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Challenges and potential of data-driven automation in complex manufacturing systems

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STMicroelectronics

We are creators and makers of technology

- One of the world’s largest semiconductor companies
- 2020 revenues of **$10.2 B**
- **46,000** employees of which **8,100** in R&D
- Over **80** Sales & marketing offices serving over **100,000** customers across the globe
- **11** Manufacturing sites
- Signatory of the United Nations Global Compact (UNGC), Member of the Responsible Business Alliance (RBA)

As of December 31, 2020

Welcome to Industry 4.0

- CROLLES 300mm fab
  - **24/7 – 365 days a year**
  - **100% of process starts**
    on production tools done automatically
  - **100% of transportation** of material to tool done
    by Automated Material Handling System
  - **95% of the dispatching** decisions
    done without human intervention
- Advanced real-time Equipment and Process Control techniques fully deployed

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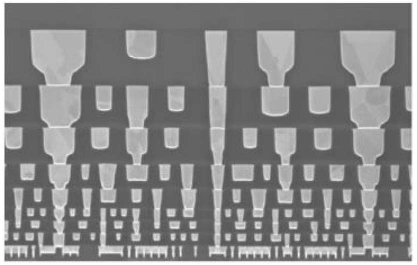
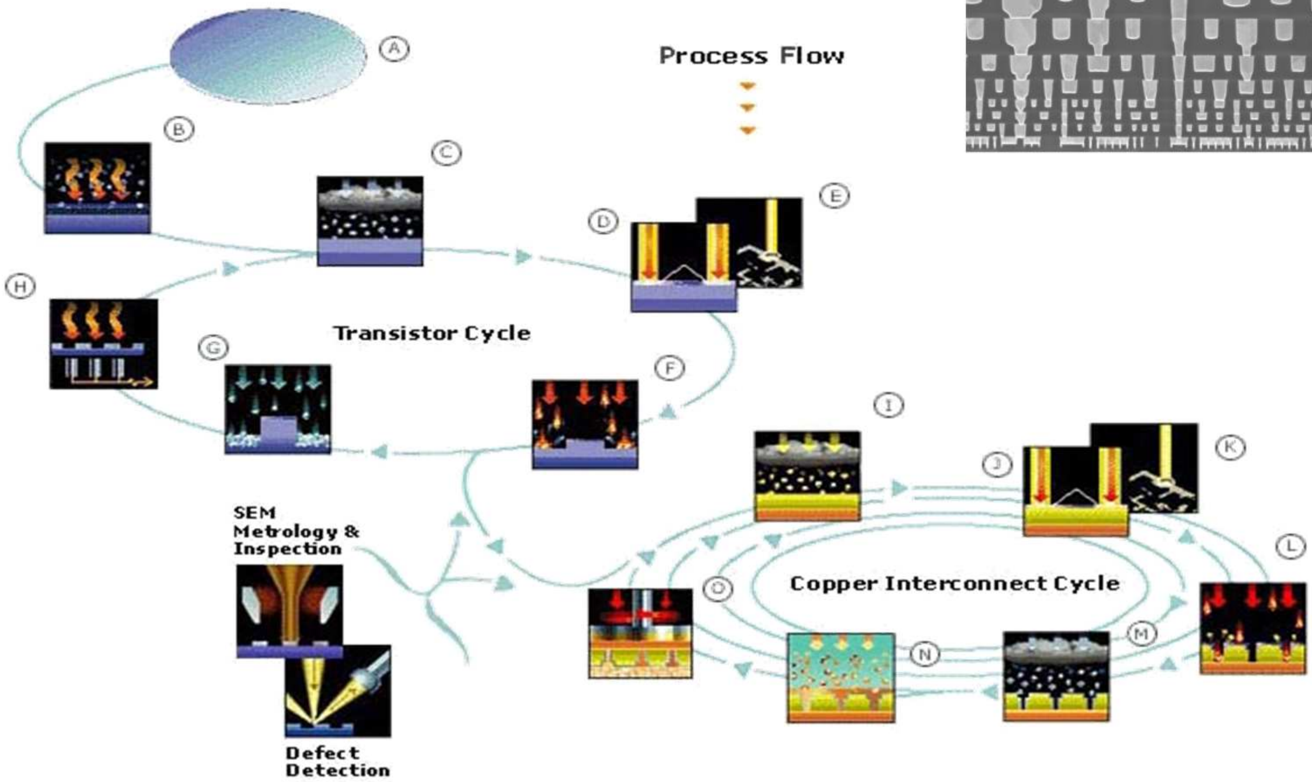
So what? Job done?

A bit of context and history

Reentrant process flows

From 200 to 1400
Individual operations





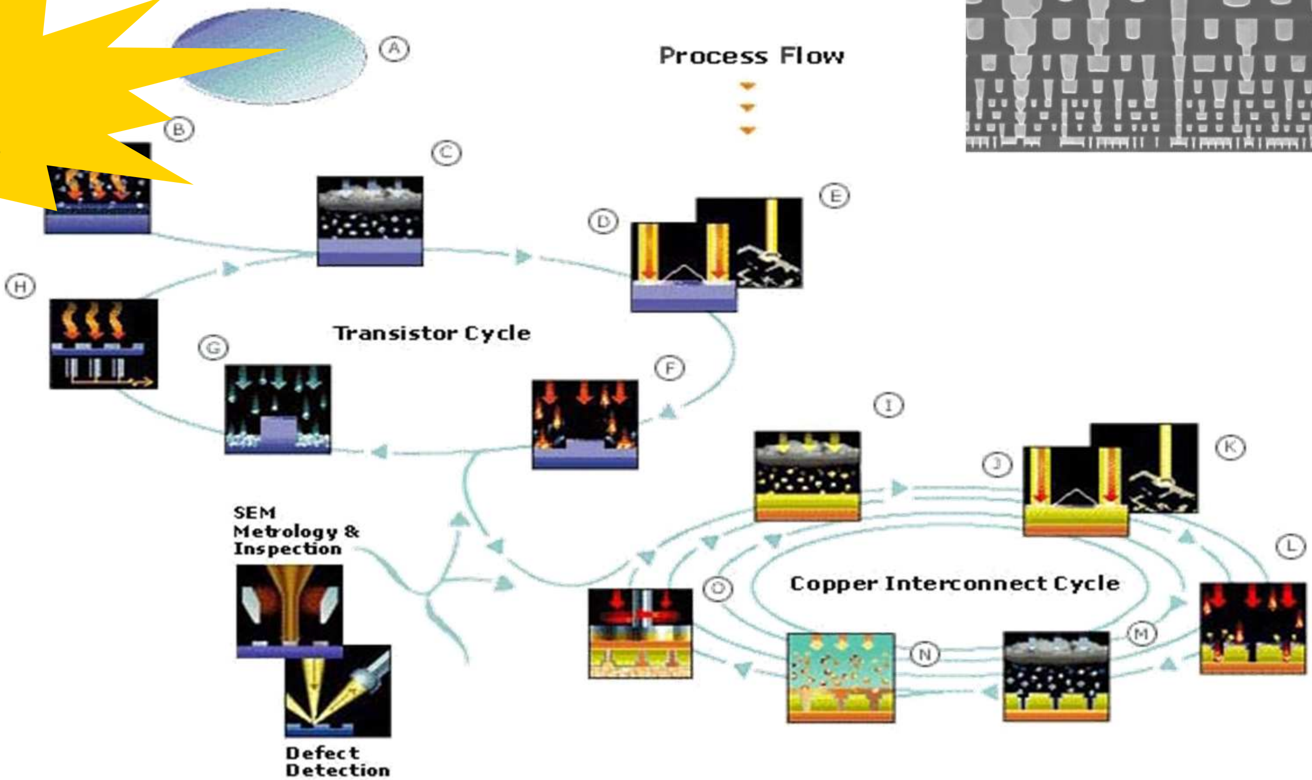
Reentrant process flows

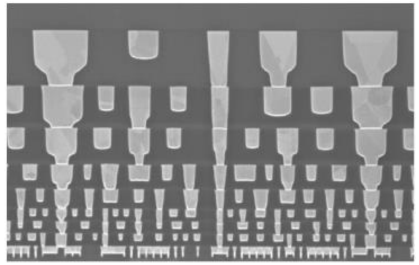
From 200 to 1400
Individual operations

MES

Process
Adjustments

Recipe Qualification





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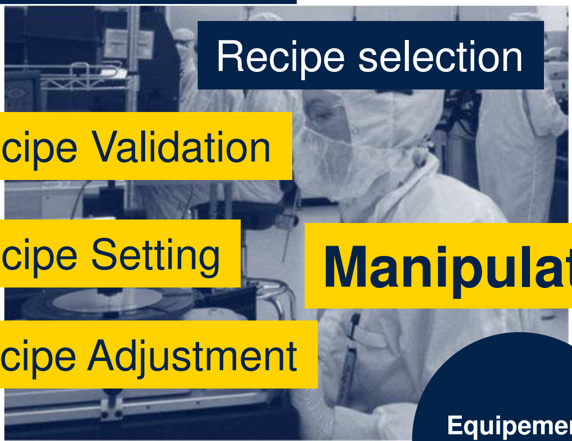
(Tool, Recipe) qualification

From 200 to 1400
Individual operations

MES

Recipe Qualification



Recipe selection

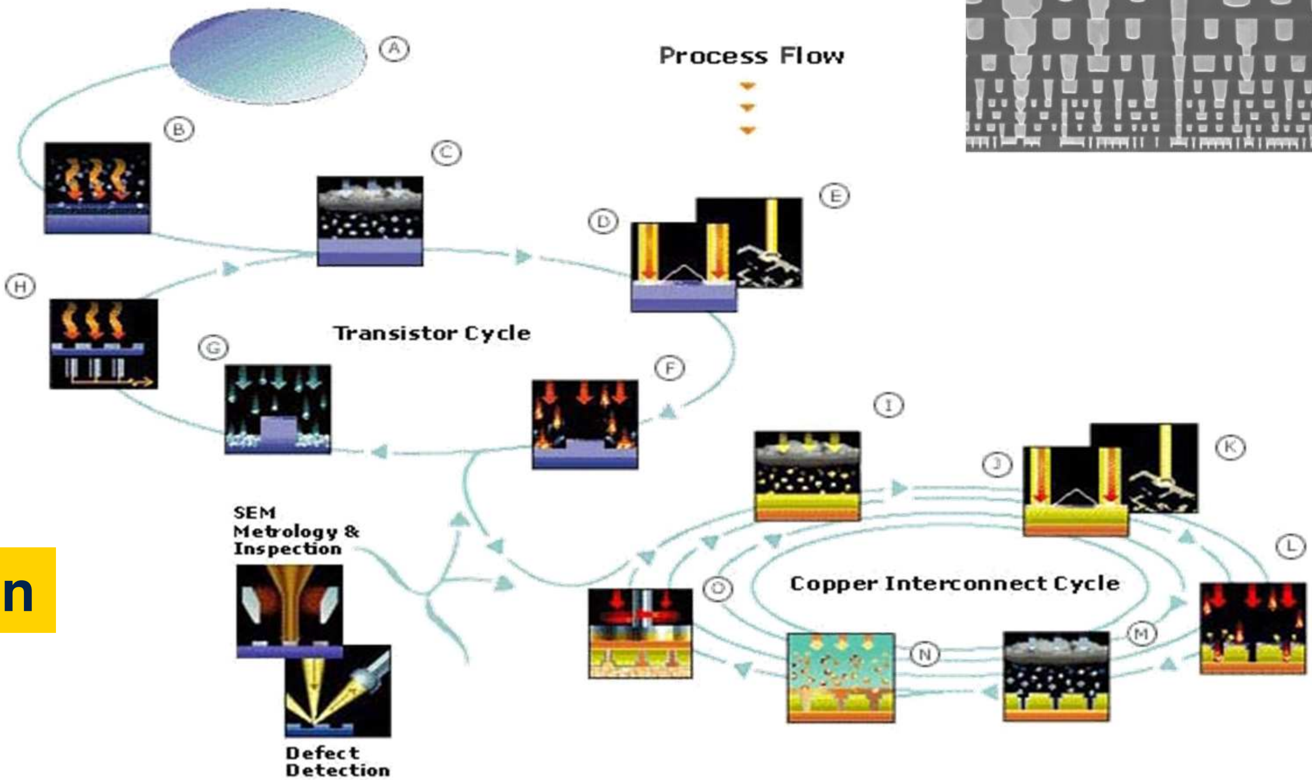
Recipe Validation

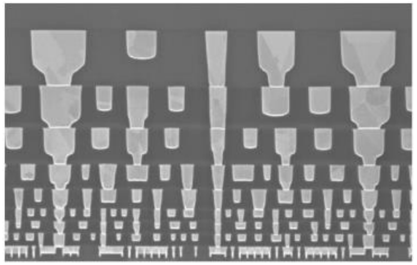
Recipe Setting

Manipulation

Recipe Adjustment

Equipement Automation





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Statistical Process Control

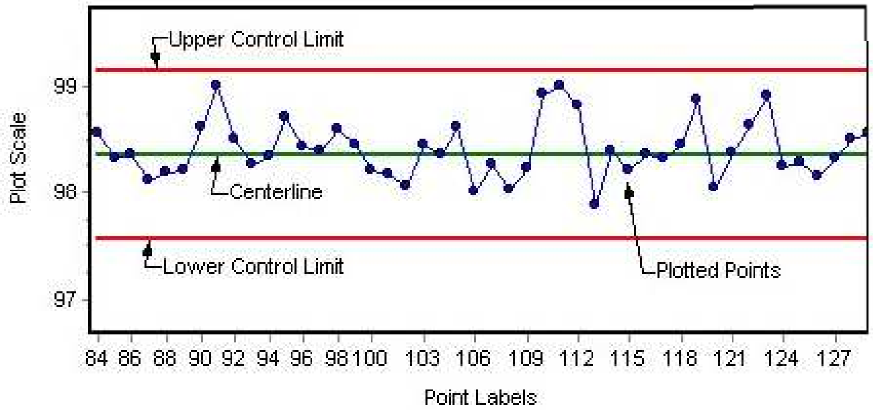
MES

SPC

Manipulation

Automatic Measurement
Recipe Creation

Equipement Automation



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Statistical Process Control

Volume

Data Coll. Errors

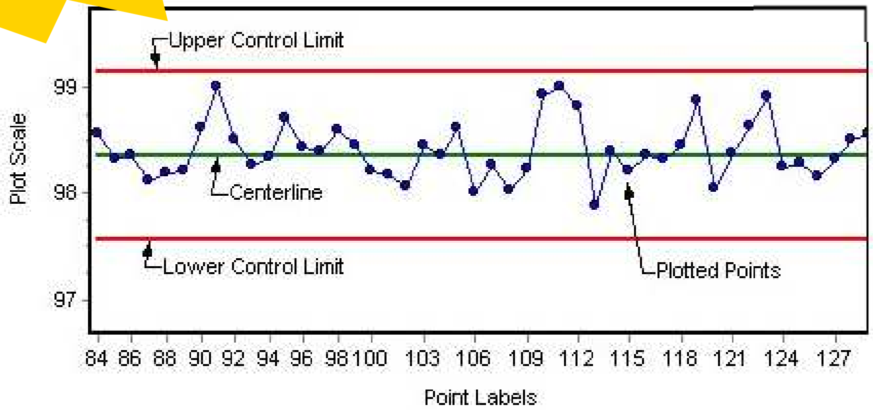
MES

SPC

Manipulation

Automatic Measurement
Recipe Creation

Equipement
Automation



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Statistical Process Control

MES

Automatic Data Collection

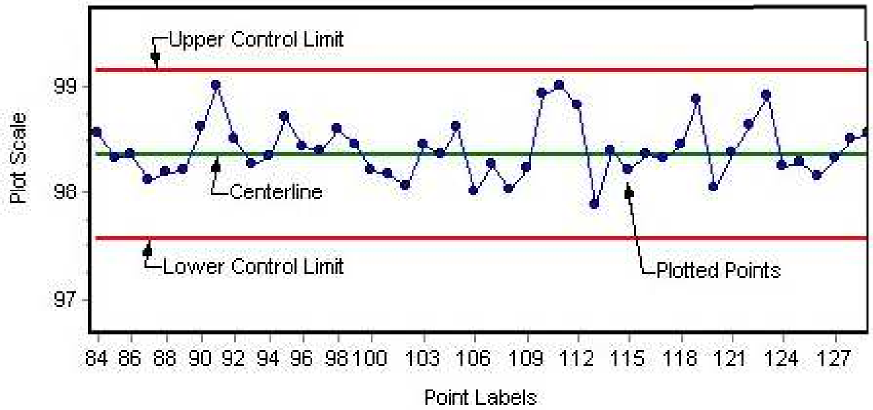
SPC

Automatic
Tool Stoppage

Manipulation

Automatic Measurement
Recipe Creation

Equipement Automation



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Automatic Process Compensation

High Mix
Smaller Geometries

MES

Automatic Data Collection

SPC

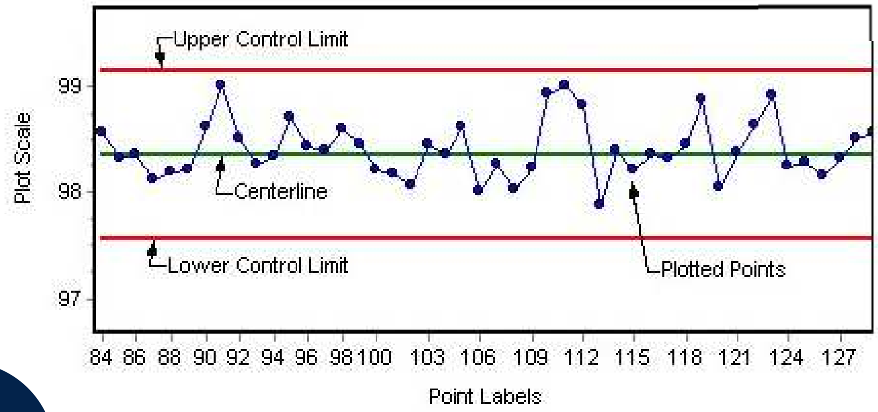
Automatic
Tool Stoppage

Recipe Adjustment

Manipulation

Automatic Measurement
Recipe Creation

Equipement
Automation



R2R

Sensors Integration
FDC

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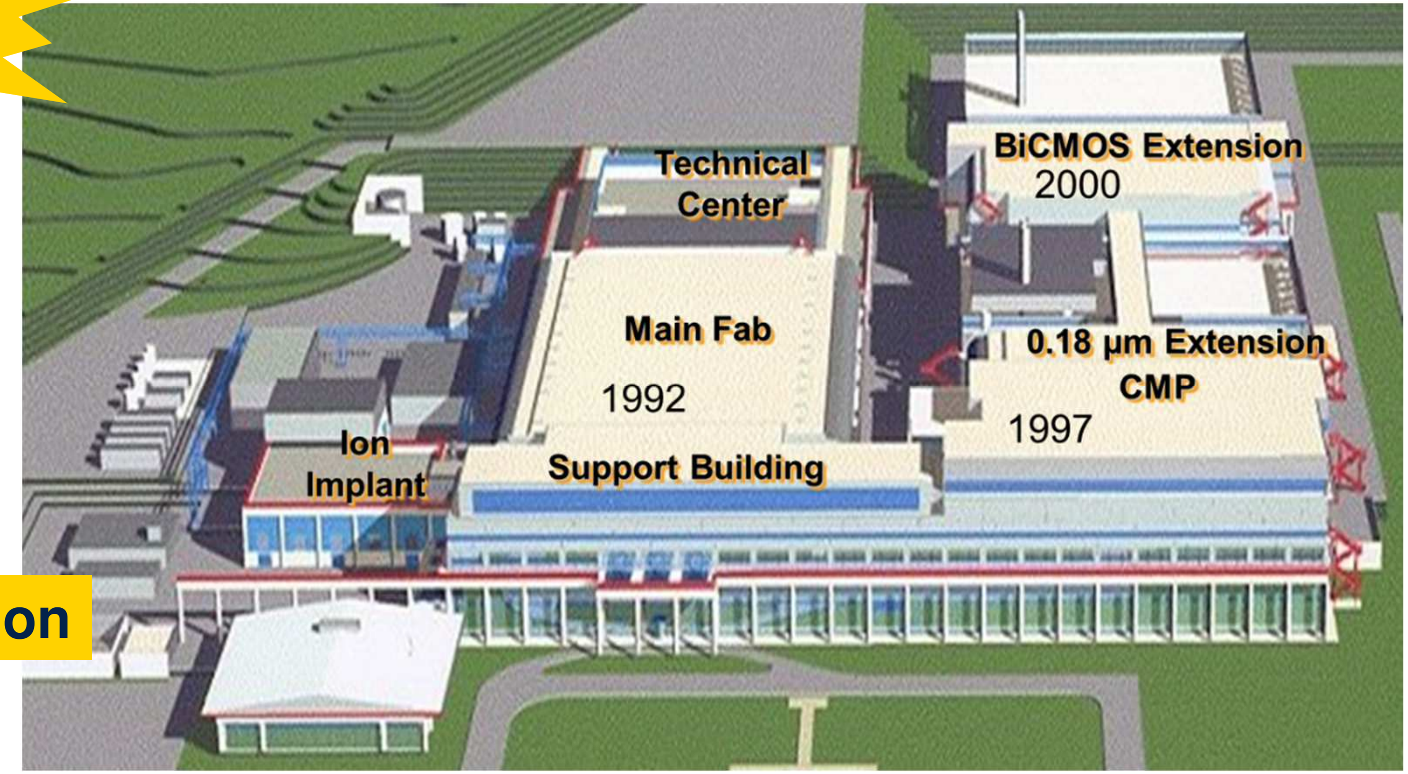
Industry expansion

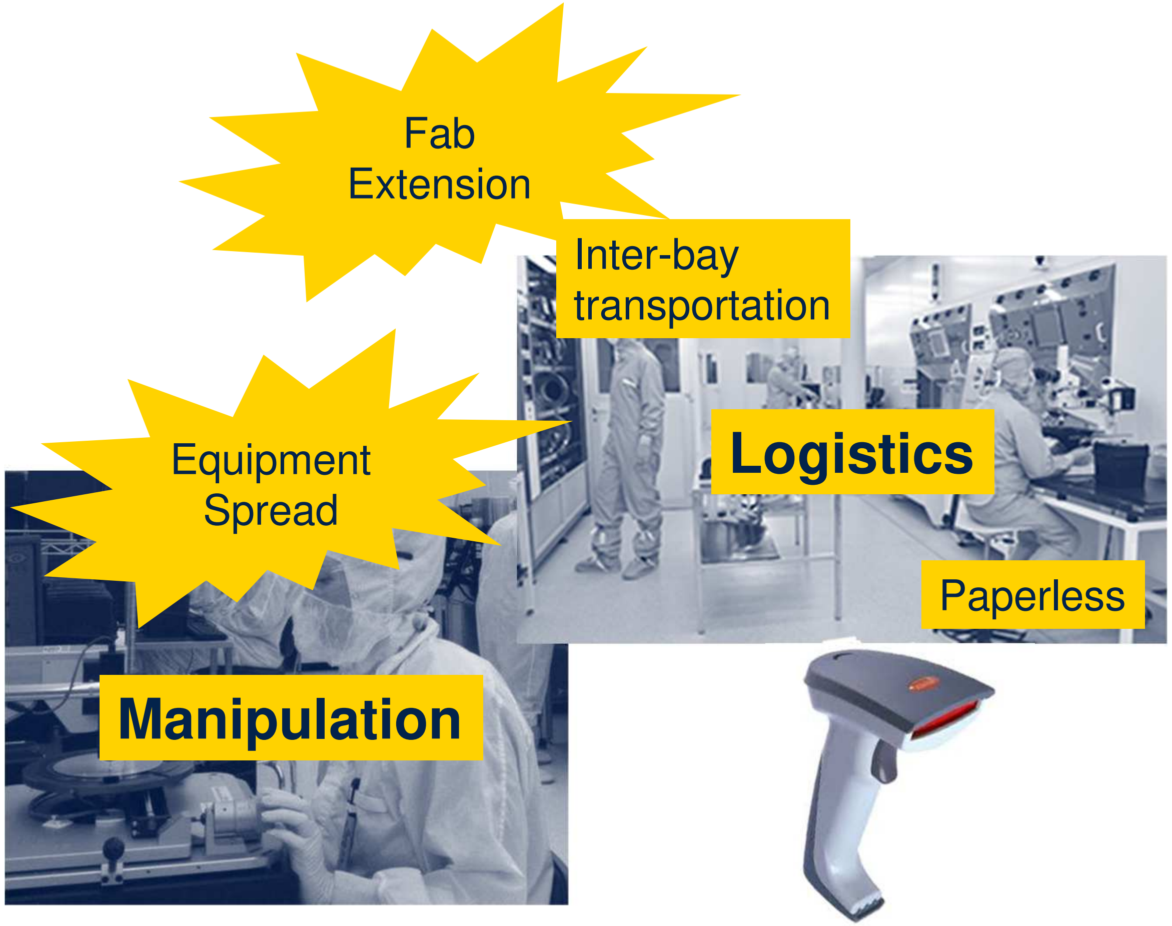
Fab Extension

Equipment Spread

Manipulation



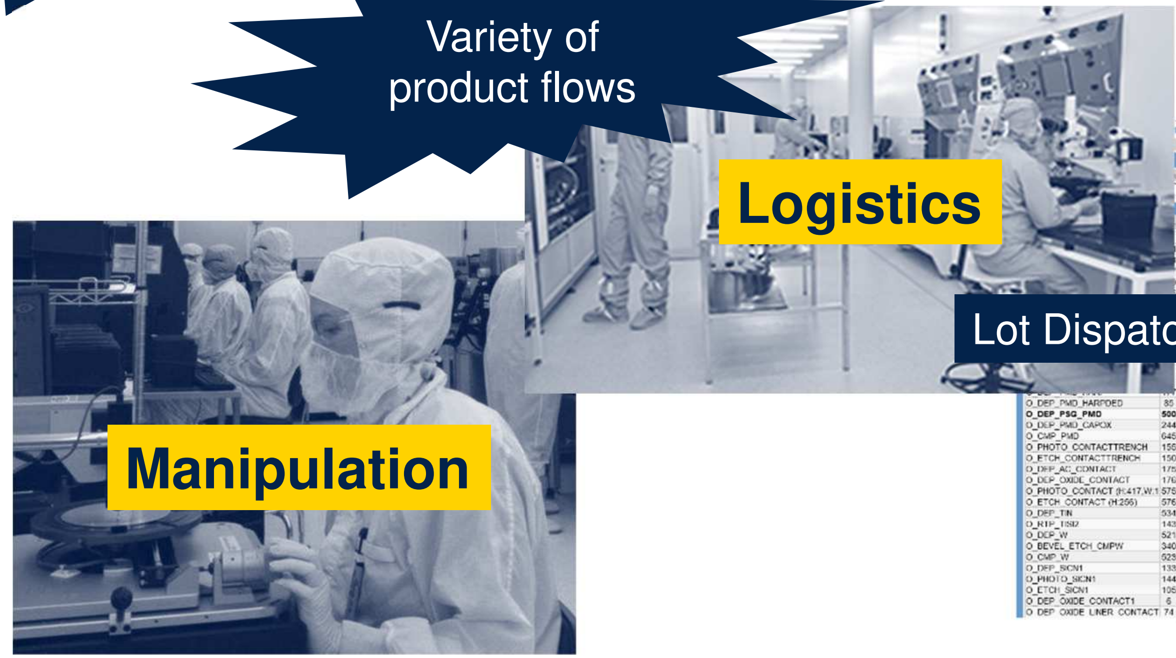
On the road to Industry 4.0



On the road to Industry 4.0

Process Complexity

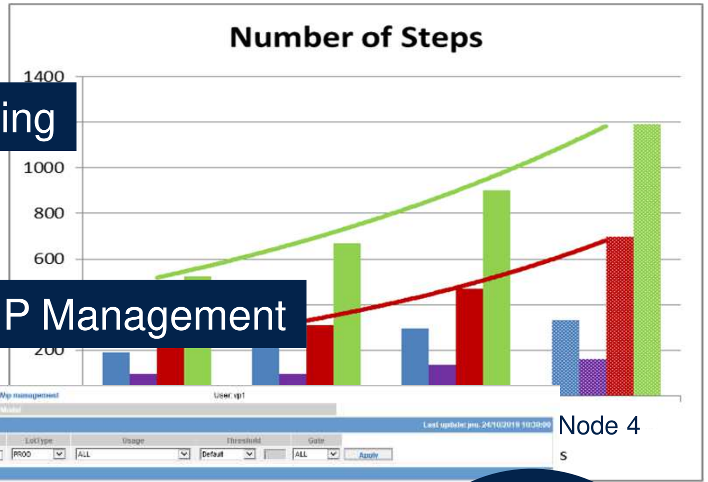
Variety of product flows



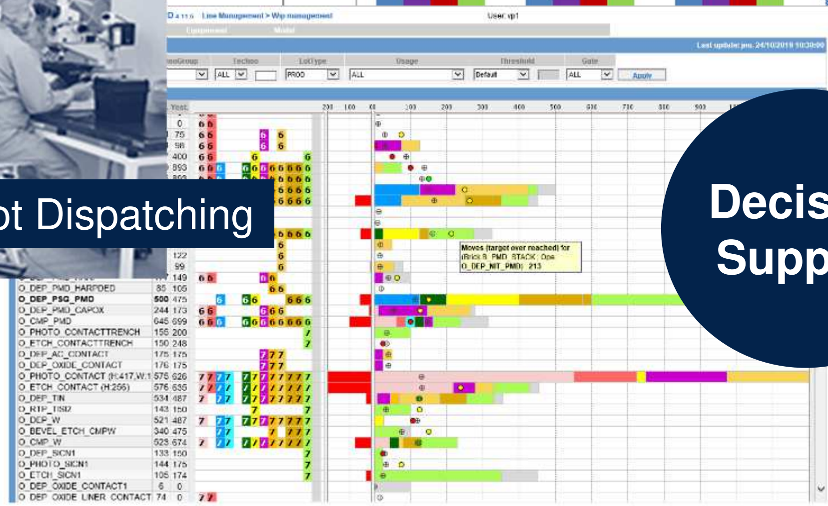
Logistics

Manipulation

WIP Planning



WIP Management

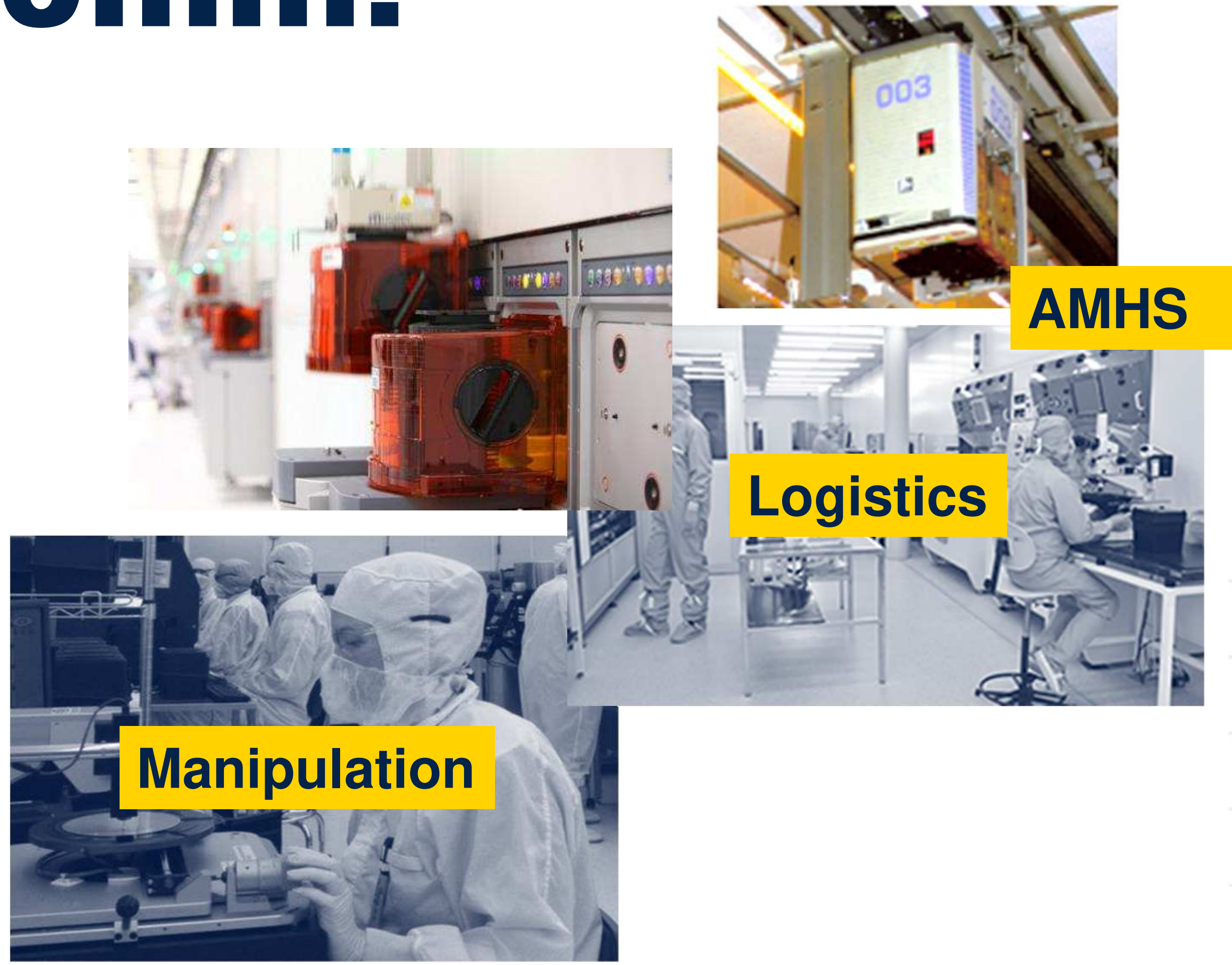


Lot Dispatching

Decision Support

300mm!

On the road to Industry 4.0



Width	**416 mm (16.4")**
Depth	333 mm (13.1")
Height	335 mm (13.2")
Empty	4.2 kg (9.26 lb)
With wafers	7.3 kg (16.09 lb)

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On the road to Industry 4.0

300mm!

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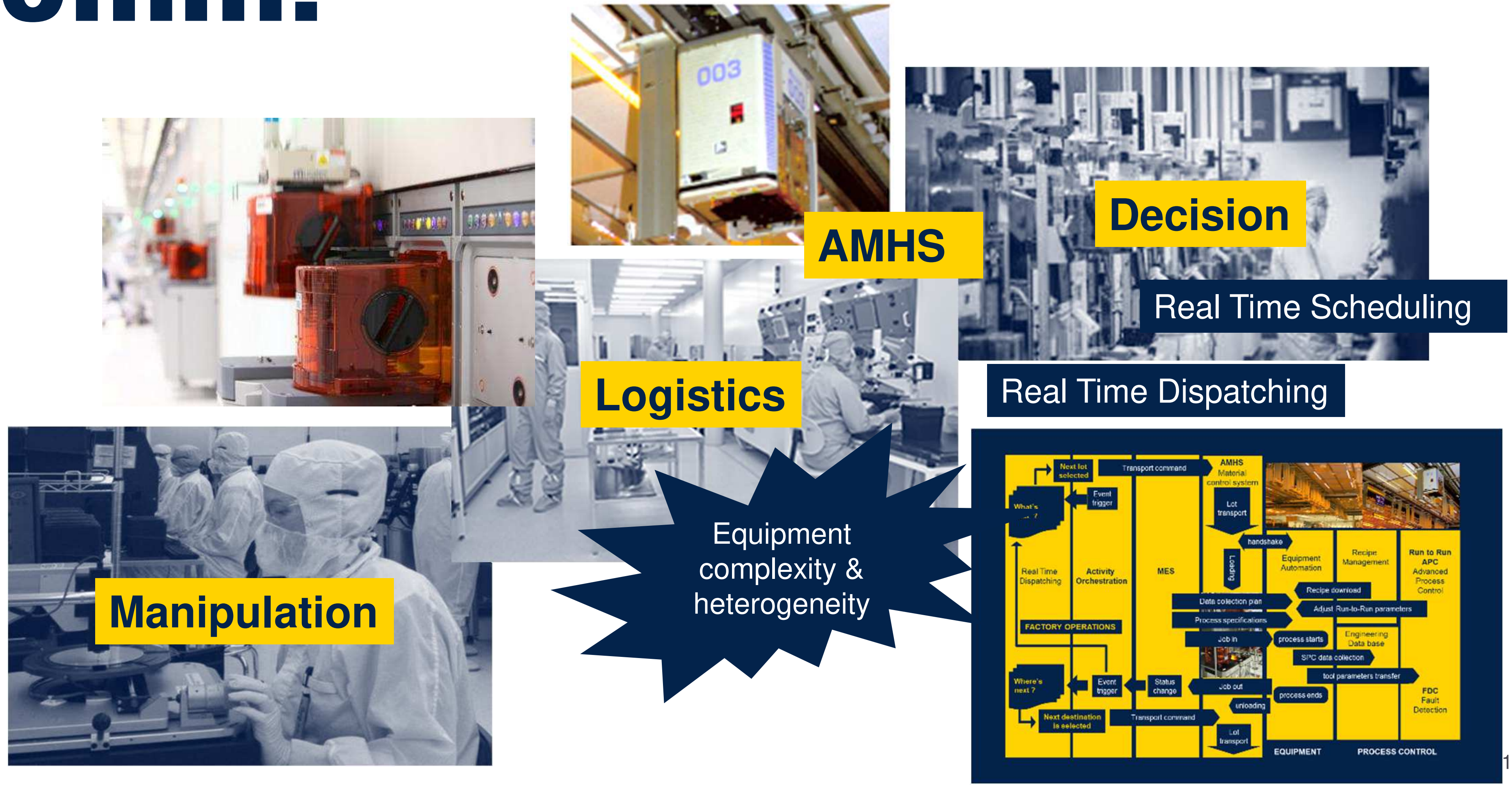
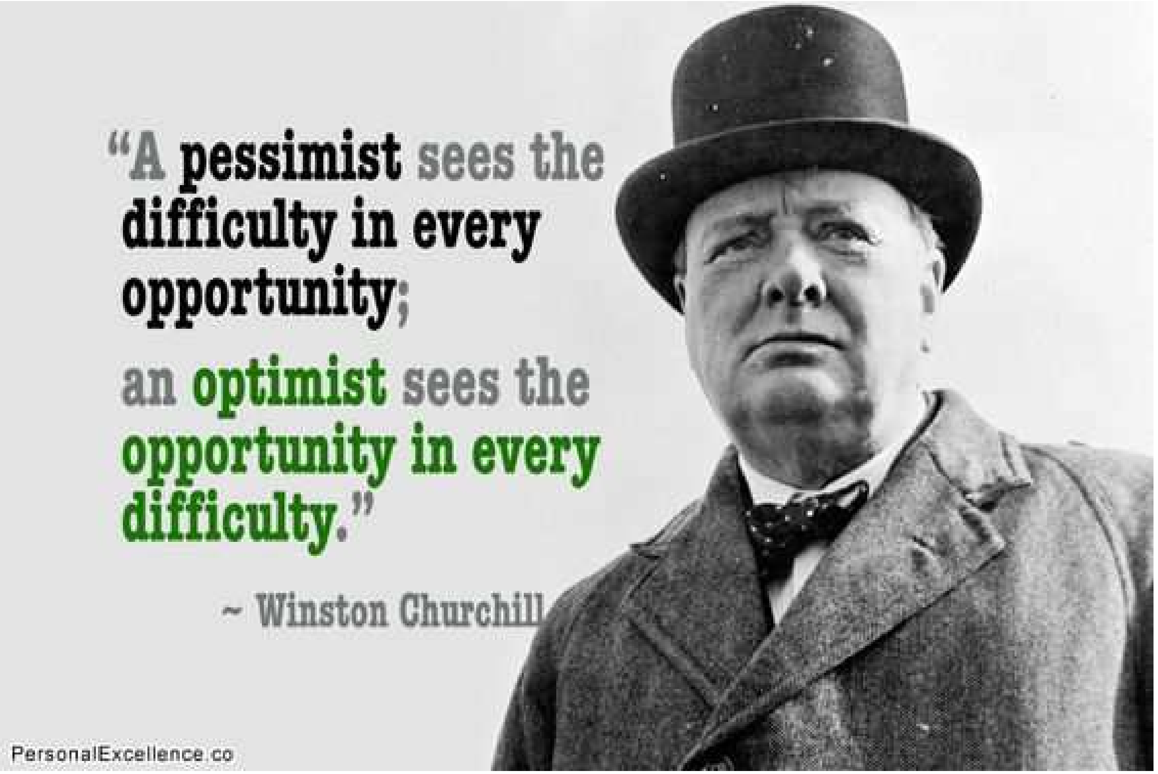
On the road to Industry 4.0

300mm!

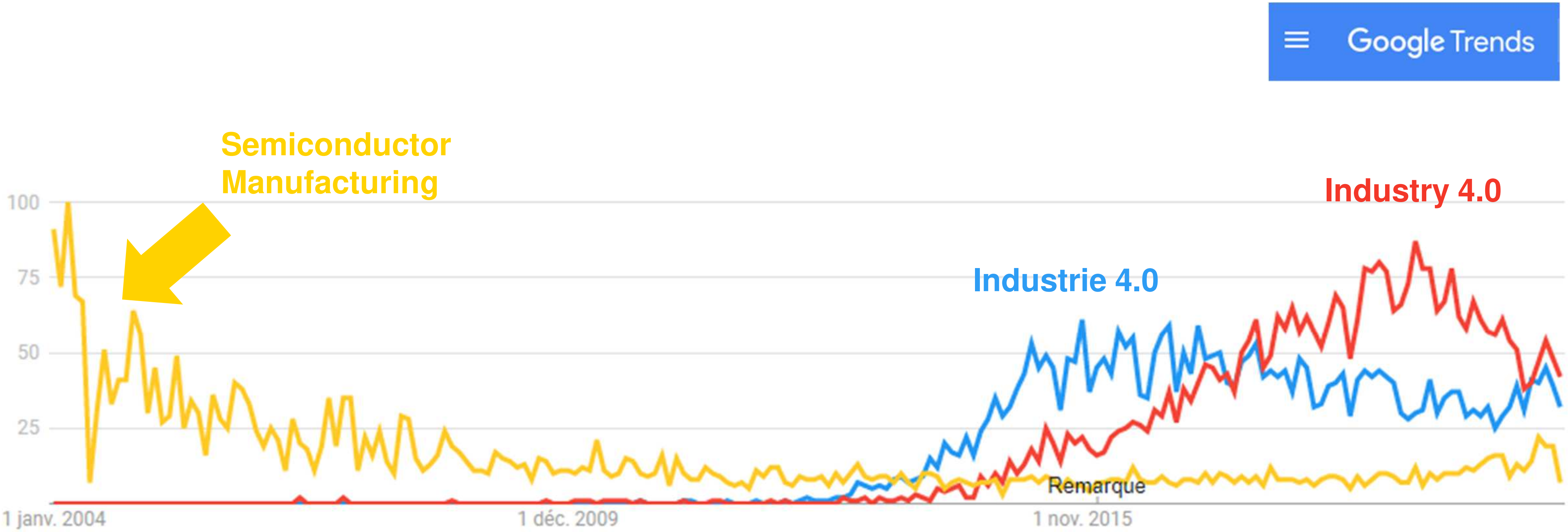


Full Automation didn’t come in one day



- A balance between challenges or threats linked to **business needs / context** and **opportunities** open by solutions to former difficulties
- A progressive understanding between pragmatists and visionaries

SC Manufacturing vs. Industrie/y 4.0
All countries 2004 till today



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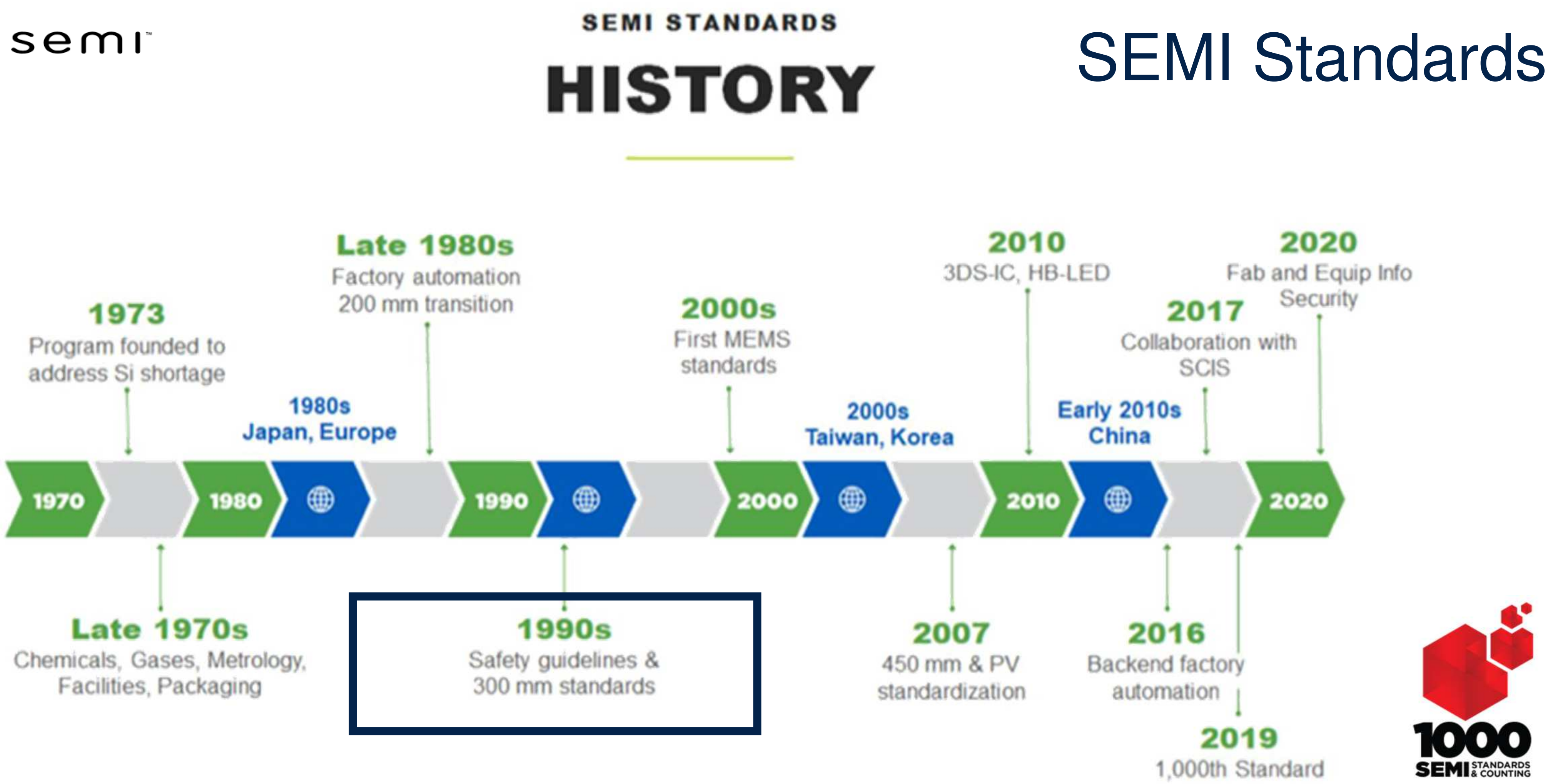
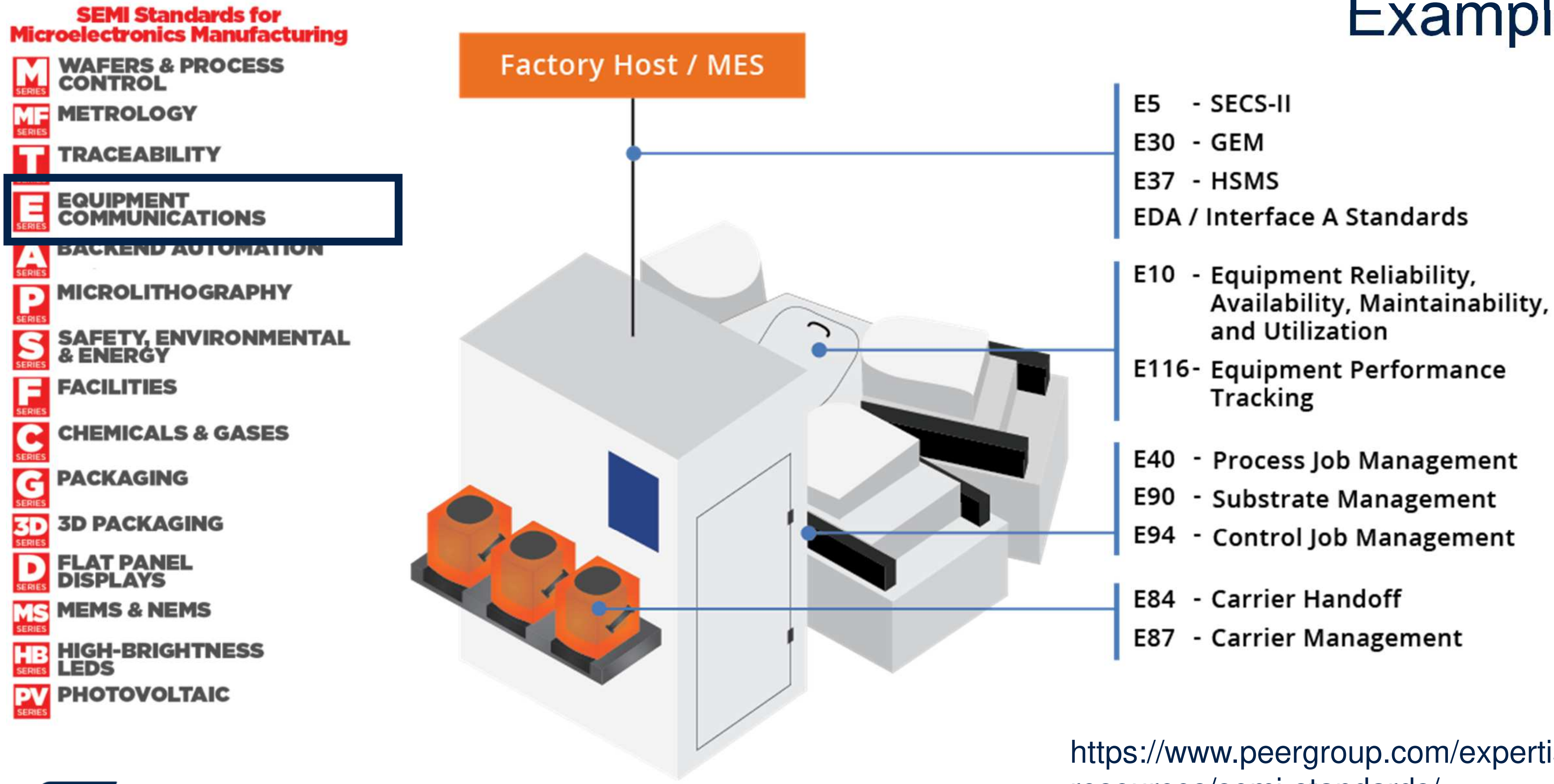
SEMI Standards



https://www.semi.org/en

Example



https://www.peergroup.com/expertise/resources/semi-standards/

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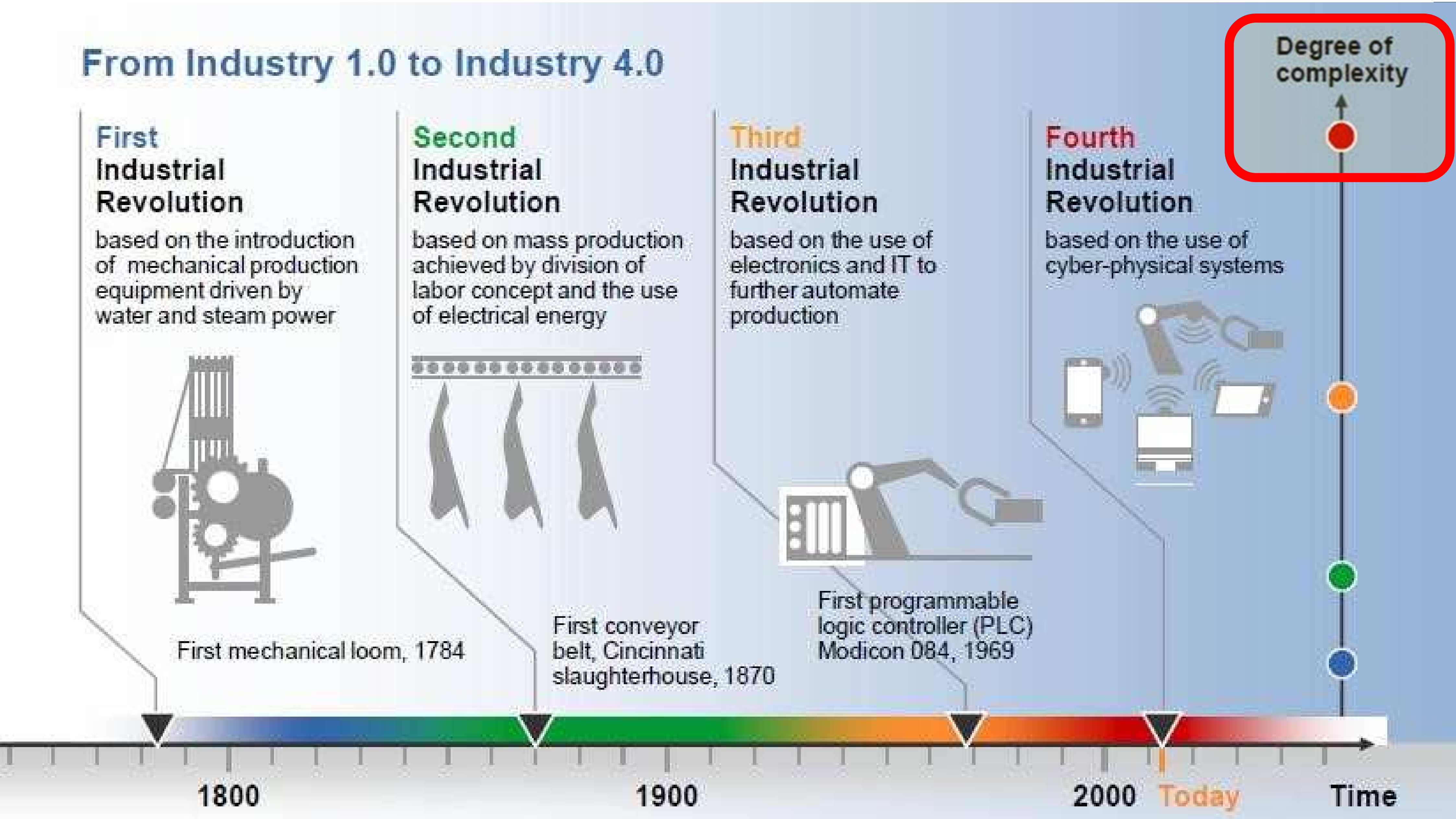
From Industry 1.0 to Industry 4.0
First Industrial Revolution
based on the introduction of mechanical production equipment driven by water and steam power
Second Industrial Revolution
based on mass production achieved by division of labor concept and the use of electrical energy
Third Industrial Revolution
based on the use of electronics and IT to further automate production
Fourth Industrial Revolution
based on the use of cyber-physical systems
Degree of complexity
First mechanical loom, 1784
First conveyor belt, Cincinnati slaughterhouse, 1870
First programmable logic controller (PLC) Modicon 084, 1969
1800
1900
2000
Today
Time

Happy?

- CROLLES 300mm fab is today operated in automatic mode
  - **24/7 – 365 Days a year**
  - **100% of process starts** on production tools done automatically
  - **100% of transportation** of material to tool done by AMHS*.
  - **95% of the dispatching** decisions done without human intervention
- Advanced real-time Equipment and Process Control techniques fully deployed.

YES!

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YES!

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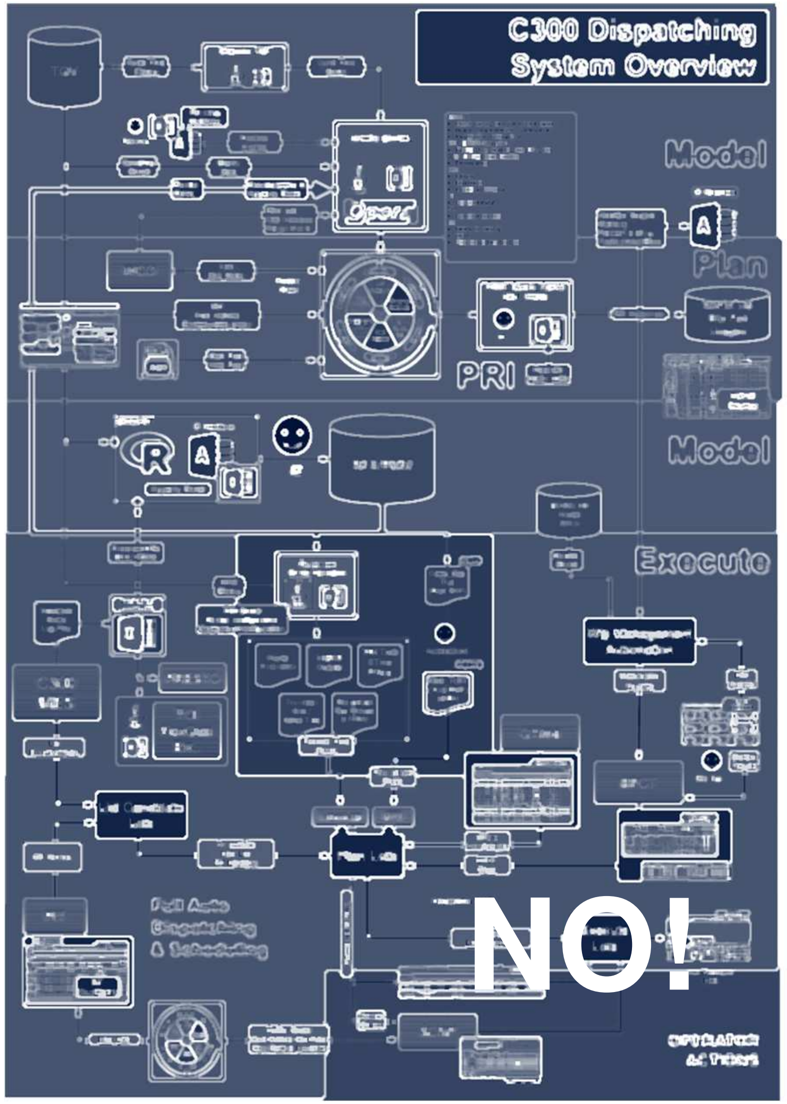

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An ever-broader scale of interaction

2000 — **2020**

A good engineer can analyze and understand almost everything

Several specialists are required to come to the same result

Depth of knowledge + **Breadth of knowledge**

Physics
and physical

Still Physics
But cyber-physical

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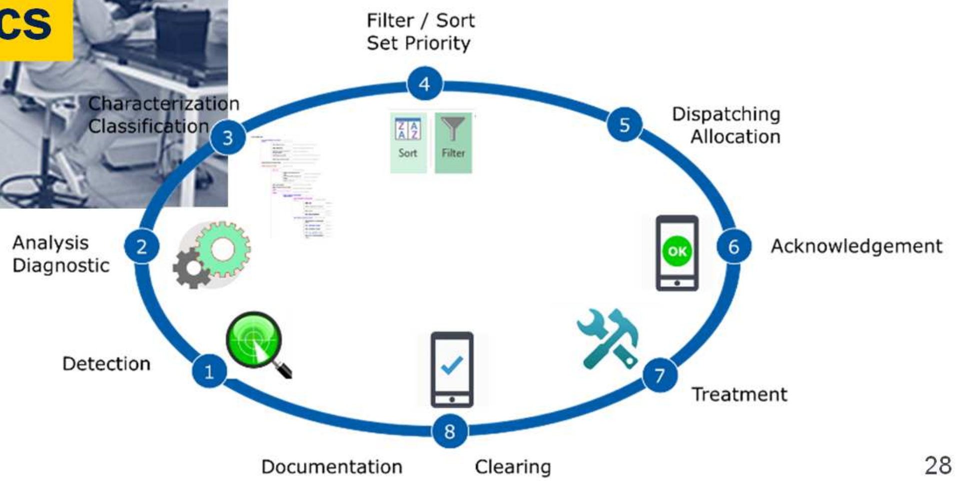
Detection, diagnostic and prescription



Replacing the “human glue”

Operator

drives the machines and moves the products

is physically present on the production floor

uses his five senses to continuously analyze the situation

Indoor patrols, real-time detection of problems in the field and almost instant diagnosis

Technician

Technical field expert

Maintenance & Process diagnostic

Resolving issues on his perimeter

Workstation, Static personnel

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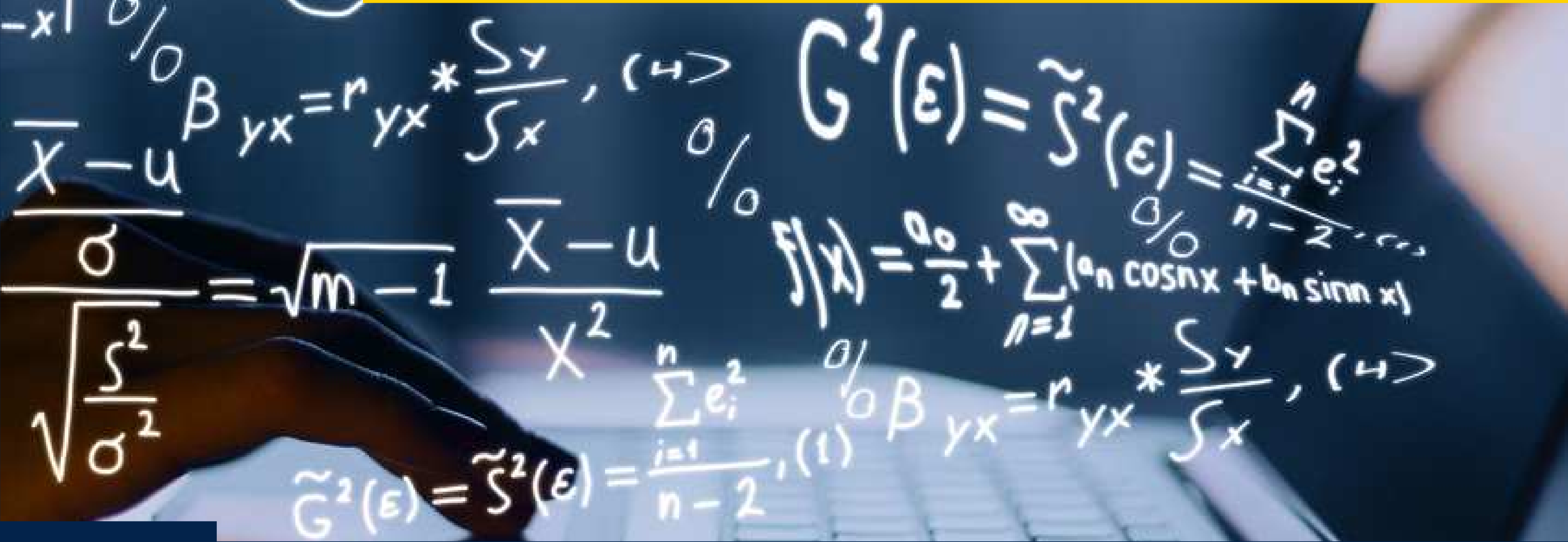
Potentials of data-driven automation



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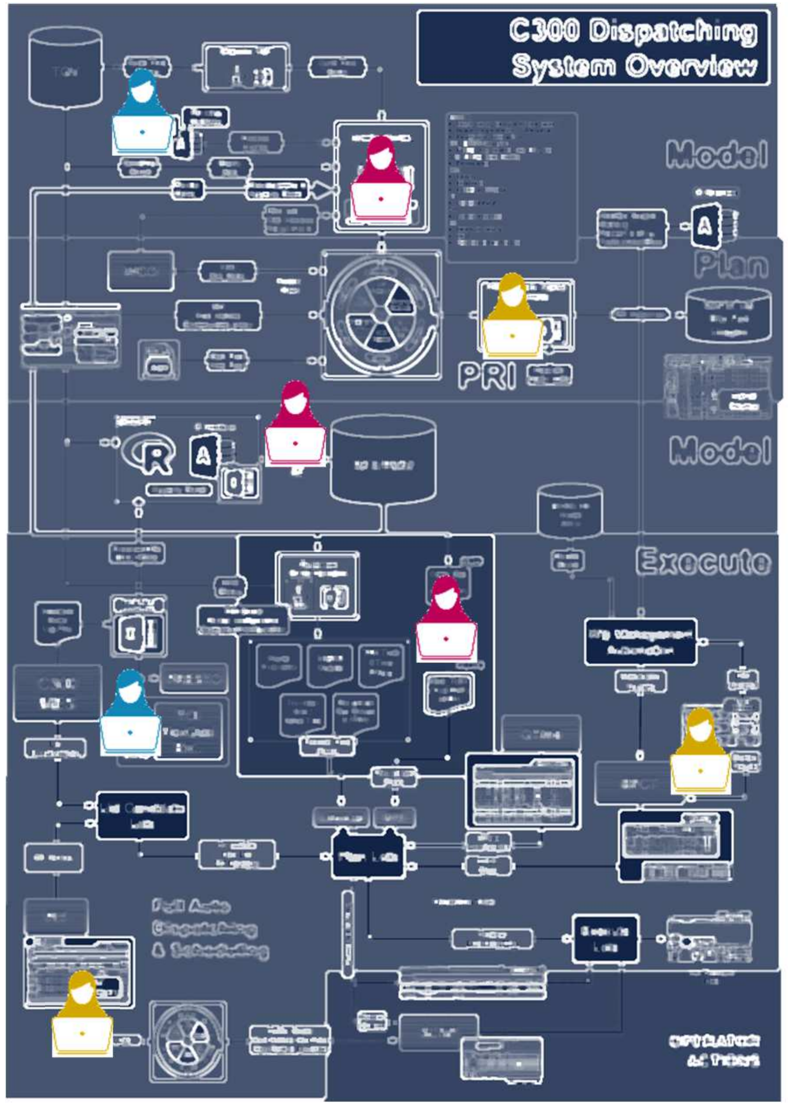
A very complex system

- **Manual** configuration & maintenance
- Complexity & criticality require **expert / trained resources**



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The AMHS example

- System configuration:
  - Number of vehicles per zone
  - Default storage scenario by tool
  - Storage bins grouping and allocation
- **Operational Research** to optimize system configuration
- **Digital Twin** to simulate the system and validate proposed solution but…
- **Manual** configuration because of legacy UI

RPA could help there!

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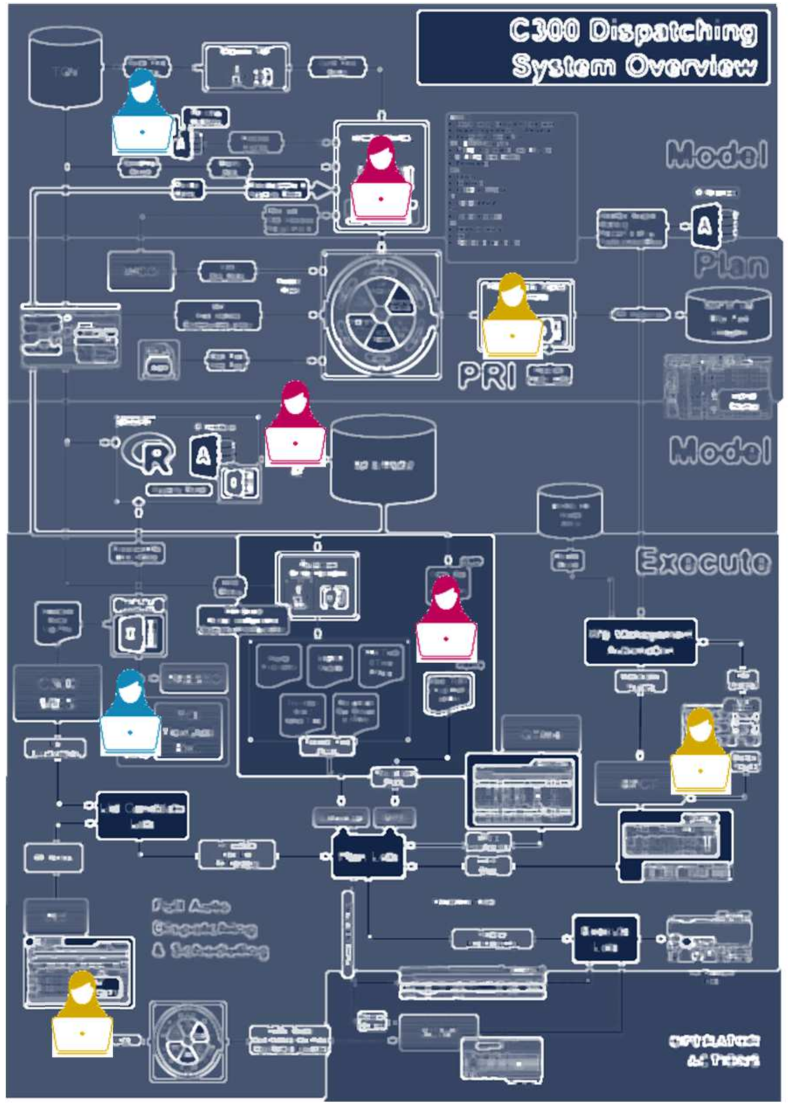
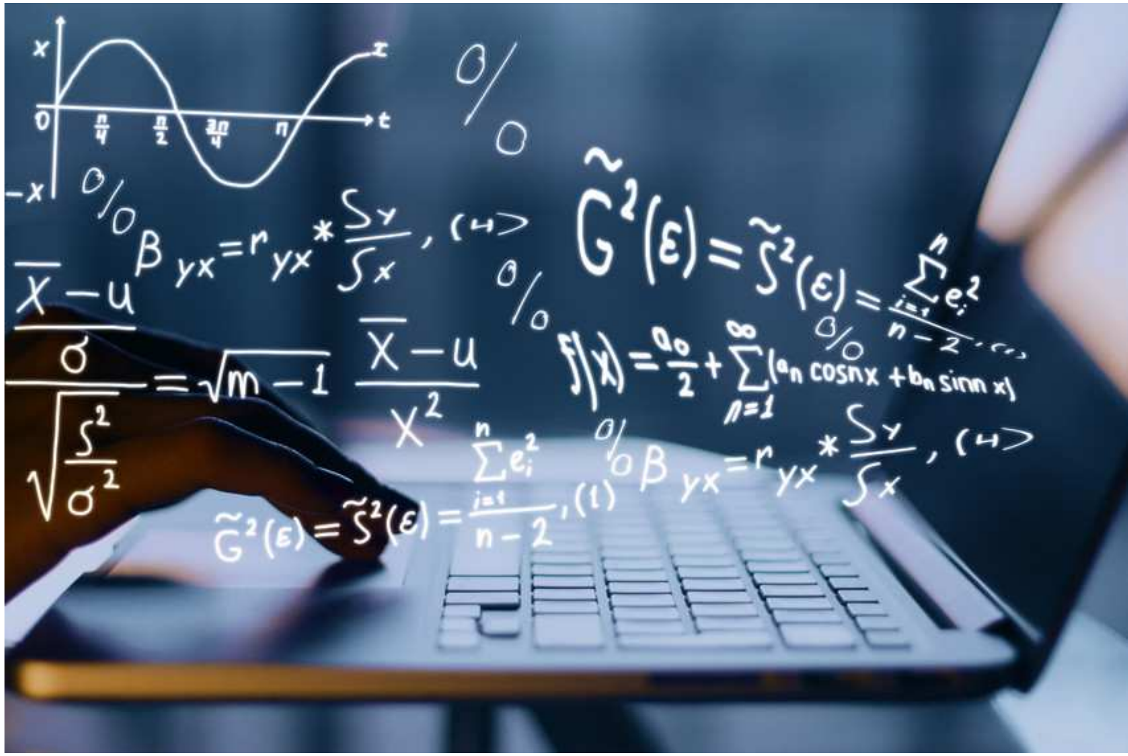
A very complex system

- **Manual** configuration & maintenance
- Complexity & criticality require **expert** / **trained resources**
- **Human** still controlling & supervising execution
- **Manual** adjustment to context when required



Data-driven automation

- A set of techniques to prescribe what to do next and take action autonomously
- A way from today’s automated systems toward real cyber-physical systems



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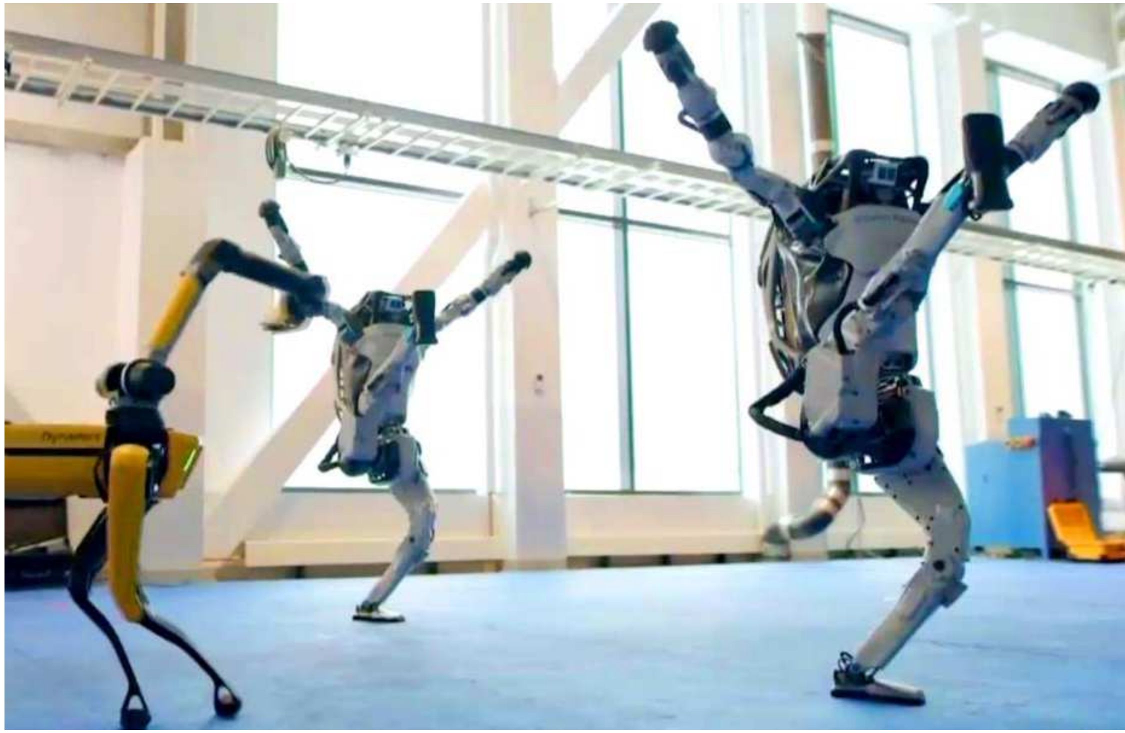
Toward real cyber-physical systems

- Physical and software components are deeply intertwined
- Able to operate on different spatial and temporal scales
- Exhibit multiple and distinct behavioral modalities
- and **interact with each other in ways that change with context**



WIKIPEDIA

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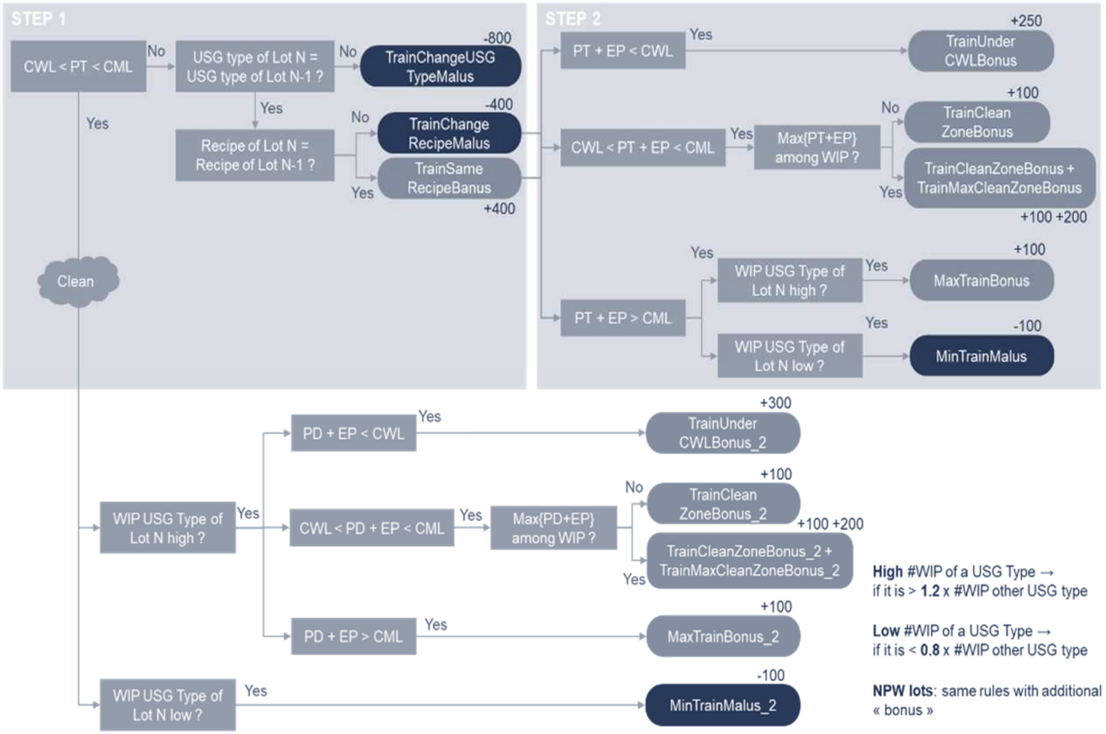
Application examples

- Adjustment of dispatching parameters and objective function to equipment and WIP situation
- Adjustment of automation parameters such as “delays” or “timeouts”
- Adjustment of local product priorities to general line and business conditions



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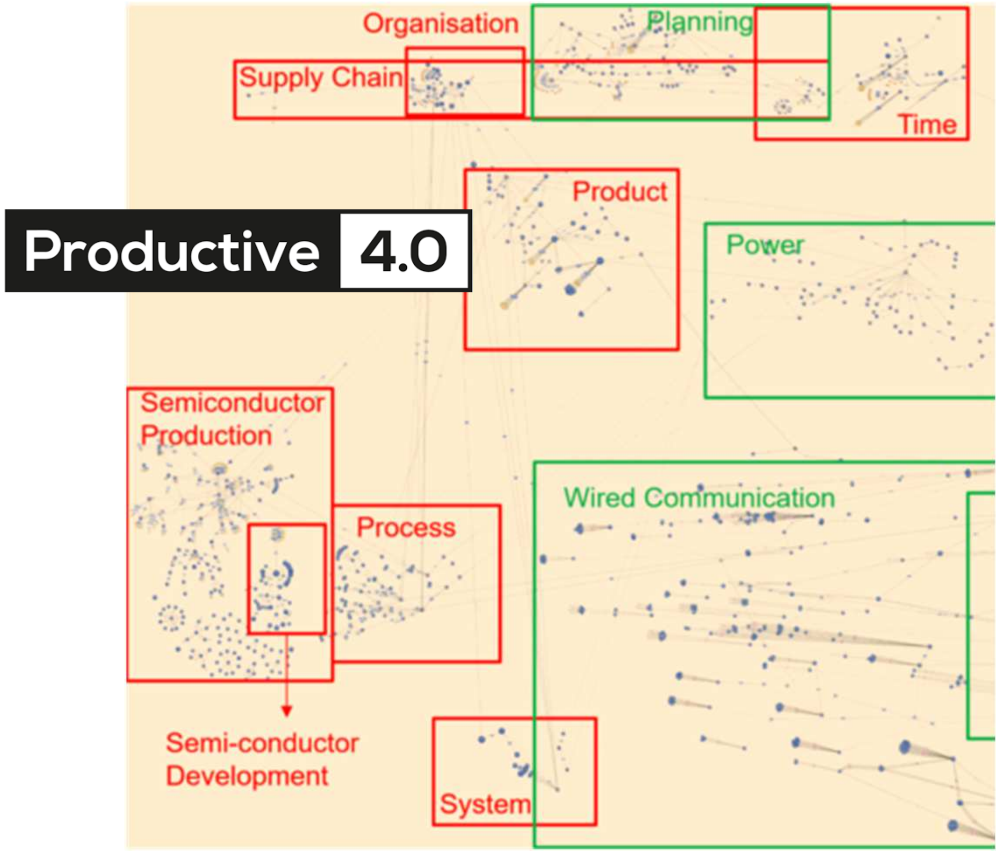
Extension to the whole Supply Chain

- Develop “context sensitivity”, model awaited behavior
- Connect contexts and concepts along the value chain, model interactions
- from rule or scenario-based logic to objective or purpose driven approaches



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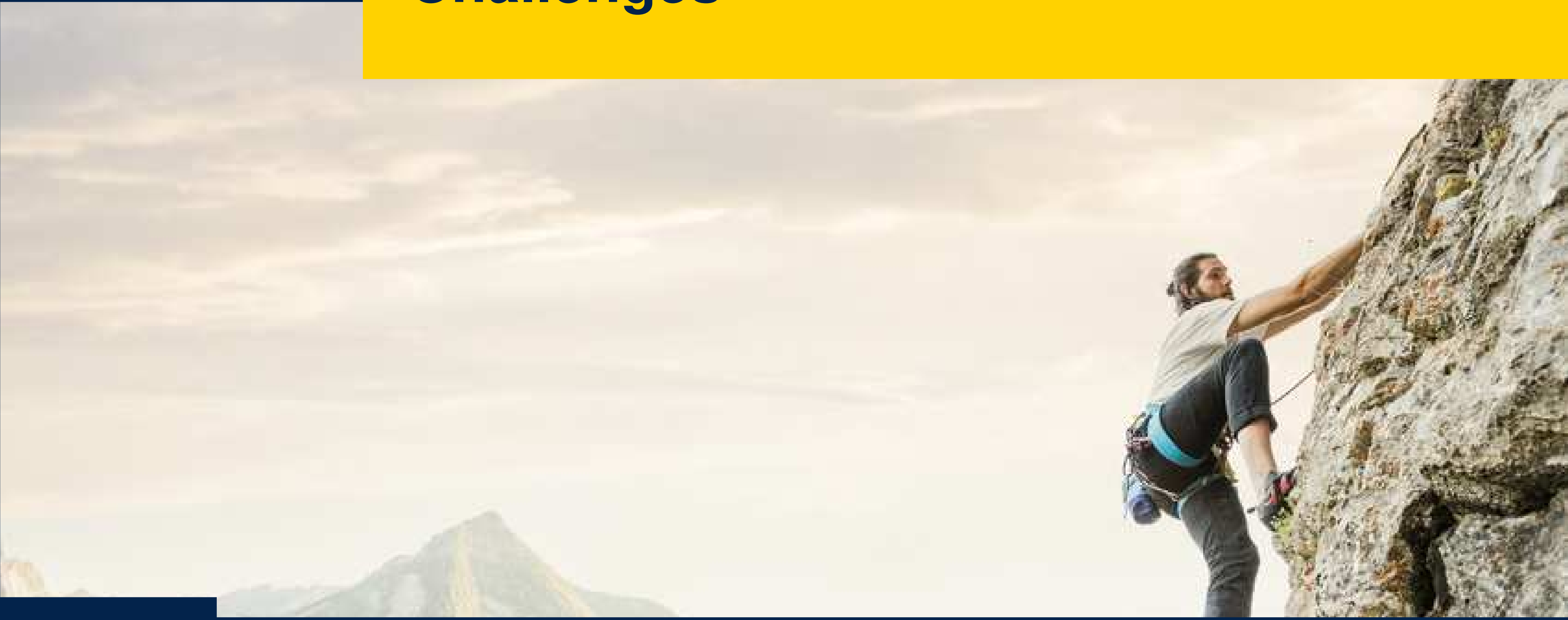
Challenges



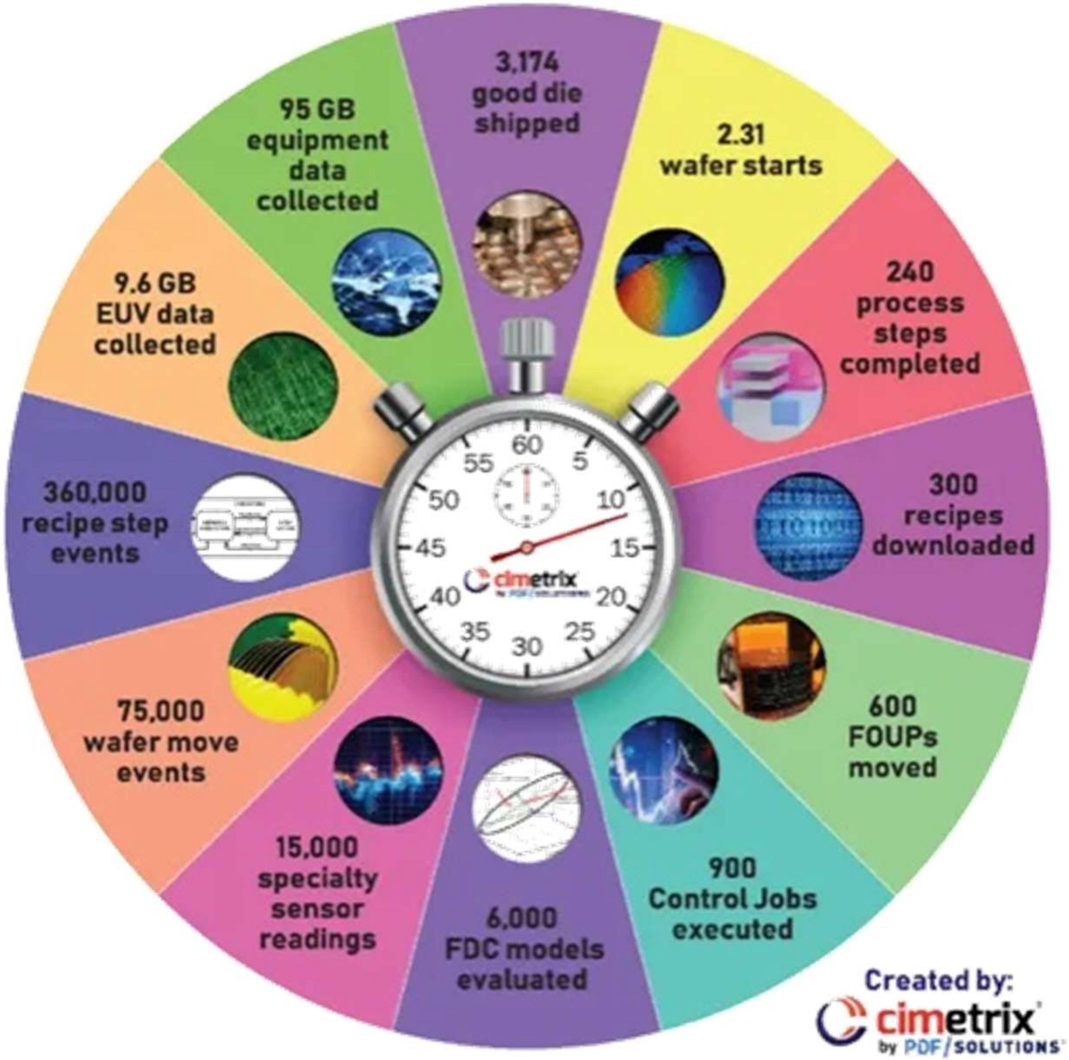
#1: Exploitable data

2 TB
per day and per tool

Advanced process control
and real-time adjustment

> 80%
never really used

Consolidation and correlation across
systems / silos



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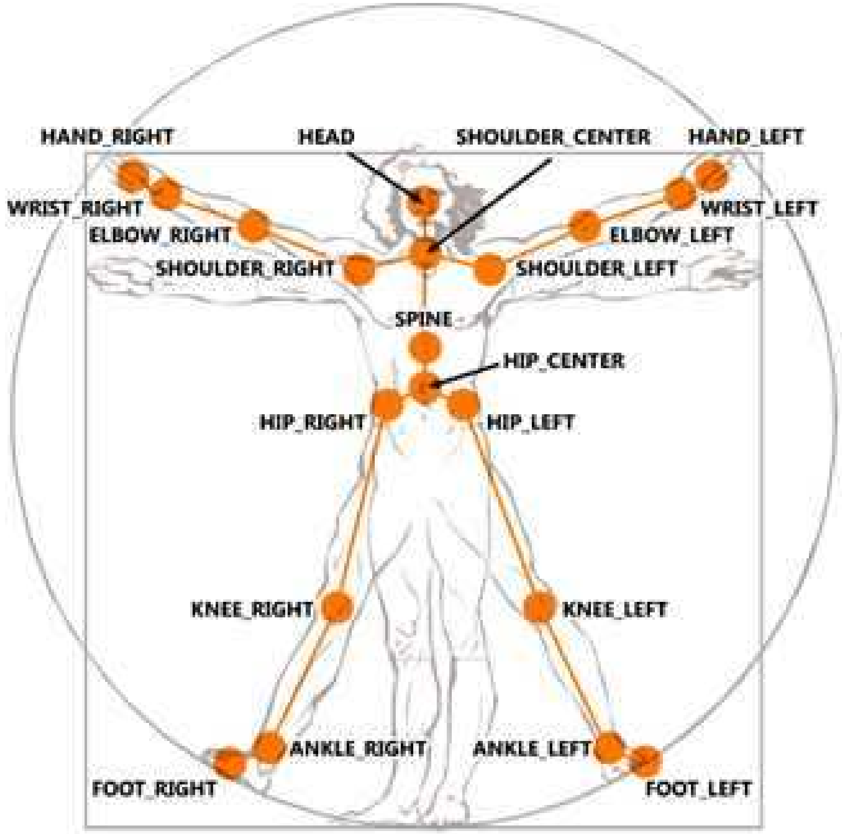
Modelling

Semantic

- Connecting the various data silos
- Modelling key articulations and interactions
- Enabling “faster & smarter” AI

Analytics

- Leveraging state of the art statistical, mathematical and AI techniques
- Fueling powerful digital twins or decision support systems



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#2: Cloud cost

- Putting AI everywhere as a “one size fits all” solution will come to a limit
- Cloud also has a cost, and it should be carefully balanced vs. expected gains
- Developing powerful models and ontologies will contribute reducing these costs
- Working on edge AI i.e., close to data source will also significantly help!

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Prescriptive Maintenance

- Data from multiple sources
  Sensors, alarm management system, Automation, MES, CMMS, Production Planning, spare parts availability, etc.
- Planning and optimization techniques
- Traditional statistics and AI
- Human "contextual awareness"

➔ Propose most suitable actions

	24_3-8		72_9-8	
Scénario	Gain Potenti...	Classement	Gain Potenti...	Classement
M2	1,91	1,00	3,87	1,00
M13	1,88	2,00	3,61	2,00
M6	1,56	3,00	3,32	3,00
M15	0,96	5,00	3,02	4,00
M1	1,01	4,00	2,21	5,00
M10	0,94	6,00	2,12	6,00
M4	0,49	10,00	1,99	7,00
M9	0,88	7,00	1,95	8,00
M18	0,86	8,00	1,93	9,00
M20	0,33	11,00	1,49	10,00
M19	0,53	9,00	1,20	11,00
M5	0,23	12,00	1,06	12,00
M22	0,16	13,00	0,33	13,00
A_Sans ...	0,00	15,00	0,00	14,00
M12	-0,12	18,00	-0,13	15,00
M17	0,03	14,00	-0,21	16,00
M3	-0,10	16,00	-0,35	17,00
M16	-0,11	17,00	-0,39	18,00
M21	-0,27	19,00	-0,60	19,00
M7	-0,32	20,00	-0,82	20,00

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#3: There is no magic

- What’s not in the system
  can’t be known by the system
- Models used to drive the system must cover the full range of utilization
- Limits must be clearly identified (Explainable AI)
- Replacing manager’s “guts feeling” is often the most difficult thing

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#4: Having AI running a fab

Will for sure require:

- 24x7 Explain ability and maintainability
- Accurate control of risk to prevent human error
- and safety fence against Artificial Stupidity

Will anyway require a kind of letting go (on top of trust) from the whole management ladder

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Data-driven automation in complex manufacturing systems

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Key takeaways

- Industrial automation is driven by business needs and constraints
- Data driven automation is needed to gain in flexibility, quality and speed
- “Brute AI” will not be sufficient **nor sustainable**
- Sophisticated, hybrid, multi-disciplinary approaches are required.

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