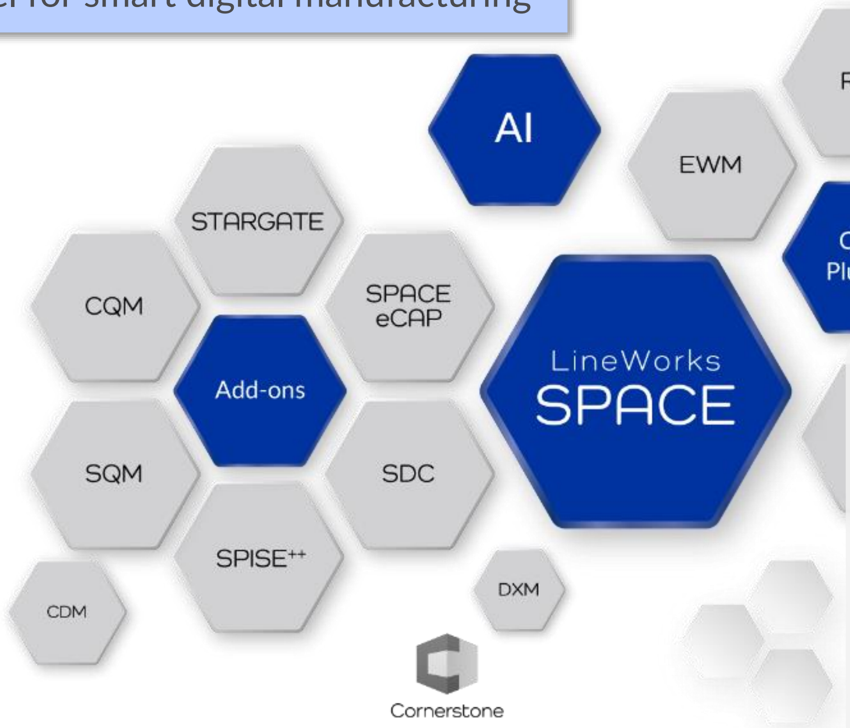
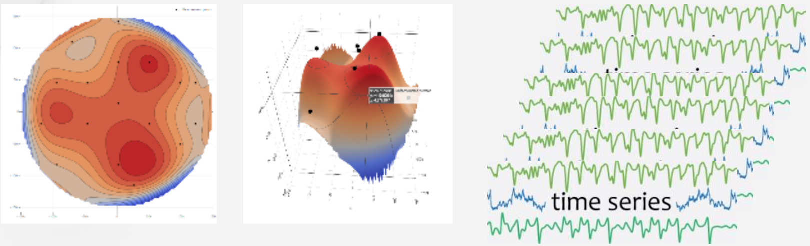


- Bringing Quality Assurance at the new level
- LineWorks SPACE with AI/ML Integration
- Wafermap profile detection
- AI is driving productivity
- Use cases
  - Critical profile detector
  - Root cause analyzer
- Benefits of AI

Kernel for smart digital manufacturing



Complex data formats – information loss



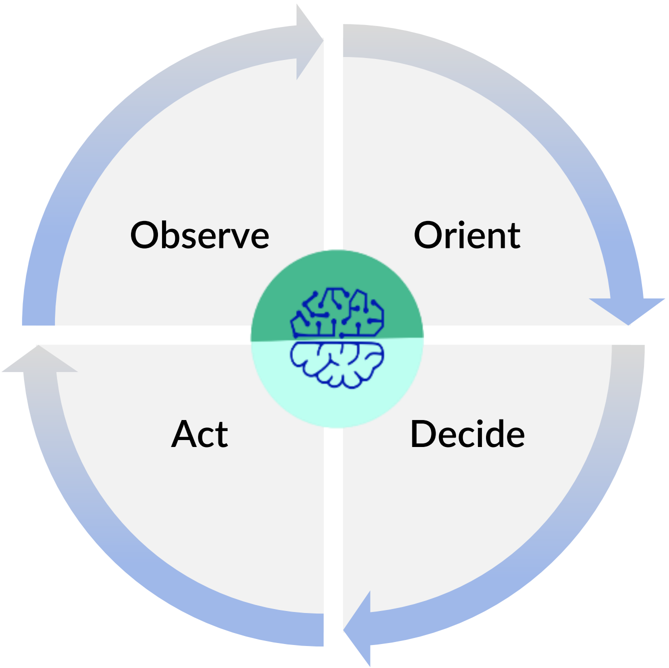
Value?

Value?

Automating and Integrating AI/ML with LineWorks SPACE

Real-time data

System view



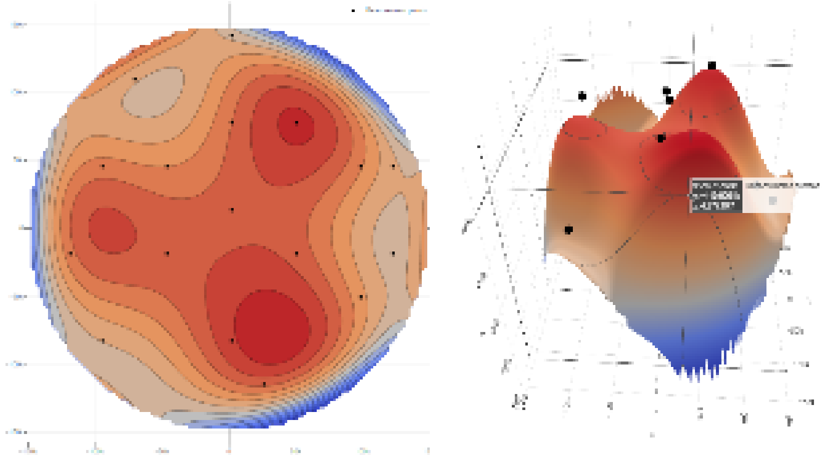
Anomaly detection

Root-cause analysis

Prediction

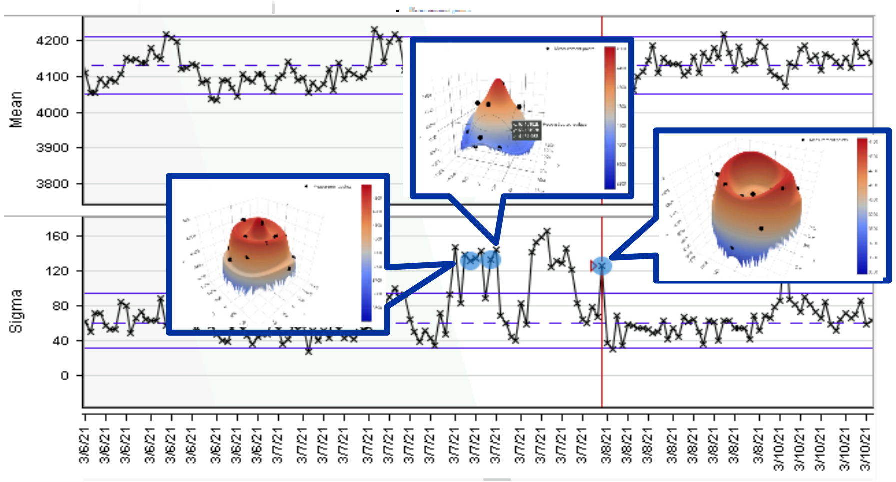
Artificial Intelligence in Smart Operations
assists human to better decision making

Wafermaps as quality indicators



- Quality characteristics vary spatially over the wafers due to processing methods and multiple process steps
  - Shifts in spatial profile are an indication of quality issue in manufacturing tools
  - Different spatial wafer profiles can result in different die yield

Wafermaps as quality indicators



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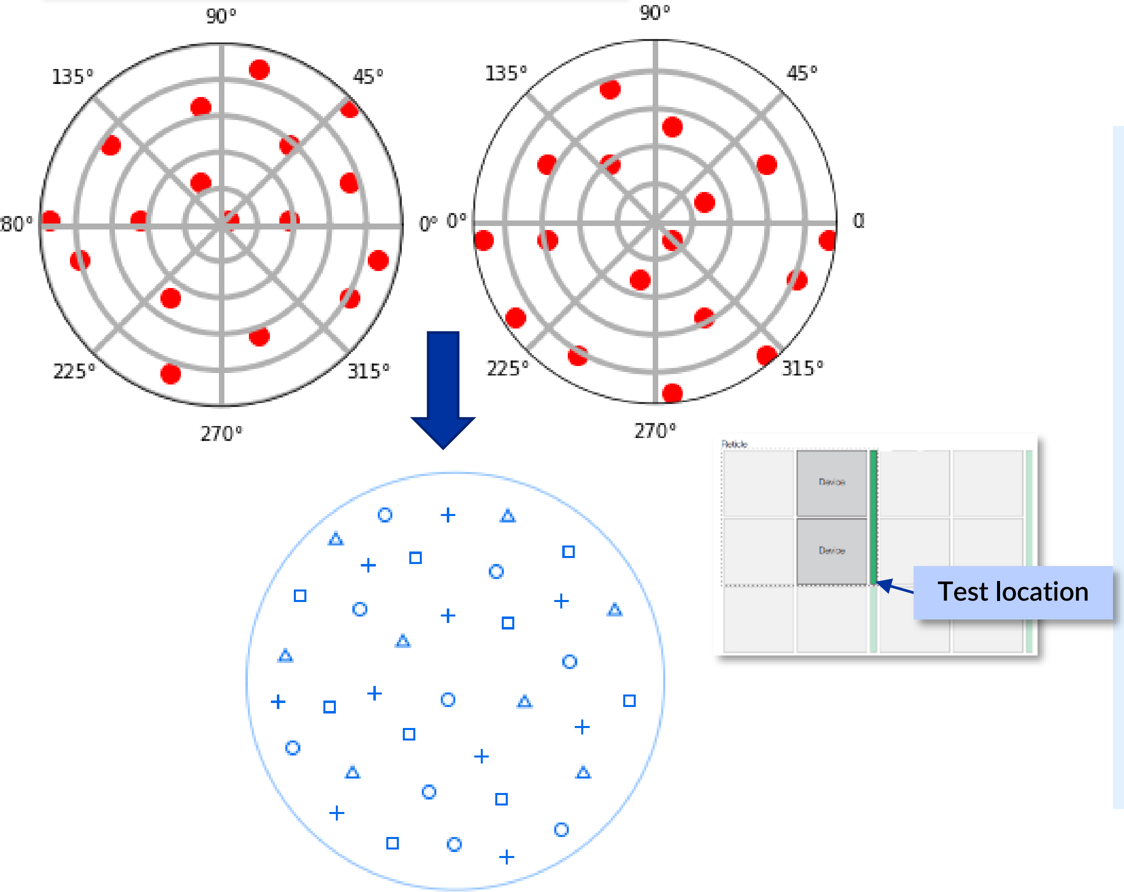
- Challenges
  - Information loss when using summary statistics

Wafermaps as quality indicators



Test location

- Quality characteristics vary spatially over the wafers due to processing methods and multiple process steps
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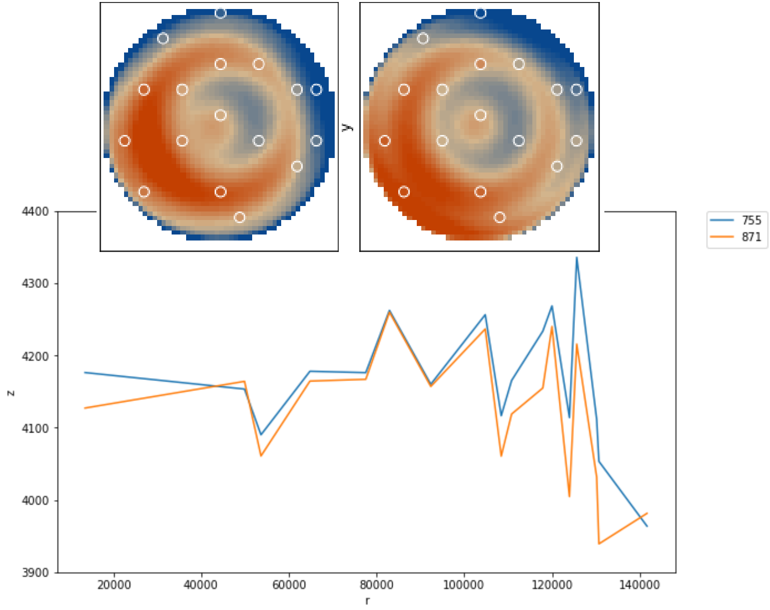
- Challenges
  - Information loss when using summary statistics
  - Different coordinates for different products

Wafermaps as quality indicators



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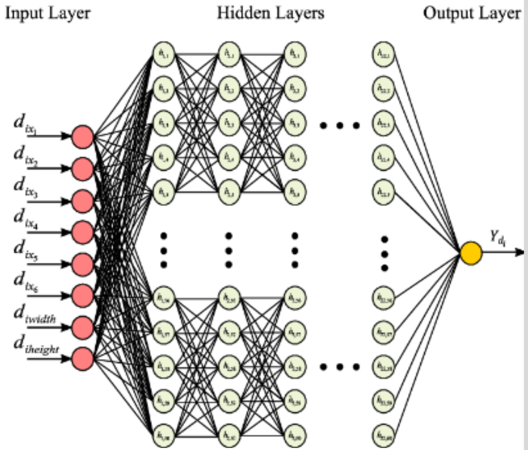
  - Radial vs asymmetric profiles

Wafermaps as quality indicators



Bad vs good:
1:1000

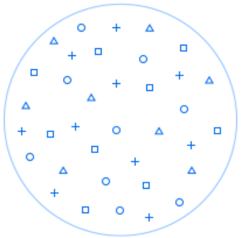
⇒ Large training sets needed

⇒ Poor adaptability

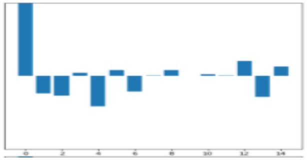
- Quality characteristics vary spatially over the wafers due to processing methods and multiple process steps
  - Shifts in spatial profile are an indication of quality issue in manufacturing tools
  - Different spatial wafer profiles can result in different die yield
- Challenges
  - Information loss when using summary statistics
  - Different coordinates for different products
  - Radial vs asymmetric profiles
  - Imbalanced/ sparse datasets of critical profiles

Wafermap profile detection

Measured wafermap

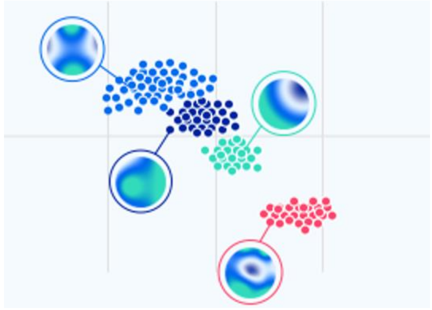


① Shape decomposition (coefficients describing patterns)

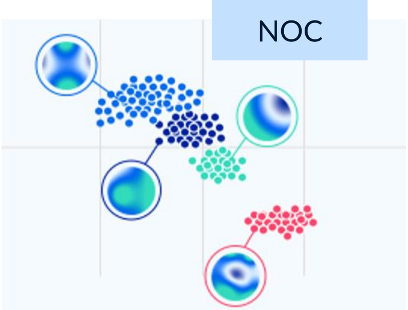


② Reconstructed wafermap pattern

③ Grouping and clustering of patterns (Knowledge base of patterns)



④ Determining Normal Operating Condition

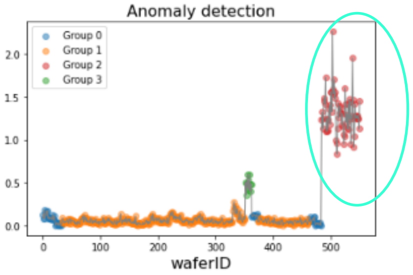

NOC

⑤ Train ML model for anomaly scoring

AI/ML

1…N

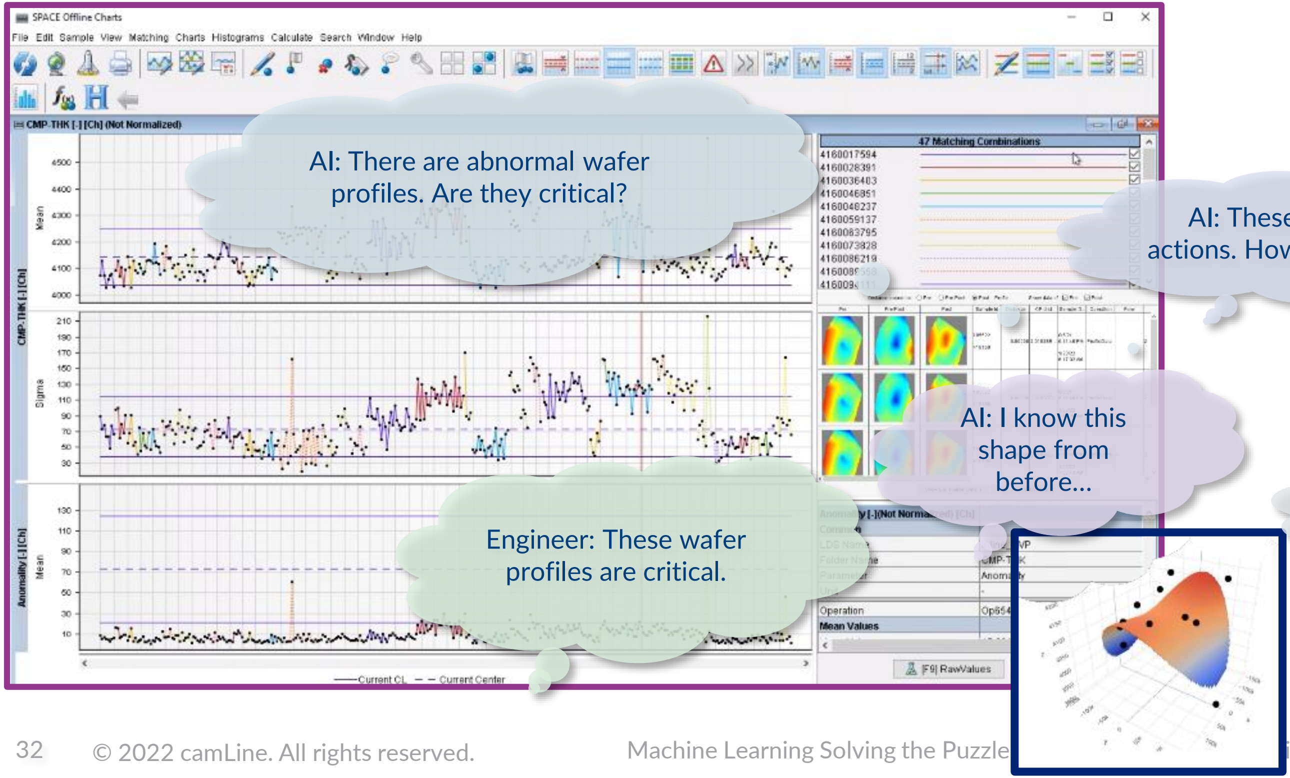
⑥ Anomaly score to SPC framework



SPC framework:

- Yield estimation
- Root-cause analysis
- Equipment matching
- Advice for alignment between layers

Driving productivity with AI complementing advanced SPC

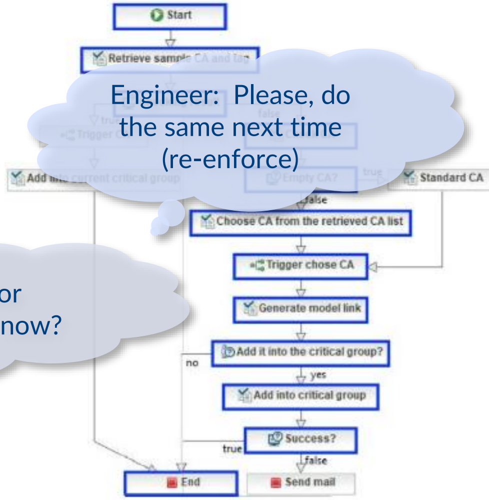


AI: There are abnormal wafer profiles. Are they critical?

Engineer: These wafer profiles are critical.

AI: I know this shape from before…

AI: These are prior actions. How about now?



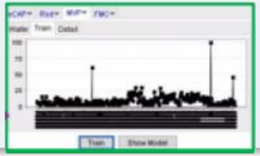
Engineer: Please, do the same next time (re-enforce)

AI: It is potato chip 1

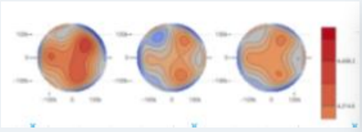
Process flow to set-up AI/ML scoring

Train

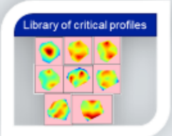
- Anomaly scorer
- Nearest neighbor model
- Critical Profiles (if already known)



Anomaly scorer



Nearest neighbours

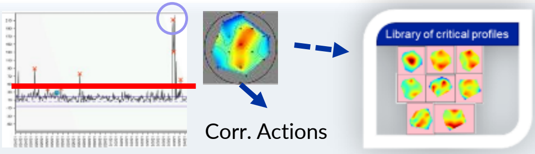


Scoring

- Anomaly score
- CP-scoring (distance to CP, nearest CP-group, within group)
- Nearest neighbors

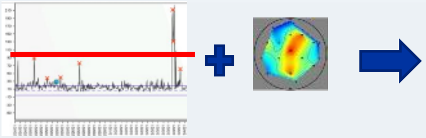
eCAP process

- Initiated if anomaly scorer over detection threshold
- User decides actions for each eCAP (root cause analysis)
- Corrective action
- Create/Add to critical profile group



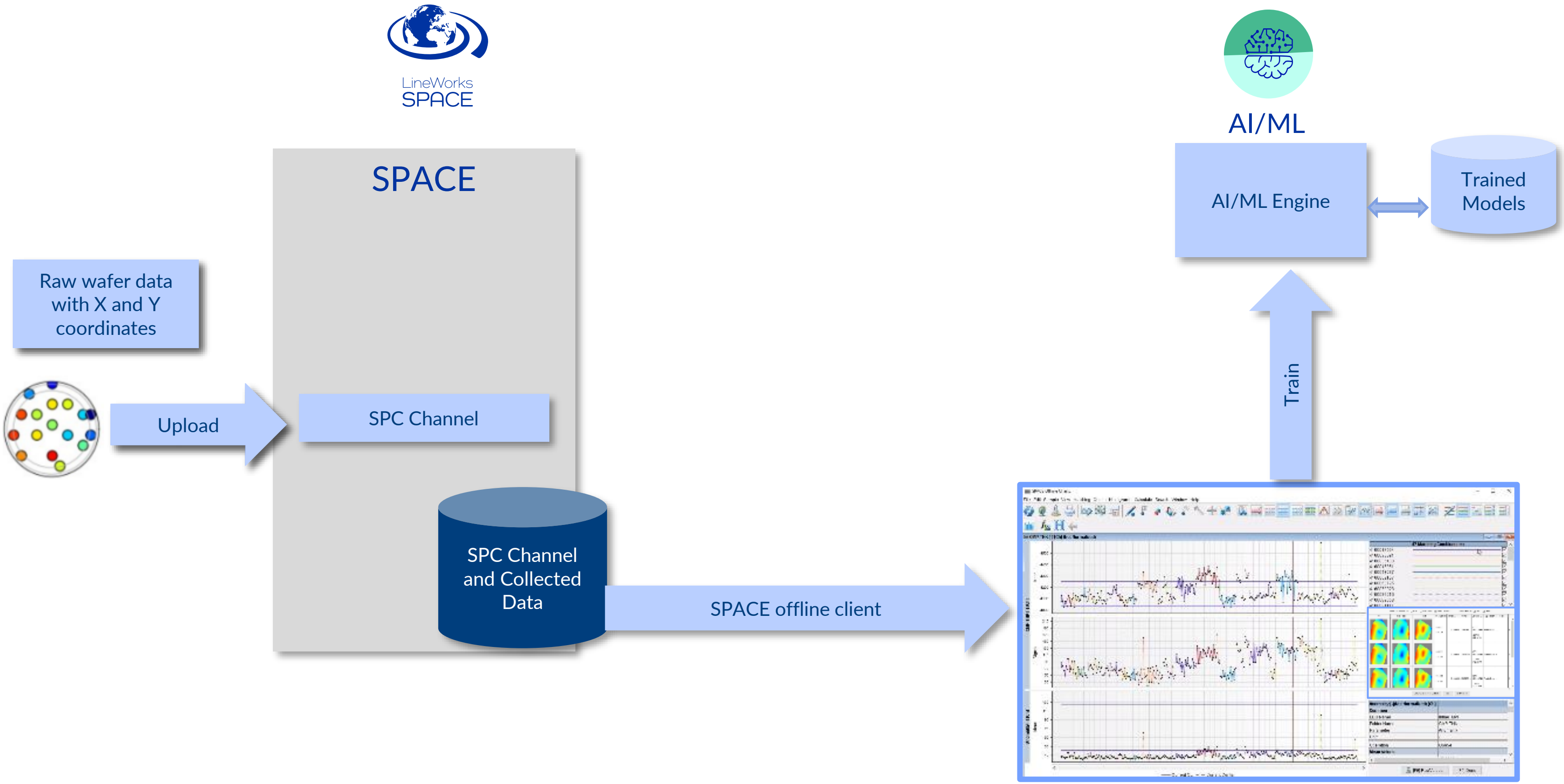
eCAP automation

- Automated actions for anomalies (+critical group)
- Trigger: anomaly scorer (custom threshold) + critical group
- When triggered operator carries out corrective actions



Corrective action

Real-time AI/ML Driven Scoring



LineWorks SPACE

SPACE

Raw wafer data with X and Y coordinates

Upload

SPC Channel

SPC Channel and Collected Data

SPACE offline client

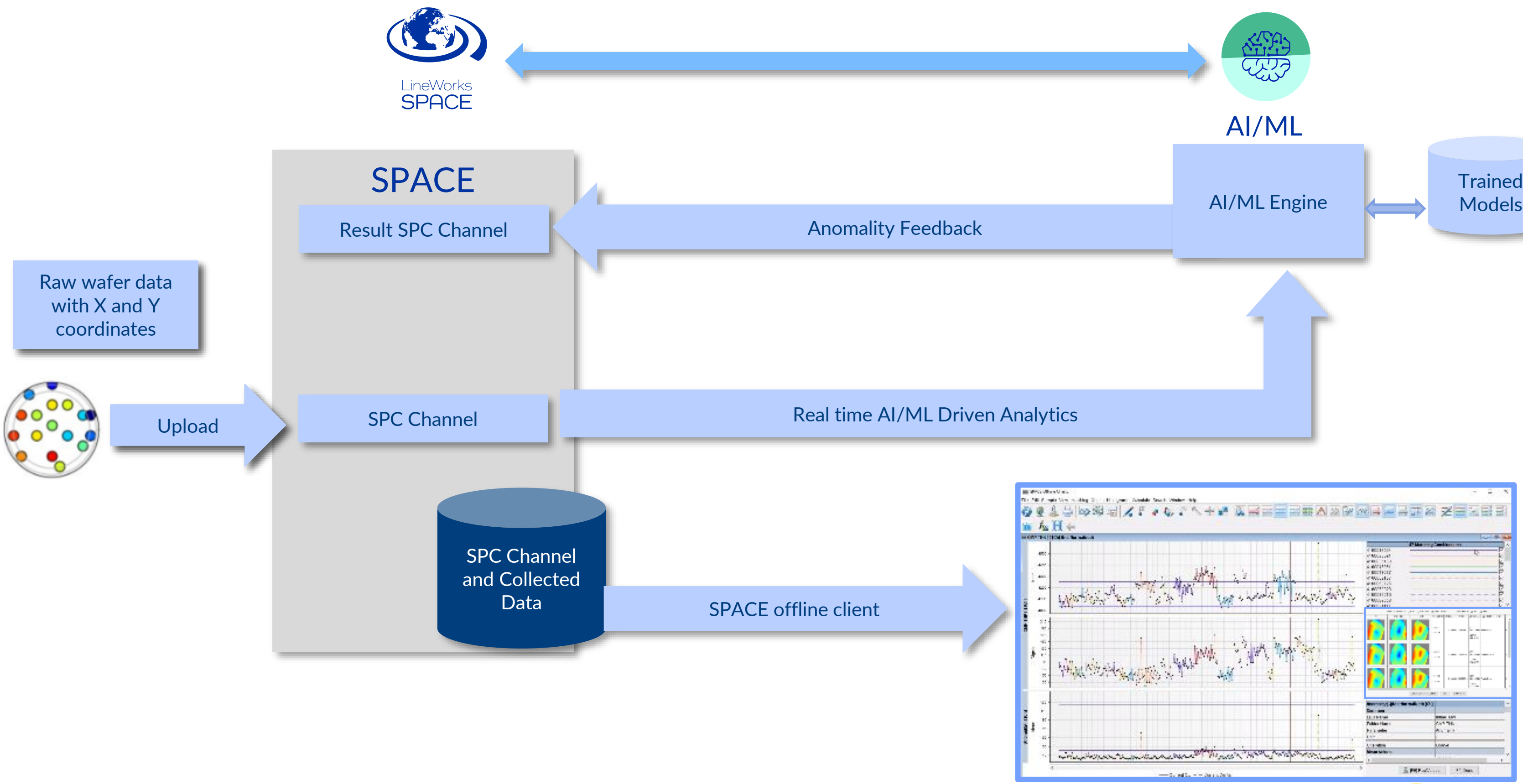
Train

AI/ML

AI/ML Engine

Trained Models

Real-time AI/ML Driven Scoring

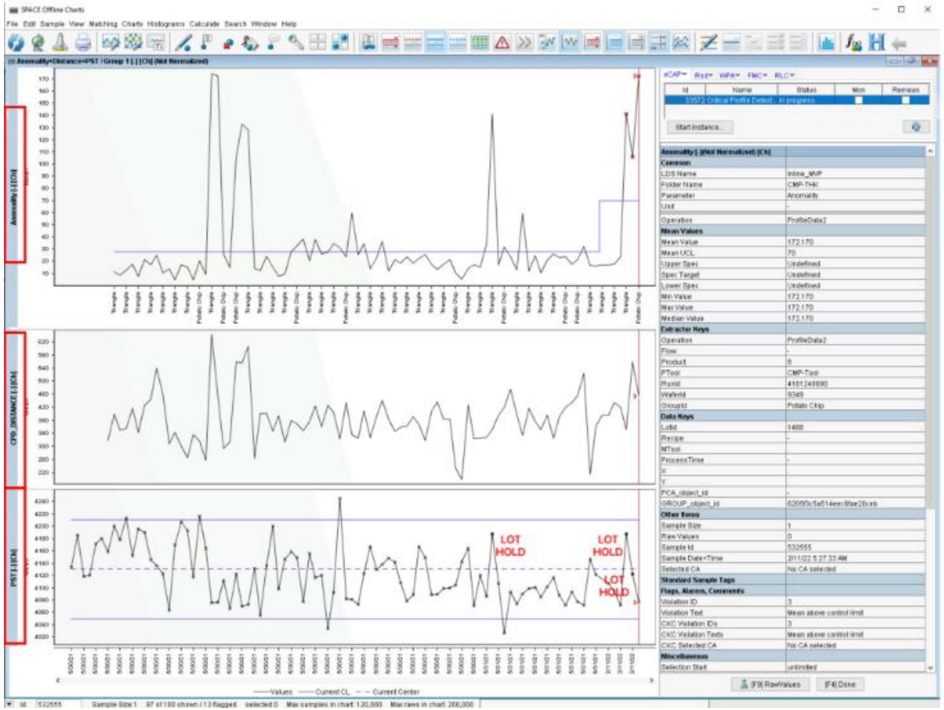


Analysis of AI results

3. Abnormality score

2. Critical profile distance

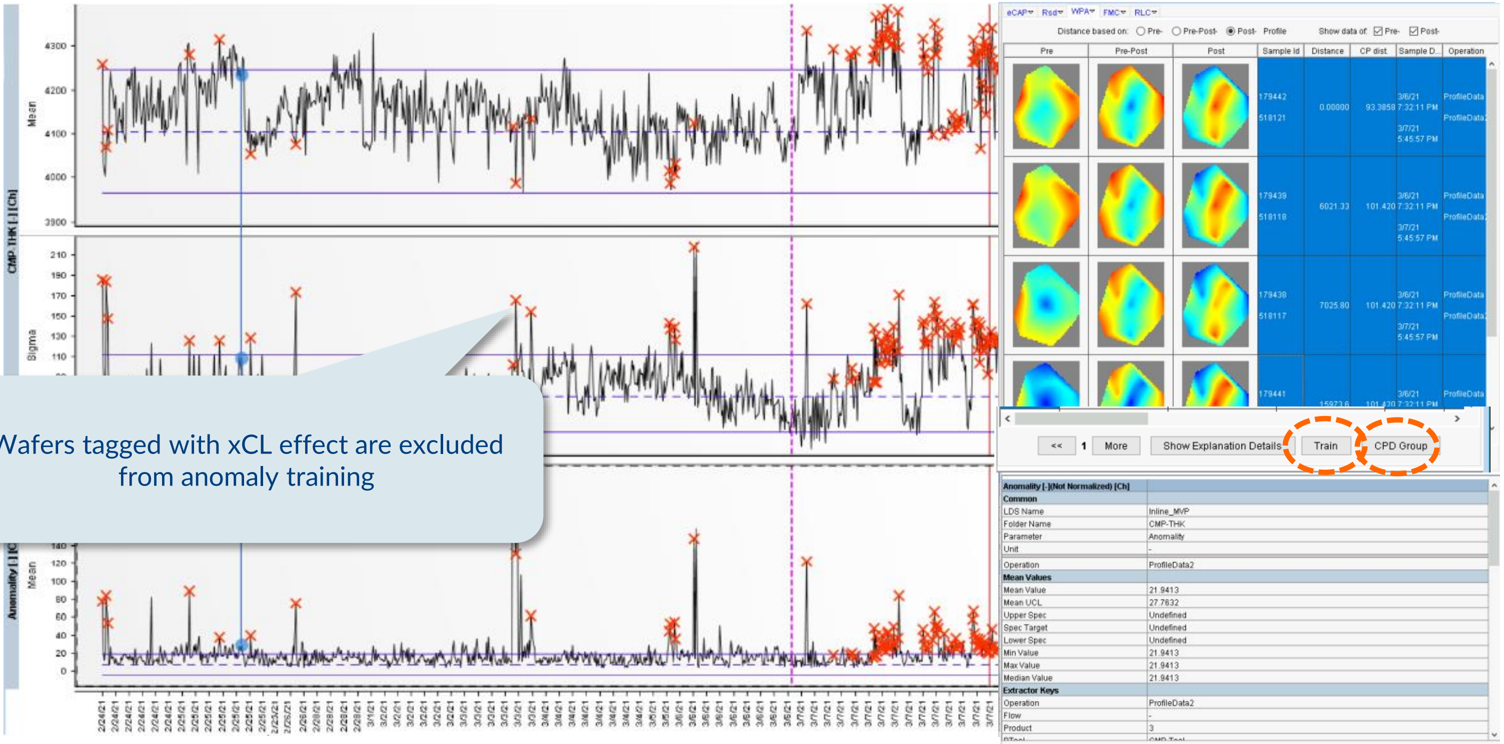
1. Wafer measurement



Id	Name	Status	Mon	Remeas
33572	Critical Profile Detect...	In progress	☐	☐

Anomality [-] (Not Normalized) [Ch]	
Common	
LDS Name	inline_MVP
Folder Name	CMP-THK
Parameter	Anomality
Unit	-
Operation	ProfileData2
Mean Values	
Mean Value	172.170
Mean UCL	70
Upper Spec	Undefined
Spec Target	Undefined
Lower Spec	Undefined
Min Value	172.170
Max Value	172.170
Median Value	172.170
Extractor Keys	
Operation	ProfileData2
Flow	-
Product	6
PTool	CMP-Tool
RunId	4181248890
WaferId	9349
GroupId	Potato Chip
Data Keys	
LotId	1488
Recipe	-
MTool	-
ProcessTime	-
X	-
Y	-
PCA_object_id	-
GROUP_object_id	[illegible]
Other Items	
Sample Size	1
Raw Values	0
Sample Id	532555
Sample Date+Time	2/11/22 5:27:33 AM
Selected CA	No CA selected
Standard Sample Tags	
Flags, Alarms, Comments	
Violation ID	3
Violation Text	Mean above control limit
CKC Violation IDs	3
CKC Violation Texts	Mean above control limit
CKC Selected CA	No CA selected
Miscellaneous	
Selection Start	unlimited

Interactive user-triggered model training



Distance based on: ○ Pre- ○ Pre-Post- ● Post- Profile   Show data of: ☑ Pre- ☑ Post-

Pre	Pre-Post	Post	Sample Id	Distance	CP dist	Sample D...	Operation
			179442 518121	0.00000	93.3858	3/6/21 7:32:11 PM 3/7/21 5:45:57 PM	ProfileData ProfileData2
			179439 518118	6021.33	101.420	3/6/21 7:32:11 PM 3/7/21 5:45:57 PM	ProfileData ProfileData2
			179438 518117	7025.80	101.420	3/6/21 7:32:11 PM 3/7/21 5:45:57 PM	ProfileData ProfileData2
			179441	15973.6	101.420	3/6/21 7:32:11 PM	ProfileData

Anomality [-](Not Normalized) [Ch]	
Common	
LDS Name	Inline_MVP
Folder Name	CMP-THK
Parameter	Anomality
Unit	-
Operation	ProfileData2
Mean Values	
Mean Value	21.9413
Mean UCL	27.7632
Upper Spec	Undefined
Spec Target	Undefined
Lower Spec	Undefined
Min Value	21.9413
Max Value	21.9413
Median Value	21.9413
Extractor Keys	
Operation	ProfileData2
Flow	-
Product	3

Wafers tagged with xCL effect are excluded from anomaly training

Interactive user-triggered model training

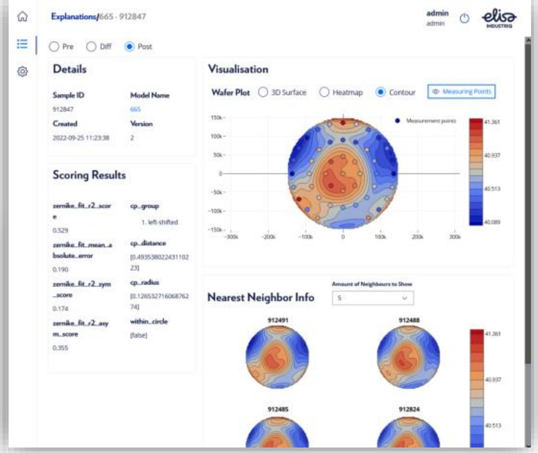
Model Name 666	**Model Type** critical_profile_detector
Created 2022-09-22 14:20:52	**Last Modification** 4 days ago
Training status ● Success	**Training Time** 00:00:05

Training Parameters

z_degree [[0,0],[1,-1],[1,1],[2,-2],[2,0],[2,2],[3,-3],[3,-1],[3,1],[3,3],[4,0],[10,0]]	**cp_threshold** 1
x_range [-150000,150000]	**ef_construction** 200
y_range [-150000,150000]	**ef** 200
metric l2	**M** 16

Data

num_samples 200	**latest_sample_date** 2022-09-26 11:36:29
earliest_sample_date 2021-02-01 11:00:00	**products** 1. P3 2. P1 3. P2

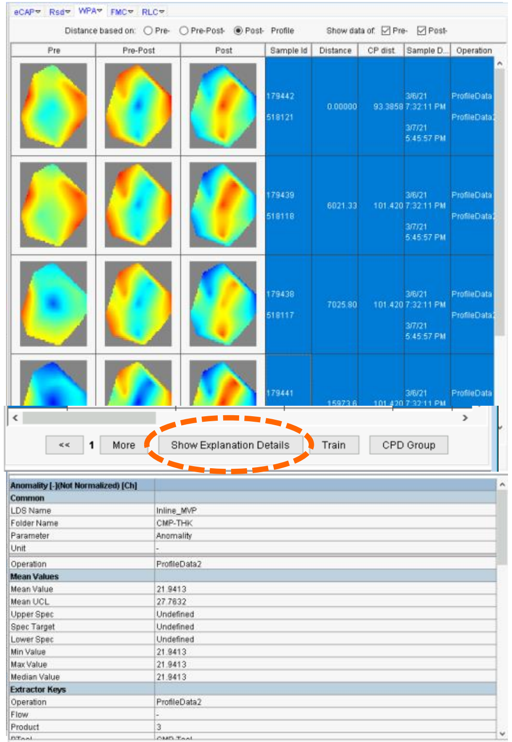


Details

Sample ID 912847	**Model Name** 665
Created 2022-09-25 11:23:38	**Version** 2

Scoring Results

zernike_fit_r2_score 0.529	**cp_group** 1. left-shifted
zernike_fit_mean_absolute_error 0.190	**cp_distance** [0.49353802243110223]
zernike_fit_r2_sym_score 0.174	**cp_radius** [0.1265327160687624]
zernike_fit_r2_asym_score 0.355	**within_circle** [false]



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Max Value	21.9413
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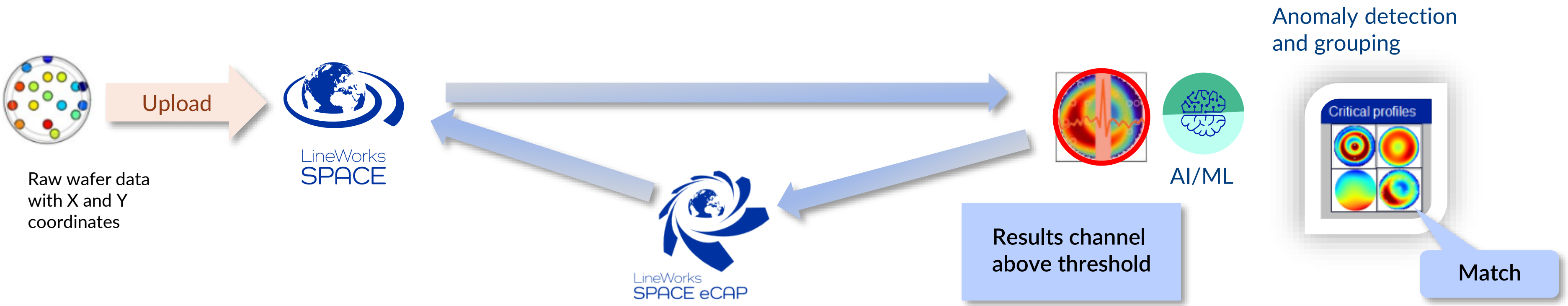
Operation	ProfileData2
Flow	-
Product	3

camLine elisa company

elisa INDUSTRIQ

OCAP (eCAP) process to drive productivity



Raw wafer data
with X and Y
coordinates

Upload

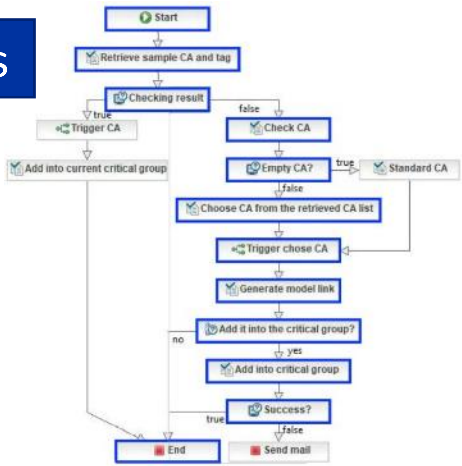
Anomaly detection
and grouping

AI/ML

Results channel
above threshold

Match

Setting up corrective actions



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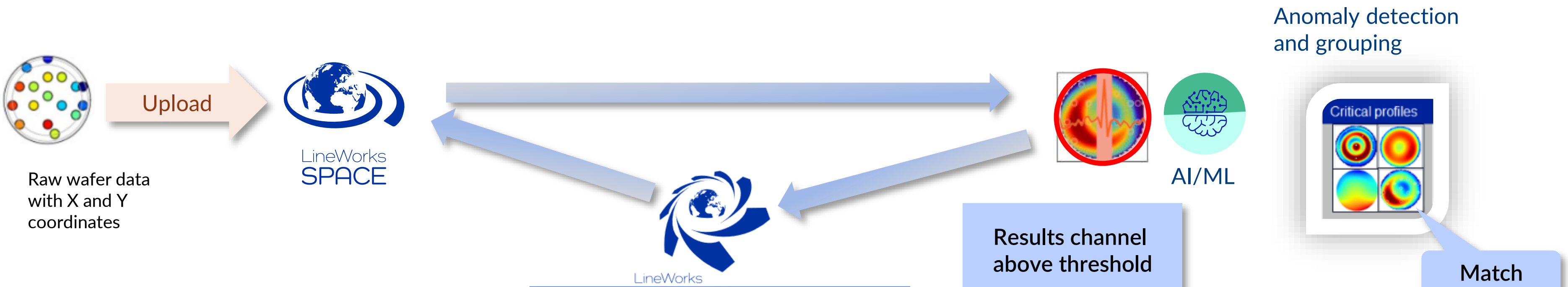
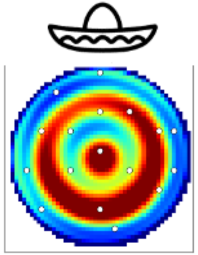
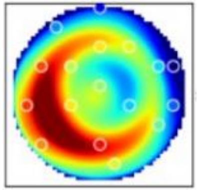


Detection	
Sombrero	Asymmetric
Automated execution	Human assisted with AI/ML advice



- Found the wafers of the same critical group
- All wafers have the same “Lot hold action”.
- Execute “Lot hold action”

- Found the wafers of the same critical group
- All wafers have two different sets of “Inhibit Tool” and “Chamber hold” action.
- User decides the actions required.



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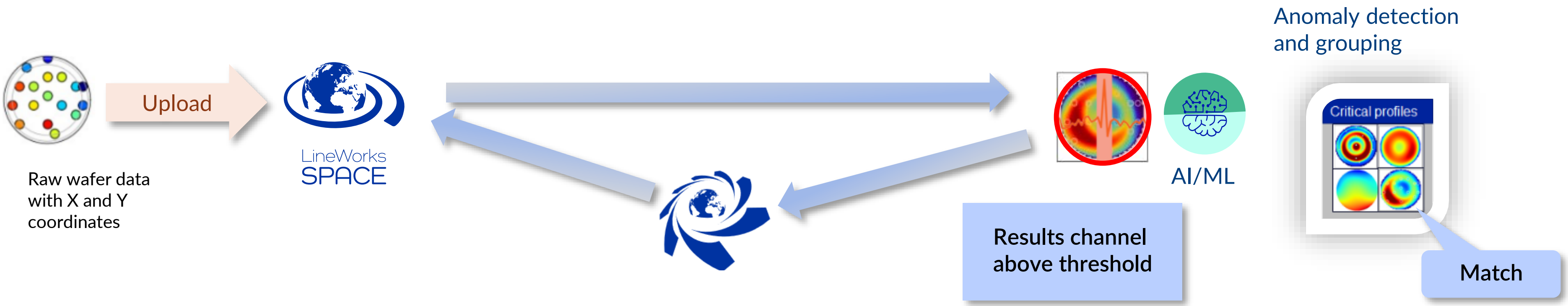


Anomaly detection and grouping

Upload

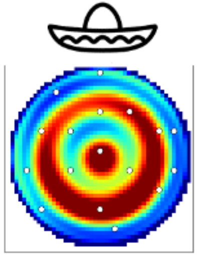
Raw wafer data with X and Y coordinates

LineWorks SPACE

AI/ML

Results channel above threshold

Match



- Found the wafers of the same critical group
- All wafers have the same “Lot hold action”.
- Execute “Lot hold action”

✓ Complete automated profile detection and classification process

✓ Real-time and Online analysis with AI

✓ Real-time Corrective Actions

✓ Well documented with automated execution and follow-up

- Found the wafers of the same critical group
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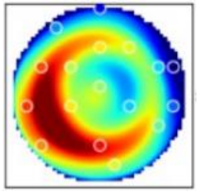
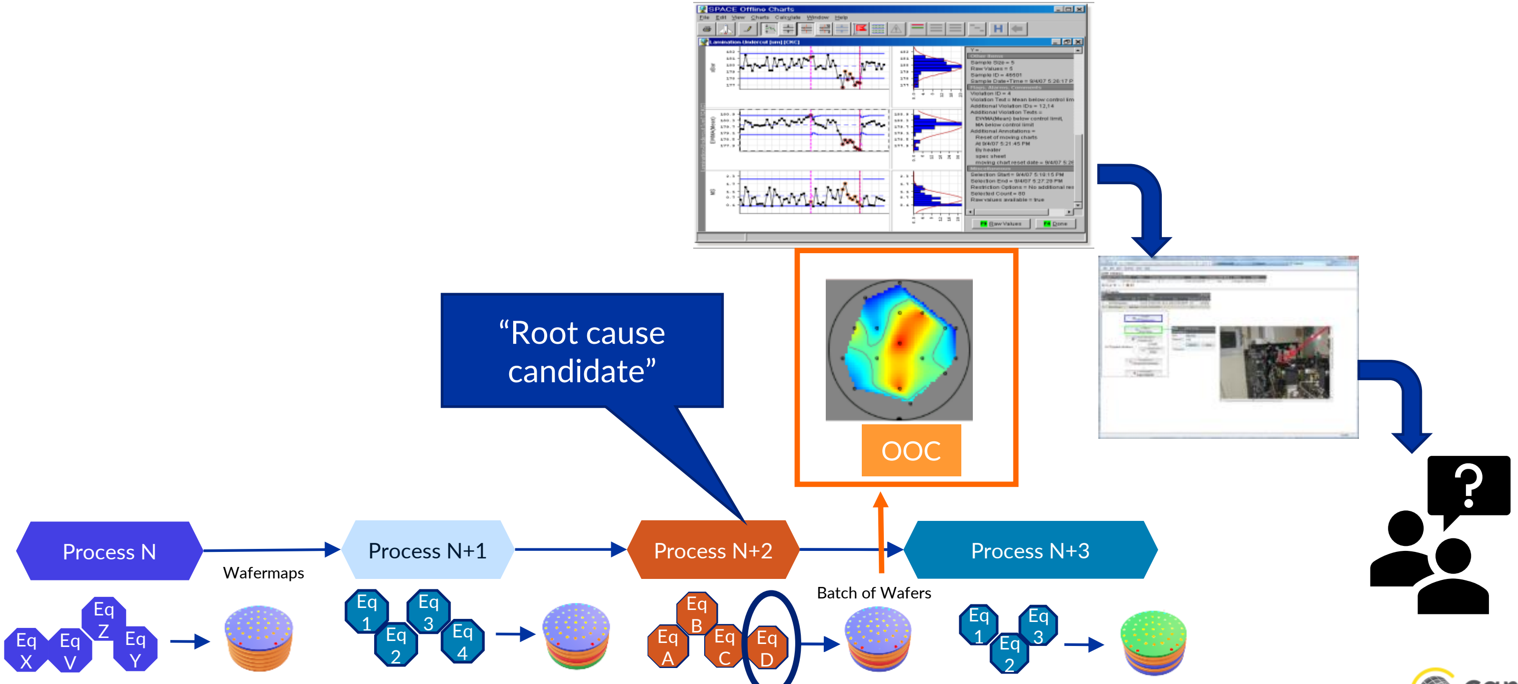


Limitations of root cause analysis with SPC

As the technology node in semiconductor wafer fabrication process has advanced, identification of root cause is getting more difficult with a “classical OCAP approach” that is based on the last process operation.



“Root cause candidate”

OOC

Process N

Wafermaps

Process N+1

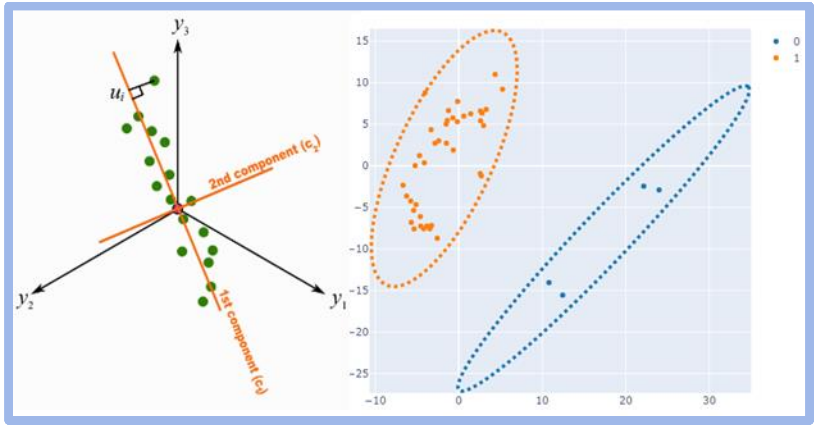
Process N+2

Batch of Wafers

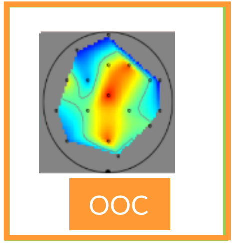
Process N+3

AI assisted root cause analysis

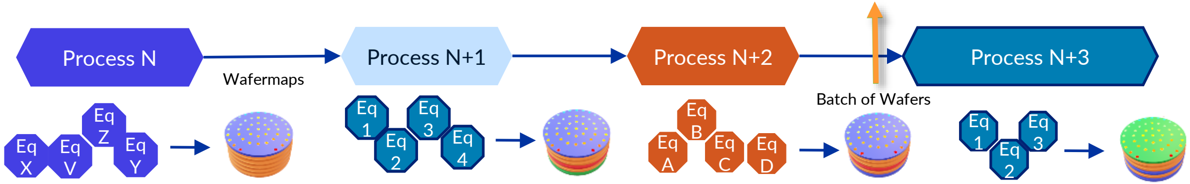
- Include all the process data: metrology (numerical) and process operation (operation-step, equipment, recipe)
- With multivariate discriminant analysis, find the real root cause (highest contributor to the observed OOC)



AI/ML



OOC



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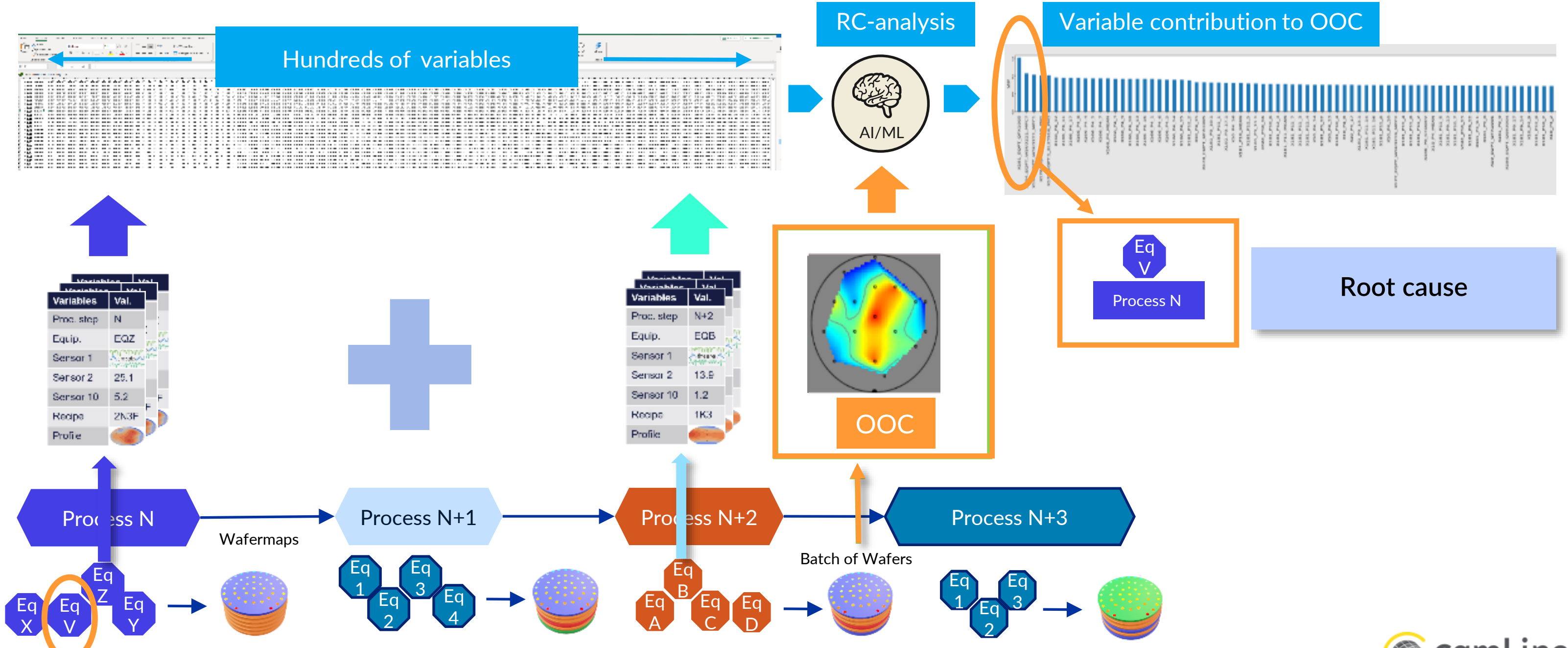
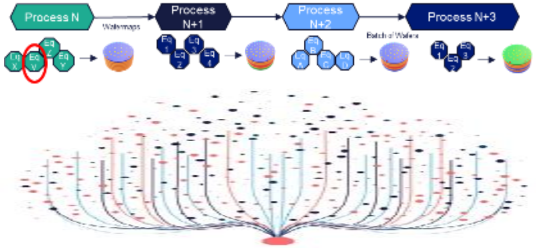


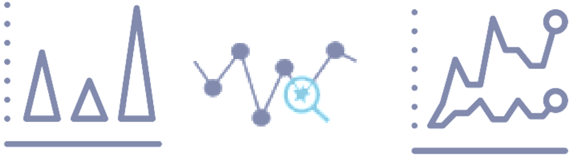
Variables	Val.
Proc. step	N
Equip.	EQZ
Sensor 1	
Sensor 2	25.1
Sensor 10	5.2
Recipe	2N3F
Profile	

Variables	Val.
Proc. step	N+2
Equip.	EQB
Sensor 1	
Sensor 2	13.9
Sensor 10	1.2
Recipe	1K3
Profile	

Benefits of an AI integrated SPC framework



Data collection



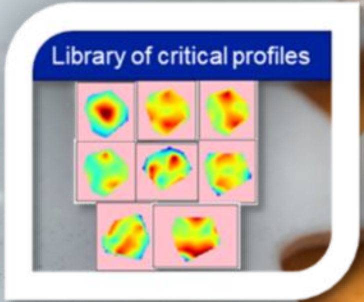
Analytics

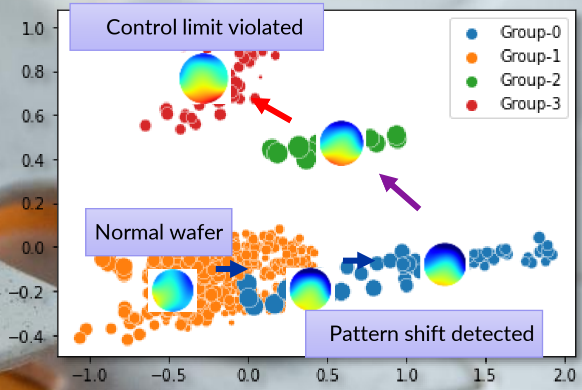
AI Insights

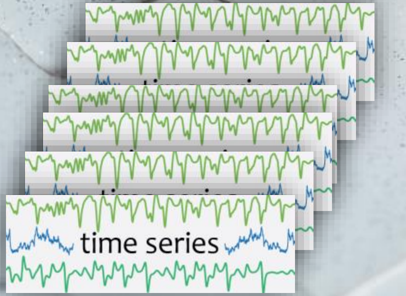
Actions!

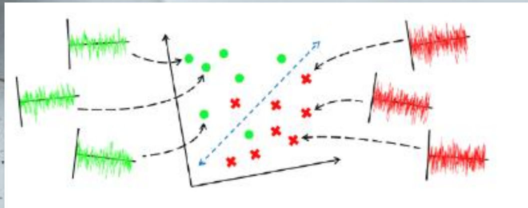
"Real-time online analysis with AI insights leading to actions enhancing productivity"

Benefits of an AI integrated SPC framework







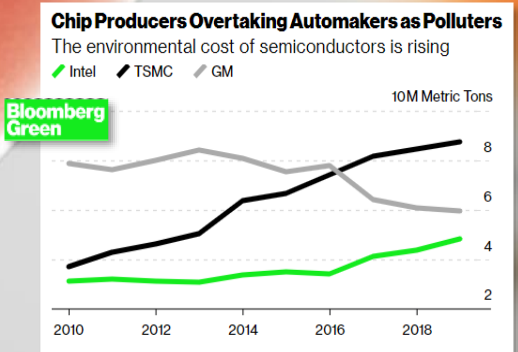


"Lifting SPC to a new level by enriching change and anomaly detection with complex data types"

Benefits of an AI integrated SPC framework

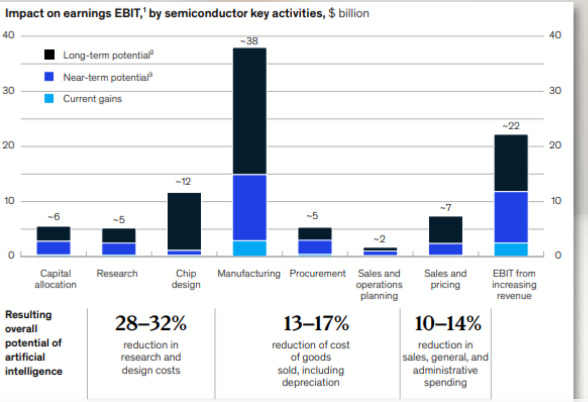
Up to 80% of engineer time to solve issues is spent on gathering data

Real-time availability of expert insights



Source: Company disclosures
Note: Metric tons of green house gas emissions

Improving yield is being sustainable!



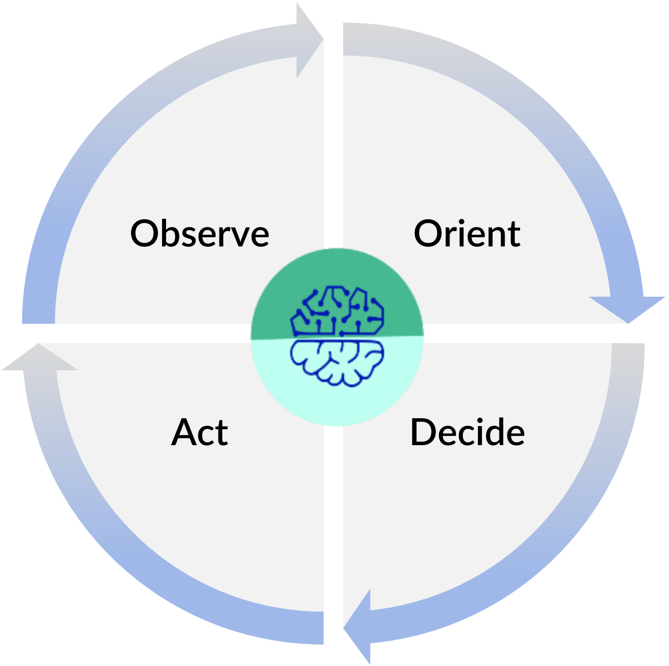
<30% have implemented AI/ML to generate value currently $5B → 2-3 years $35B

Source: IBM, McKinsey

Automating and Integrating AI/ML with LineWorks SPACE

Real-time data

System view



Observe

Orient

Act

Decide

Anomaly detection

Root-cause analysis

Prediction

Artificial Intelligence in Smart Operations assists human to better decision making

A SUSTAINABLE
FUTURE THROUGH
DIGITALISATION

Thank you
for your attention

47 Matching Combinations

4160017594
4160028391
4160036403
4160046851
4160048237
4160059137
4160063795

Anomality [-](Not Normalized) [Ch]	
Common	
LDS Name	Inline_MVP
Folder Name	CMP-THK
Parameter	Anomality
Unit	-
Operation	Op654
Mean Values	