ASML predictive maintenance

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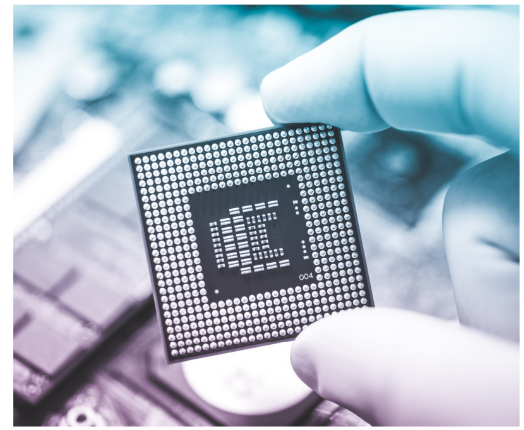
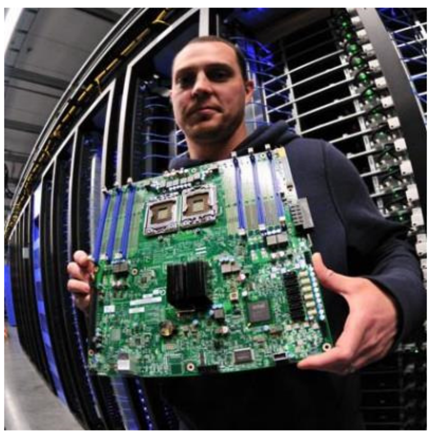
PUBLIC

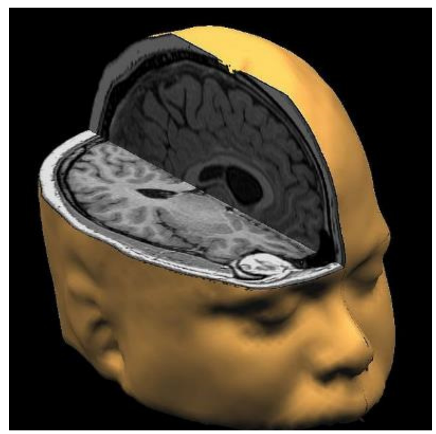
- Introduction to ASML
- How to maintain/diagnose complex systems?
- Applying Causal Analytics for ASML Diagnostics
- Explanation of Global Operations Center
- Questions

Introduction to ASML

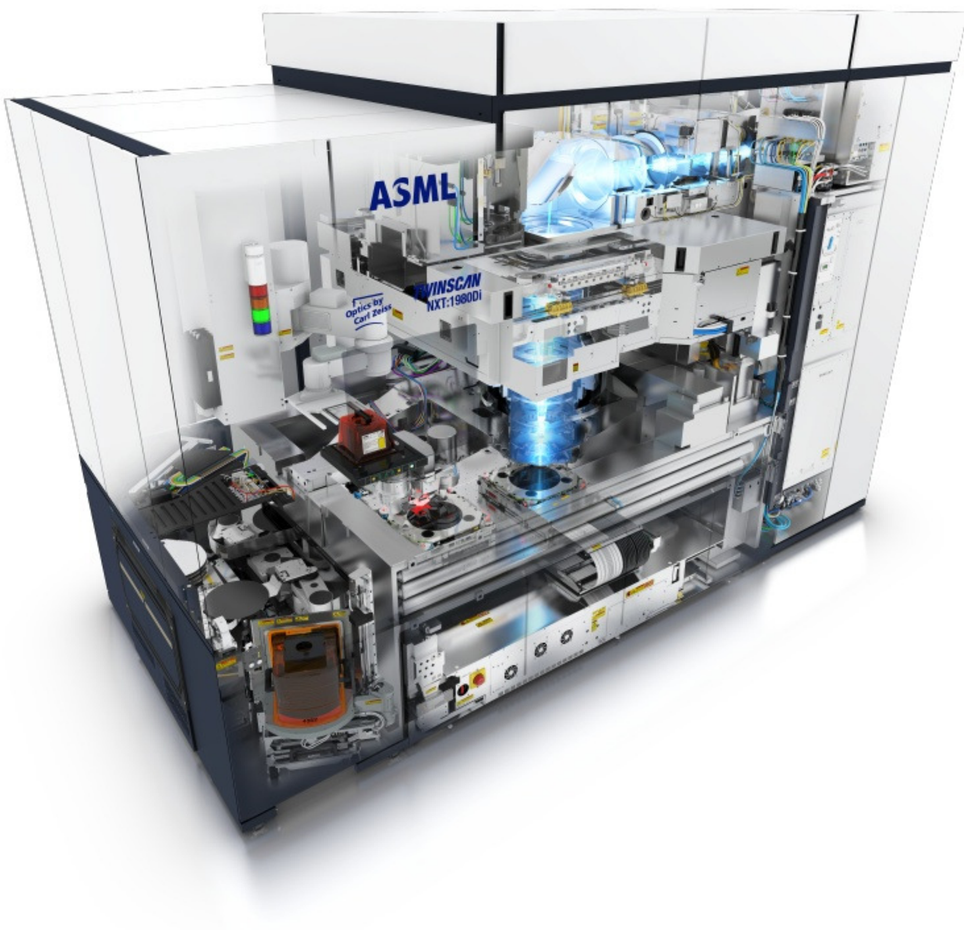
It’s hard to imagine a world without chips







ASML makes machines for making chips



- Lithography is the critical step for producing chips
- ASML products:
    - Lithography systems
    - Metrology and inspection systems
    - Computational lithography
- All the world's top chip makers are our customers
- 2022 sales: €21.2 billion
- >39,000 employees worldwide
    - 143 nationalities

Our key locations

Wilton (CT)

San Diego(CA)

Korea

Veldhoven

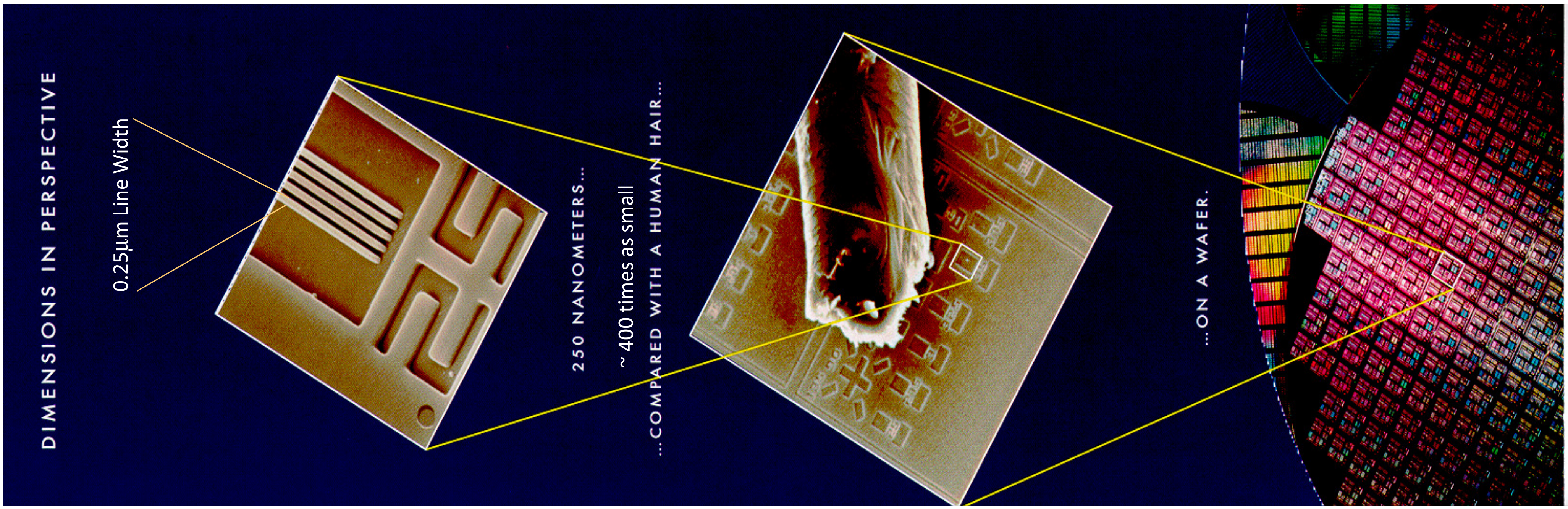
Chandler (AZ)

Taiwan

ASML in 60 seconds

[(22) Post | Feed | LinkedIn]

What is a nanometer ?
Chip dimensions in perspective



A human hair is about 4000 times as thick as a 25nm line on an IC.
ASML scanners currently print lines of less than 10 nm width !

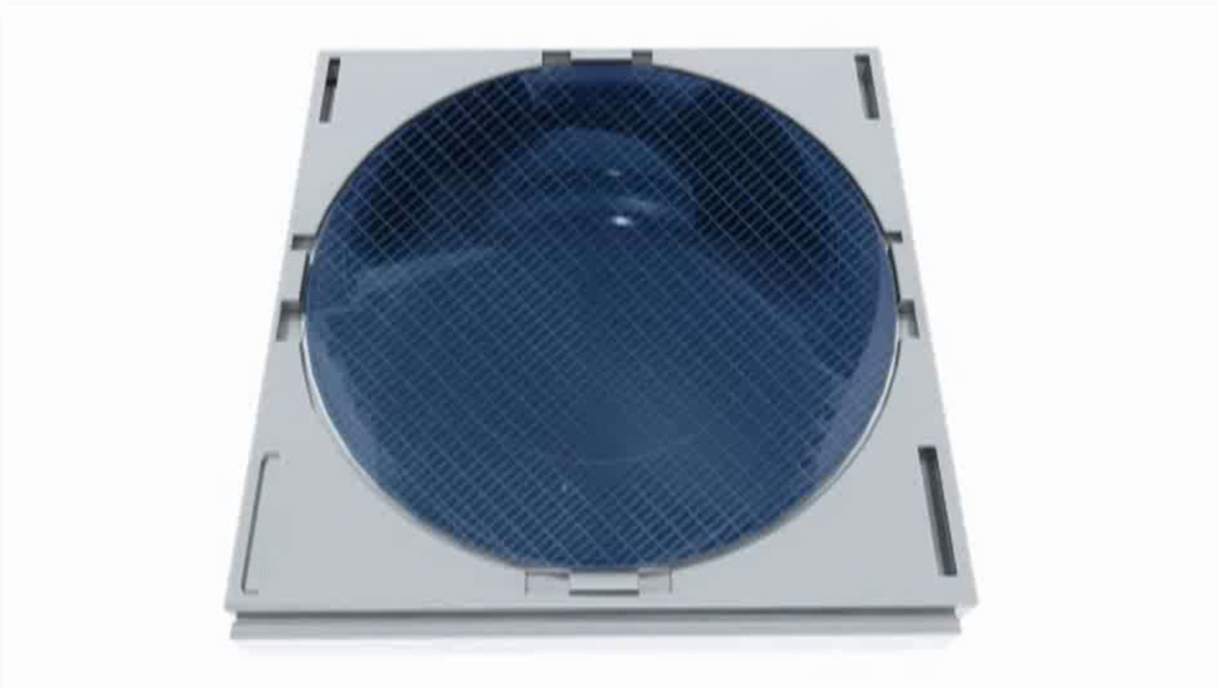
What is a nanometer?

Compared to the growth of grass

Grass grows roughly 2 centimeter per week,
that is 33 nanometer per second!

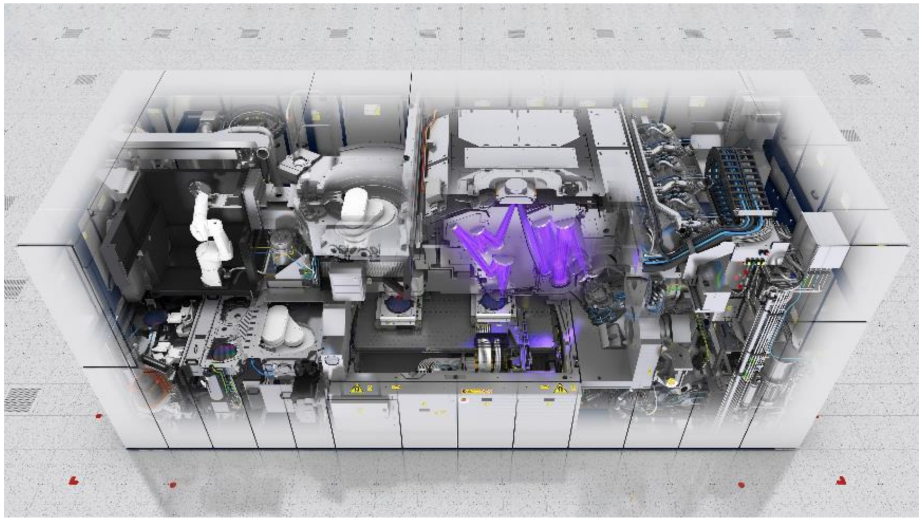
After folding the “paper” of this presentation 280.000.000 times a strip remains of 1 nanometer wide. This strip however is 80 kilometers thick.

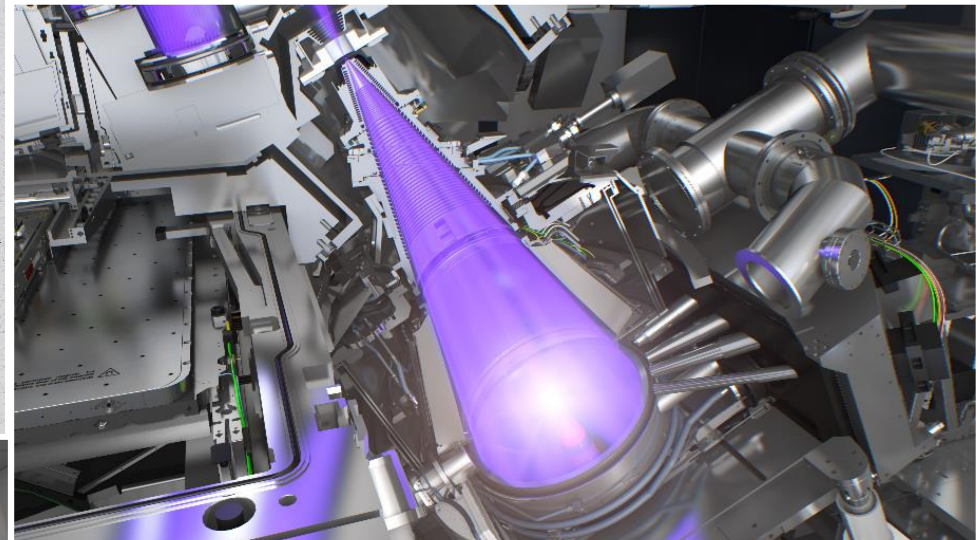
A chip is made of dozens of layers
Let's look inside an iPhone

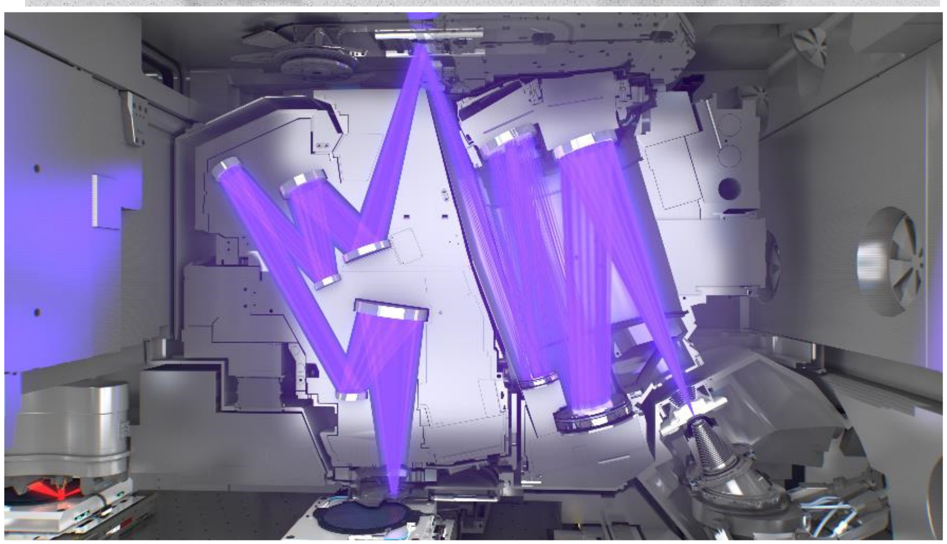


How to maintain/diagnose complex systems?
Generic maintenance strategy

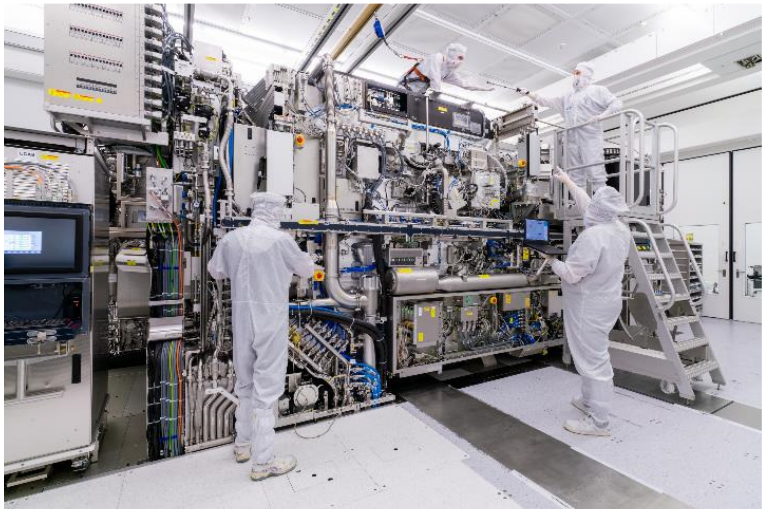
Some pictures showing the complexity of our systems 1/2

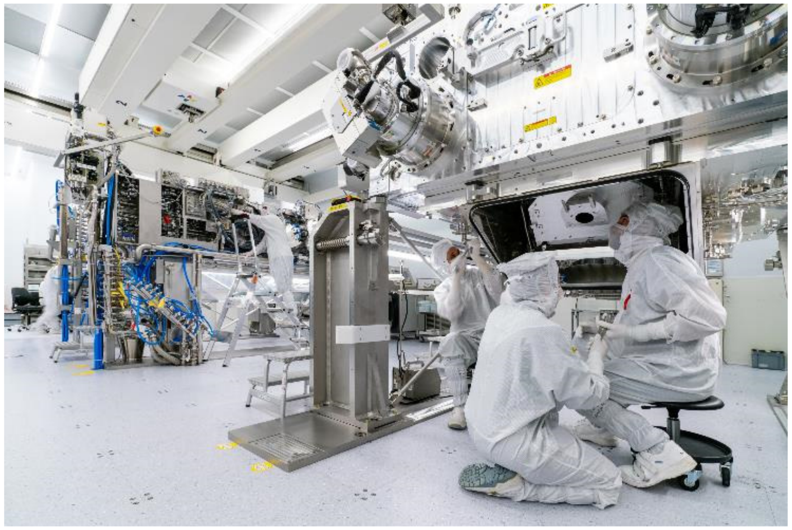






Some pictures showing the complexity of our systems 2/2





How to maintain these complex systems?

Generic PM approach

Expectations towards the customer → Maintenance Requirements Manual (MRM)

PM schedule (time based) → System engineering makes a risk and lifetime assessment, based on FMEA.

Parts → Service parts are defined and stocked

Procedures → Service procedures are created and stored in central database (machine and configuration dependent)

Skills → Maintenance personnel is trained

PM: Periodic Maintenance (Predictive? Preventive?)
FMEA: Failure Mode and Effect Analysis

MRM
Customer responsibility

ASML guarantees performance, provided customers stick to the Maintenance Requirements Manual (MRM). The MRM covers:

- Fab infrastructure (IT and physical)
- Preventive maintenance schedule
- Configuration management policy
- Performance reporting & Reconciliation policy
- Resolving machine down situation: Way-of-Working (WoW) and responsibilities
- Deviation Handling Process

Snapshot of PM schedule for EUV system

At this moment PM stands for periodic maintenance.

Schedules are typically time based (daily, weekly, monthly, half-yearly, yearly etc.)

			GREEN = Changes in new release				SCN states	SRC states			CBM			TBM				
Sub syste	Main procedure	ARE/GEAR Sequence nam	PM Description	SRC/SCN Config.	Dependency A / NA	SRC/ SCN	GAS Vacuum	Control state	Catagory	TBM/ CBM	Type	Tool	Content	Repetition [day]	Freq. #/ye	Window [day	A-time [hr	Materials
Laur	gtm016.dia	Inline monitoring	Monitor SRBB tin level	S3-MV		source	NA	NA	UPT	Monitor	KPI	TPMS	SRBB tin level	7	52	±1	0.2	NA
VES	ght074.ins	GEAR: PM: VES: PE	Collector swap and recovery	S3-MV		source	NA	Service	PER	CBM	KPI	Grafana	SLIE/DT	NA	4		23.3	link
DG	gdg102.per	GEAR: PM: DG: UPT	Inline Tin Refill	S3-MV		source	NA	Heated	UPT	CBM	KPI	Tracking sheet		NA	73		6.2	NA
DG	gdg069.ins	GEAR: gdg069.ins - F	RPA Tin reload	S3-MV		source	NA	Heated	UPT	CBM	KPI	Tracking sheet		NA	26		1.4	link
ST	gsm060.cal	PM MV: ST: UPT: TB	TruCoax **Manual** Gas Refill	S3-MV		source	NA	Standby	UPT	TBM				14	26		2.1	NA
TM	gtm074.per	Inline monitoring	Monitoring Tin fill level of TCBA	S3-MV		source	NA	NA	UPT	Monitor	KPI	ADT	fill level >70%	21	17	±1	0.1	NA
DL	gdl056.cal	PM MV: DL: PER: TE	Calibrate PA PEMs + Power Meters	S3-MV	**A: HPAC mk1.0**	source	NA	Standby	PER	TBM				**91**	**4**		6.9	link
DS	gpg018.man	Inline monitoring	Track the pellicle contamination	S3-MV		source	NA	NA	UPT	Monitor	KPI	TPMS	Viewport/Pellicle	30	12	±1	0.5	NA
ST	gsm036.dia	PM MV: ST: PER: TE	Check the Matching of the Trucoax	S3-MV		source	NA	NA	PER	Monitor	KPI	TPMS	RF Impedence	30	12	±5	0.8	NA
ST	gsm201.adj	PM MV: ST: PER: CE	➢ Adjust the matching of the Trucoax	S3-MV		source	NA	Standby	PER	CBM				NA	1		4.9	link
DL	gdl032.chl	Inline monitoring	Monitor MP energy at PA3OUT	S3-MV		source	NA	NA	UPT	Monitor	KPI	TPMS	Power level	30	12	±5	0.2	NA
DL	gdl069.adj	PM MV: DL: UPT: CE	➢ Recalibrate DLSS Threshold	S3-MV		source	NA	Standby	UPT	CBM				NA	4		1.5	NA
DL	gdl114.per	PM MV: DL: PER: TE	Performance check of DL Heat Exchanger	S3-MV		source	NA	NA	PER	Monitor				30	12	±5	0.8	link
ST	gsm047.dia	Inline monitoring	Do PP/ MP Seed Lasers Power drop diagnosis (HPSM)	S3-MV		source	NA	H2	PER	Monitor	KPI	TPMS/ D	FWD PEM energy	30	12	±1	0.3	link
ST	gsm032.ins	PM MV: ST: UPT: CE	➢ Replace MP and PP Seed Laser (LARS)	S3-MV		source	NA	Standby	UPT	CBM				NA	0.4		42.5	link
FT	ect123.adj	GEAR: PM MV: FT: S	H2 Safety Maintenance for SRC and SCN	MV/ 3400C/3600D		SRC/SCN	N2	Ar	SAF	TBM				365	1	±60	15.2	link
TM	gtm074.rep	GEAR: PM: TM: UPT	Replace Tin Catch Drain Assembly (TCDA) O-Rings	S3-MV		source	NA	Service	UPT	TBM				91	4	±14	12.2	link
VS	gvs081.per	Inline monitoring	Check HP-RGA MK2 performance	S3-MV		source	NA	NA	PER	Monitor	KPI	SDT		91	4	±14	0.5	NA
CT	ect123.adj	PM: CT: SAF: TBM_1	Calibrate H2 LEL sensor in GFU	3400C/3600D		scanner	N2	Ar	SAF	CBM	Eventl	W2IN	CT-A004	183	2	±30	10.2	link
WS	ews130.per	[ARE:3400C/ GEAR:3	Inspect Cable Slab wheel mount assy	3400C/3600D		scanner	service	NA	UPT	TBM				90	4	±14	7.9	
DL	gdl056.cal	GEAR: PM MV: DL: F	Calibrate PA PEMs + Power Meters	S3-MV	**A: HPAC mk≥ 2.0**	source	NA	Standby	PER	TBM				**365**	**1**		6.9	link
DL	gdl144.per	GEAR: PM: DL: PER	Check turbine rundown performance	S3-MV	DL sw < 3.6.1	source	NA	Standby	PER	TBM				91	4	±10	3.3	link
DL	gdl144.per	GEAR: PM: DL: PER	Check turbine rundown performance	S3-MV	DL sw ≥ 3.6.1	source	NA	Standby	PER	TBM				182	2	±10	3.3	link
EL	gel289.per	GEAR: SRC: Test Se	Test Service Outlet RCD of PDU	S3-MV		source	NA	NA	SAF	TBM				183	2	±30	0.1	link
DL	gdl355.rep	GEAR: SRC: Replace	Replace CDA filter for BILZ damper	S3-MV		source	NA	Standby	PER	TBM				365	1	±60	3.3	link

Why does ASML need good Diagnostics?

If our machine breaks down…

- How bad is that?
- What happens?
- How long could it take to fix it?

Impact of unscheduled down

What happens when an NXT1970 is down for 24hrs?

Photolithography

24Hrs Unscheduled down

High end NXT1970Ci

	D20	D18
OVL Margin	SMO	SMO
SMO step (Total ArFi)	**92%**	**100%**
Machine Fingerprint (Lens, Grid, Matching, etc)		

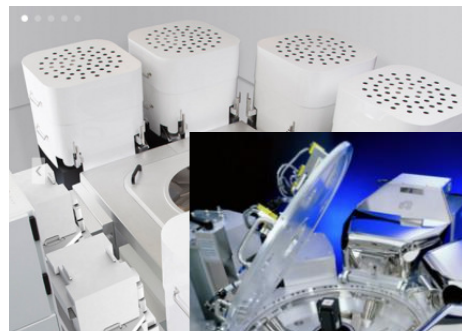
2,000 Wafers stand by to be exposed

- Thousand of wafers should wait in front of the machine ~ 2,000WFs/day
- The wafers **cannot go to other scanner** because of SMO

Other processes

Waiting for wafers to be exposed.

Etch



CVD

And others…

It costs > **1 M€** for an unscheduled down of NXT1970 for **24hrs** because product overlay requires critical dedicated machine overlay.

Downtime needs to be prevented

The future → Smart diagnostics or predictive maintenance

Lithography system is the bottleneck and most expensive system in fab

With a price of many millions for a NXE3600D (NXE Average Selling Price is 160-165mEuro), every hr of downtime comes with even higher cost………

Next generation machines are even double that price.

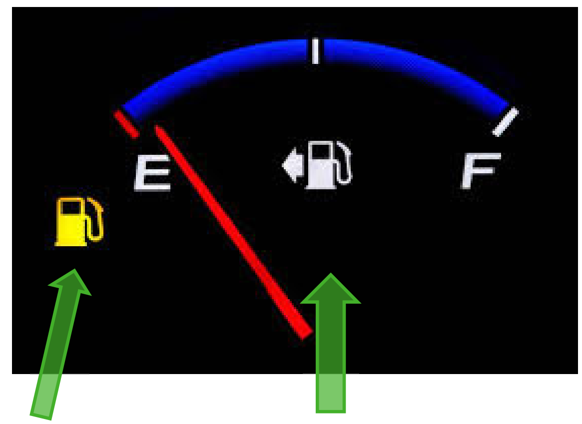
Today maintenance is typically very reactive.

ASML wants to make the transition from periodic maintenance to predictive or even preventive maintenance.

In order to achieve this, we need advanced diagnostics.

TPMS Dashboard for Health Monitoring (USD2SD)

From USD to SD



Reactive diagnostics (SDT)

Proactive / Predictive diagnostics (TPMS)

TPMS: TWINSCAN Parameter Monitoring System

SDT: System Diagnostic Tool

USD: Unscheduled Down

SD: Scheduled Down

Lithography systems are challenging to diagnose

- ASML system diagnostics mainly rely on data and physics-based models

- However, modeling is challenged by growing system complexity:
  - High-dimensionality
  - Nonlinear phenomena
  - Non-stationary processes
  - Non-observables

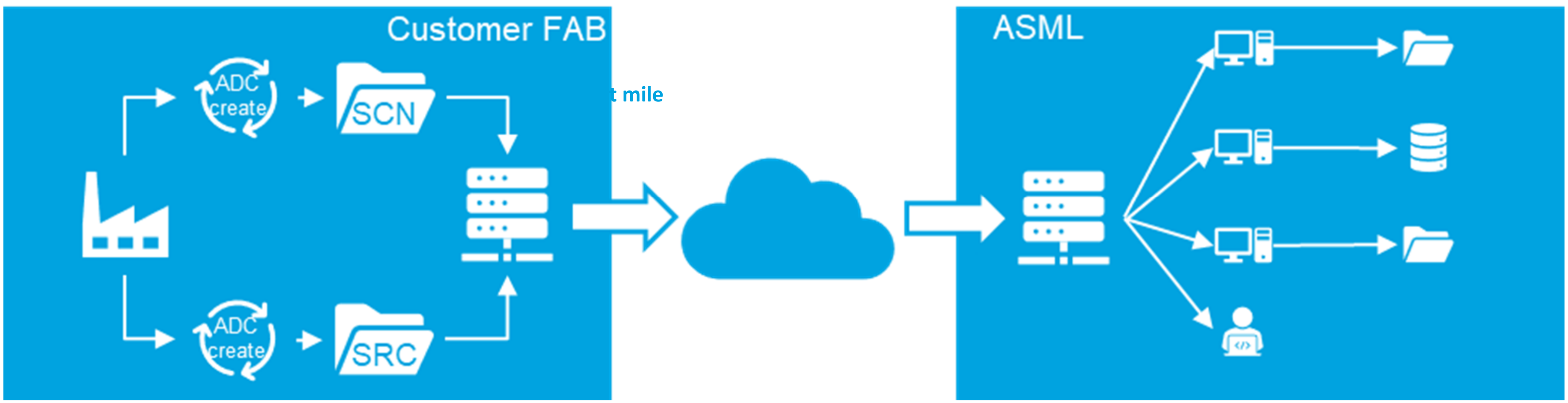
Lithography systems for production of integrated circuits

- Optics, vacuum technology, plasma physics
- Nanometer and milliKelvin accuracy
- Thousands of sensors for measurement / control
- sampling rates from microseconds to days

Machine data pipeline – high level

The as-is (todays) pipeline from Customer Fab to ASML on-premise

Data is crucial to do the correct diagnostics. How to get this complex, large volume data?



Available data

- Main data sources:
  - Event logs, board dumps, signal tracing, test reports
  - Performance data (throughput, latency, queue sizes)
- Data volume
  - For high-end systems (1 Gb/wafer, 200+ wafers/hour)
  - Number of parameters (~10e5)
- Processing all this data is a challenge
  - Wide range of sampling rates, 50 Khz vs. 1 or 2 / day
  - Poor data quality (missing data, outliers, noise)

Data-driven approach

- Main focus
  - Unknown and rare system failures (the hard cases)
  - System performance degradation
  - Root cause indication as fast as possible

- Information-theory based approach:
  - does not require predefined models
  - enables causal graph inference from data, including non-obvious links
  - allows the use of graph-based measures (e. g. spectral centrality)

Applying Causal Analytics for ASML Diagnostics

Research done at ASML on this topic

Basics of Transfer Entropy (TE)

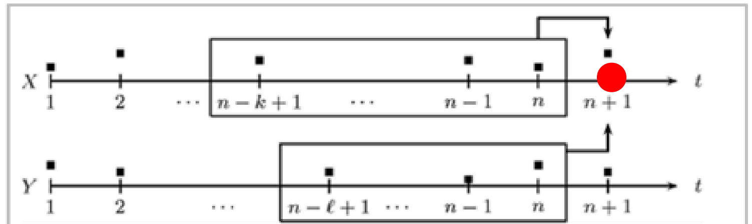
A statistical method to determine ‘causality’

TE estimates causality by measuring *information transfer* between time series X and Y:

1. Predict future (●) of X, given history of X itself

2. Predict future (●) of X, given history of X and Y

3. IF using history of Y results in better prediction y is said to be causal to X



$$TE_{Y\rightarrow X} = \sum_{x,y} p(x_{n+1}, x_n^{(k)}, y_n^{(l)}) \log_b \frac{p(x_{n+1}|x_n^{(k)}, y_n^{(l)})}{p(x_{n+1}|x_n^{(k)})}$$

$$TE_{X\rightarrow Y} = \sum_{x,y} p(y_{n+1}, x_n^{(k)}, y_n^{(l)}) \log_b \frac{p(y_{n+1}|x_n^{(k)}, y_n^{(l)})}{p(y_{n+1}|y_n^{(l)})}$$

4. Do this for all variable combinations. This will result in a ‘causal graph’

Slide courtesy of Errol Zalmijn (ASML)

Basics of Transfer Entropy (TE)

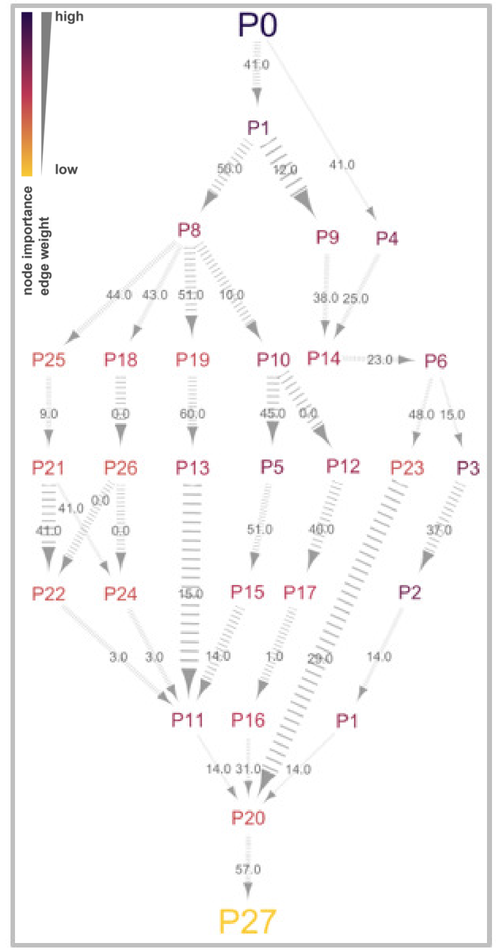
A statistical method to determine ‘causality’

- Data selection: ~ 350 parameters,
  ~ 300 samples each

- 30 minutes of data-processing on laptop

- 1 signal identified as common source

- Domain experts confirmed this to be the correct *root-cause*



Slide courtesy of Errol Zalmijn (ASML)

Questions and observations related to causal analysis

Why not successful so far @ ASML?

- In the field, the field engineer at the system, does not care about the cause, but about what to do to solve *now.*
- Engineers, like all of us, have a particular picture of the world in their mind.
  - If causal relations determined by these statistical methods are non-intuitive, it is difficult to get it accepted.
    Statistics is complex, this is complex statistics, and thus has the nature of a black-box
- Often the pictures are not very clear, with multiple 'loose-ends' as causes.
  - This complicates diagnostics and acceptance.
- Statistics is difficult, causality based on statistics is even more difficult (to grasp)
- Finding solutions for the above is future work….

Explanation of Global Operations Center

Focus on proactive monitoring

Global Operations Center – objectives and benefits

Goal and how to operate

Global Operations Center

Improve the level of service to our customer by:

- Creating transparency in escalation.
- Build pro-active mindset and processes, increasing the service scope.
- Pro-active support to prevent unnecessary delays

3 workstreams

Escalation management

Objective: Create insight in escalation status Worldwide
Assign resources based on this status
Report out to management
Improve quality of action plans and take into account the availability of parts/tools

Pro-active Monitoring

Objective: Learn to predict machine behavior pushing service from USD to SD
How: Phase 1: 1: From USD/Critical performance issues use case, identify fingerprint, to dashboards (IB monitoring, preventive plan, repair plan)
2: Create dashboards to monitor for critical parts failure, work with CSCM on top x
3: Work with ZEISS on critical optics monitoring
Phase 2: Make roadmap for future machine behavior understanding

Pro-active Support

Objectives: 1) Reduce NPI dip, 2) prevent unnecessary service delays and escalations
How: 1) Prevent downtime, rapid recovery, fast track issue resolution
2) Remote support for complex service actions, GOC available for SMIX questions, manage top-5 service mix related questions from field teams

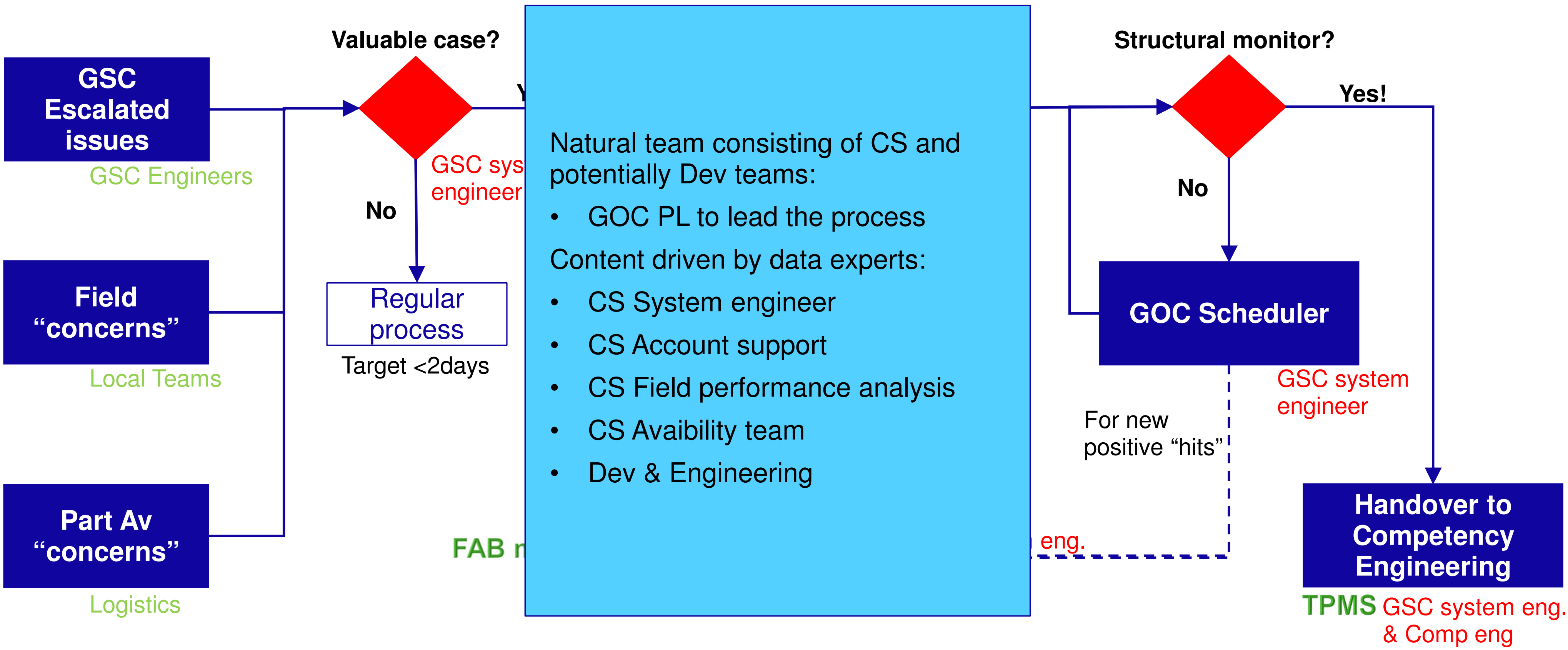
GOC Room
Facilities in place to operate as operations and escalation room

Deliverables: Pro-active monitoring

- 2. Pro-active monitoring
  - 2.1 Deliver structural intake process
    - 2.1.1 Select SO's — GSC SE, PL CI GSC
    - 2.1.2 Review current practice with D&E and SE — PL CI GSC, Intern
    - 2.1.3 Benchmark ASML vs other companies — PL CI GSC, Intern
  - 2.2 Data analysis process
    - 2.2.1 Start data analysis with select SO's — GSC SE, D&E data science, DAV
    - 2.2.2 Review current practice with D&E and SE — GSC SE, D&E data science, DAV
    - 2.2.3 Benchmark ASML vs other companies — PL CI GSC, Intern
  - 2.3 Create dashboarding
    - 2.3.1 Start data analysis with select SO's — GSC SE, D&E data science, DAV
    - 2.3.2 Review current practice with D&E and SE — PL CI GSC, D&E data science
    - 2.3.3 Monitor success rate and feedback to intake + data analysis process — PL CI GSC, D&E data science, GSC SE
  - 2.4 Roadmap of next steps — PL CI GSC

PRO-ACTIVE monitoring – high level process

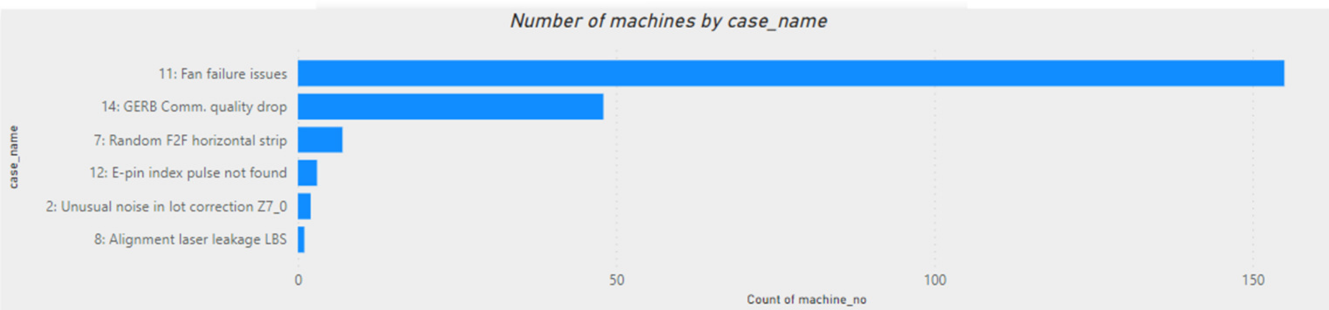
High level process



Weekly monitor (DUV example)

In total 473 systems identified (incl. one-time monitors)

230	17	7	5
Total flagged machines (number of flagged machines to this week)	Ongoing machines (number of machines with ongoing issues)	New flagged machines (number of newly flagged machines this week)	Total cases (number of active cases)



machine_no	status	intro_date	case_name	case_owner	customer	region	location
	New	2302	12: E-pin index pulse not found	Soo-Jin Ha			
	Ongoing	2251	14: GERB Comm. quality drop	Soo-Jin Ha			
	Ongoing	2251	14: GERB Comm. quality drop	Soo-Jin Ha			
	Mitigated	2251	14: GERB Comm. quality drop	Soo-Jin Ha			
	Mitigated	2251	14: GERB Comm. quality drop	Soo-Jin Ha			
	Mitigated	2251	14: GERB Comm. quality drop	Soo-Jin Ha			
	Mitigated	2251	14: GERB Comm. quality drop	Soo-Jin Ha			
	Ongoing	2251	14: GERB Comm. quality drop	Soo-Jin Ha			
	Ongoing	2249	14: GERB Comm. quality drop	Soo-Jin Ha			

It works

Examples from DUV proactive monitoring

In these examples a machine error or lack of calibration resulted in scrap wafers for the customer or unscheduled down of the machine.

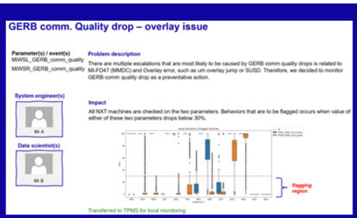
By analyzing the machine behavior and checking the install base, we found other machines showing similar fingerprint.

Triggering the field teams prevented further errors and USD's.

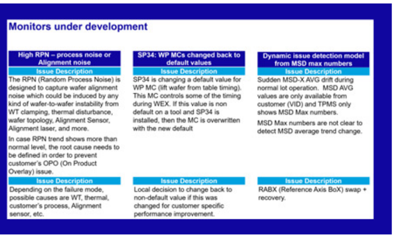
Proactive GOC monitors

9 successful monitors created, 1 model being updated, 3 new models under investigation

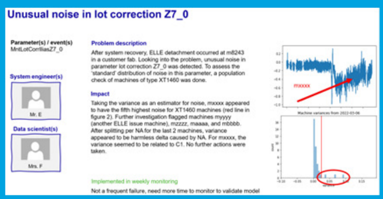
Successfully transferred to TPMS

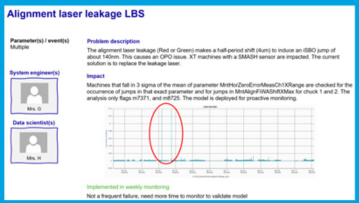


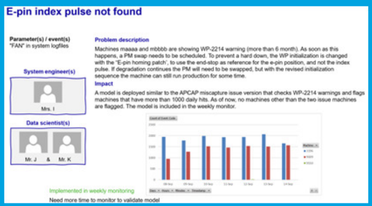
Monitors in WIP

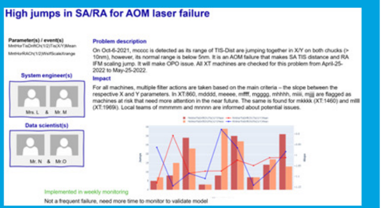


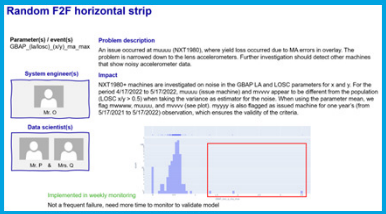
Active monitors



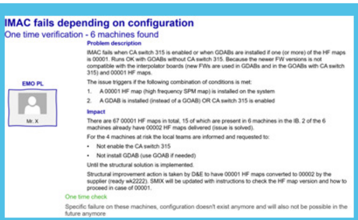


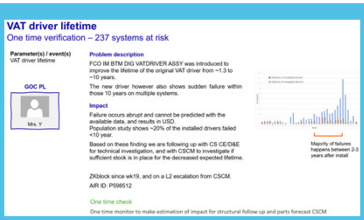


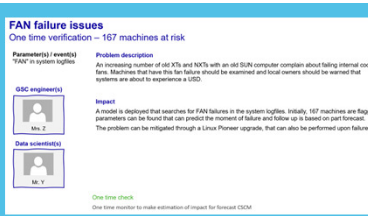




Monitors completed with single verification







Questions