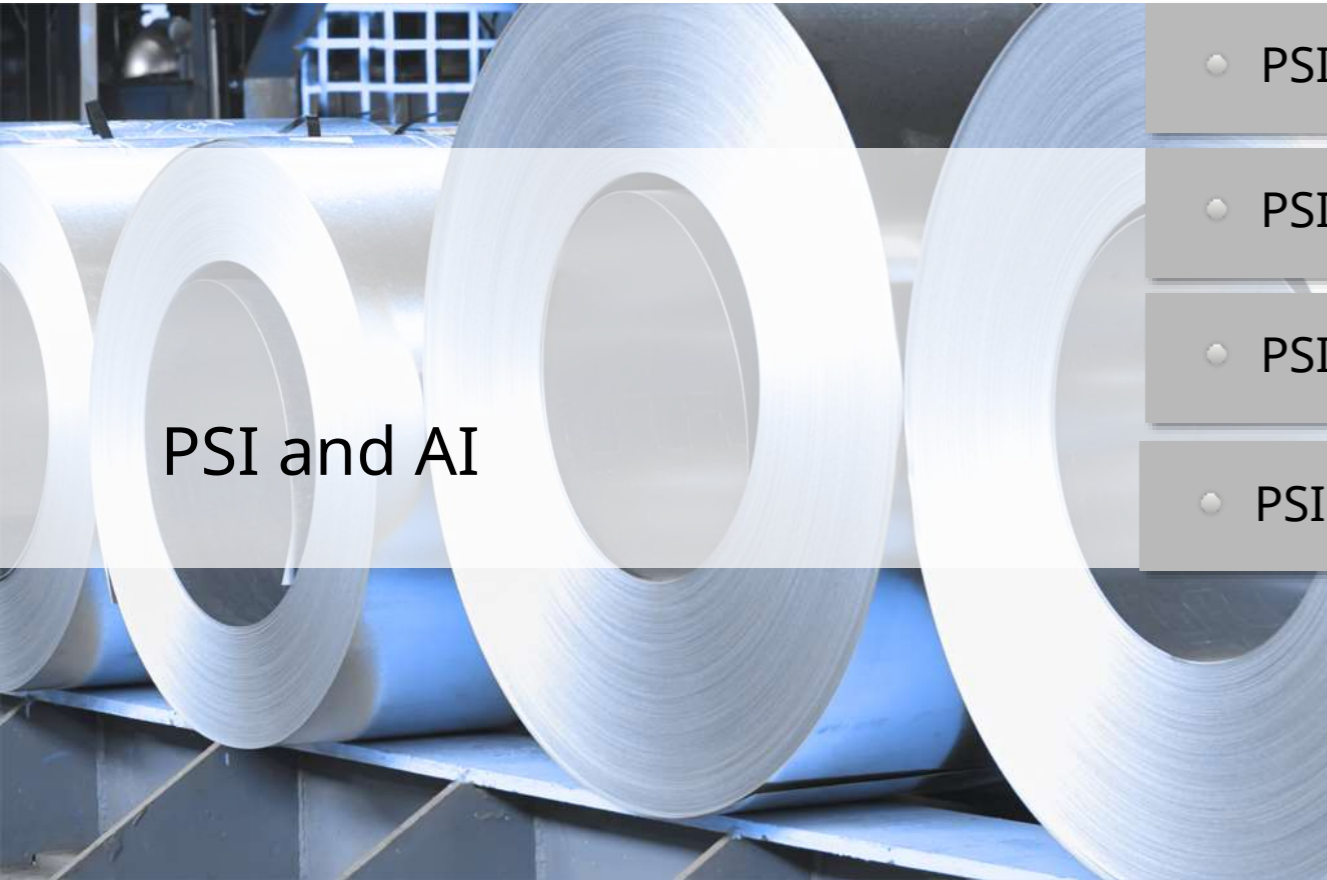


Enhancing Manufacturing Execution Systems with AI: A Collaborative Framework for Process Optimization

Frank Weber, PSI FLS Fuzzy Logik & Neuro Systeme GmbH

Luc Van Nerom, PSI Metals

AMAP Colloquium
Aachen, 22 Feb 2024



PSI and AI

- PSI and Industrial Artificial Intelligence
- PSI Metals and Artificial Intelligence
- PSI Qualicision AI
- PSI Metals and Qualicision AI

PSI segments and vertical markets

Energy Management

Electrical and combined grids



Gas grids and pipelines



Energy trading and sales



Public transport



Production Management

Mining and traffic



Metals production



Automotive and mechanical engineering



Logistics



PSI Segments and Sustainability Cycles



PSI FLS Fuzzy Logik & Neuro Systeme GmbH as a company in the PSI Group

PSI Software SE

- €247.9m revenue (2022)
- About 2,200 employees worldwide
- Worldwide customer base
- 16 national and 15 international locations
- TOP 10 of German standard software manufacturers¹

¹ Lünendonk 2014

PSI FLS Fuzzy Logik & Neuro Systeme GmbH

- KPI oriented multi-criteria optimization and machine learning with neural networks based on qualitative labeling by optimization algorithms
- Founded 1992, since 2008 a company in the PSI Group
- Offices in Dortmund, Aschaffenburg and Munich
- Installations worldwide
- Worldwide partner of BMW, Continental and Volkswagen
- AI Applications in all Fields of PSI Software SE
- Products: Qualicision AI and Deep Qualicision AI Framework, ...

Industrial Intelligence within the PSI Group

Methods

- Artificial neural networks
- Monte Carlo methods
- Simulated annealing
- Extended Fuzzy Logic Qualicision AI
- Combinatorial search techniques
- Cluster learning methods for machine learning
- ...

Application fields

- Workforce and asset management
- Optimization of gas transport and energy trading
- Sequencing in the automotive industry
- Supply chain optimization in logistics
- Transmission and distribution grids (bottleneck management)
- Traffic infrastructure management
- Real-time optimization in public transport systems
- Luggage recognition at airports
- ...



AI Timeline PSI FLS



1993

First AI based Fuzzy Logic Controller at Continental



1994

First Qualicision AI based Extended Fuzzy Logic Scheduling at BMW



1995

First Qualicision AI based Image Analysis for Surface Classification at Boge AG



1997

First Qualicision-based credit assessment and Cross-Selling recommendations at CC-Bank



1998

First Qualicision AI based Image Analysis for Color Stripes on Tires at BMW



1998

First Qualicision AI based Image Analysis for Rim Recognition at BMW



2001

First Qualicision-based Factoring Decisions at Heller-Bank



2002

Worldwide Roll-Out of Qualicision-Sequencing at BMW



2004

Implementation of Qualicision-Sequencing in Sweden at VOLVO



2008

First Qualicision-Sequencing in Automotive Plant in China at BBA BMW Brilliance



2009

First Qualicision-based Optimization of Article Stocks in a Fashion Store Chain at Ulla Popken



2015

First Qualicision-based Data Analysis of Chemical Process Data at Glanzstoff



2018

Deep Qualicision AI Machine Learning with Qualitative Labeling for all PSI Software Tools



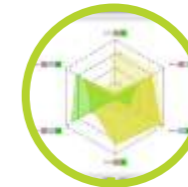
2020

Explainable AI by Means of Interpretable KPI Labels AI and KPI-Based Decision and Optimization Algorithms



2020

Sustainability in Business Processes by Qualicision and Deep Qualicision AI: Green KPIs and Intelligent Optimization



2021

PSIqualicision/F9118 Learning algorithm for automated calculation of KPI preferences



2022

PSIup/Qualicision Monitoring and Control for Predictive Maintenance



2023

Qualicision AI Generative Ask and Answer with Qualicision A2

Qualicision AI References



Qualicision AI Production

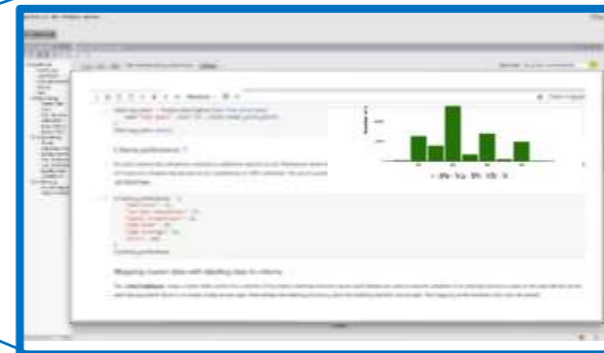
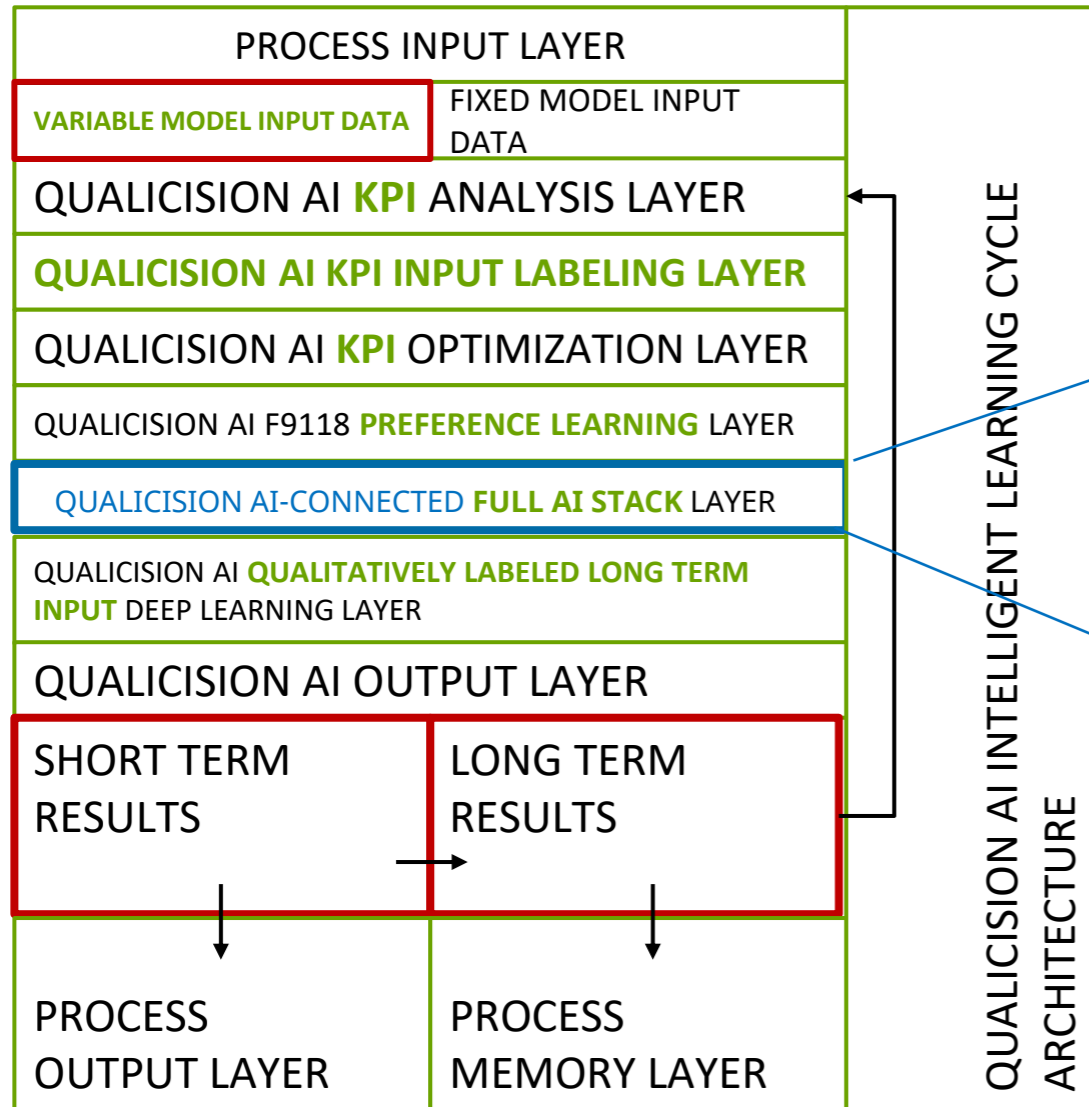


Qualicision AI Flow of Energy and Goods



Qualicision AI Automation and Quality Control

Qualicision AI – Qualitative Labeling + Qualicision AI Decision Engine + Full AI Stack



- Keras / Tensorflow / PyTorch
- Scikit-learn / XGBoost / Scipy
- Matplotlib / Seaborn
- Numpy / Pandas / Dask
- PySpark
- NLTK, Gensim
- Hugging Face Transformers
- PyTesseract / OpenCV
- NetworkX
- PyMC3 / Statsmodels
- ... + User- / Customer-own



PSI DeepQualicision AI Framework – User Concept by User Groups

- **Operator**

Process control and **time series feedback information** for rolling training of self-learning AI



- **Key user**

Configure and **parameterize the application** as well as modify and extend it on the process KPI level



- **Data analyst**

Full access to **AI stack** as well as all **Deep Qualicision AI functionalities** via appropriate Python imports and Jupyter notebooks



Innovation 2023: Qualicision—A2 Asks and Answers with Generative AI

- Cost-efficient
- Own docs can be used
- Completely on-prem
- Ownership of model
- Highly scalable
- Integrable in own applications
- Open interfaces

The image displays two overlapping windows from the Qualicision AI interface. The background window is the 'Qualicision Dashboard', which features a sidebar with navigation options like 'Home', 'Qualicision Projects', 'Qualicision Dashboard', 'Input dialogs', 'Output dialogs', 'Configurations', and 'System configuration'. The main area shows a 'Criteria' table with columns for 'Name', 'D...', and 'Preference'. The table lists various criteria such as 'order', 'production', 'scheduling', 'planning', 'sequence', 'process', 'system', 'time', 'schedule', 'capacity', 'user', 'scheduler', 'resource', 'optimisation', 'sequencing', 'delivery', 'control', 'assembly', 'stock', 'flexibility', and 'management', each with a corresponding preference value and a visual slider.

The foreground window is a code editor showing a Python script. The script is titled 'Production Manager Settings' and contains a function that generates a system prompt for an AI model. The prompt asks the AI to provide a detailed summary to answer a question in a structured format. The script also includes a list of steps to follow when scheduling orders based on arbitrary properties, such as defining objectives, gathering data, developing a model, defining constraints, applying AI algorithms, evaluating the solution, and iterating and refining the solution. The script is executed in a Python 3.9 environment.

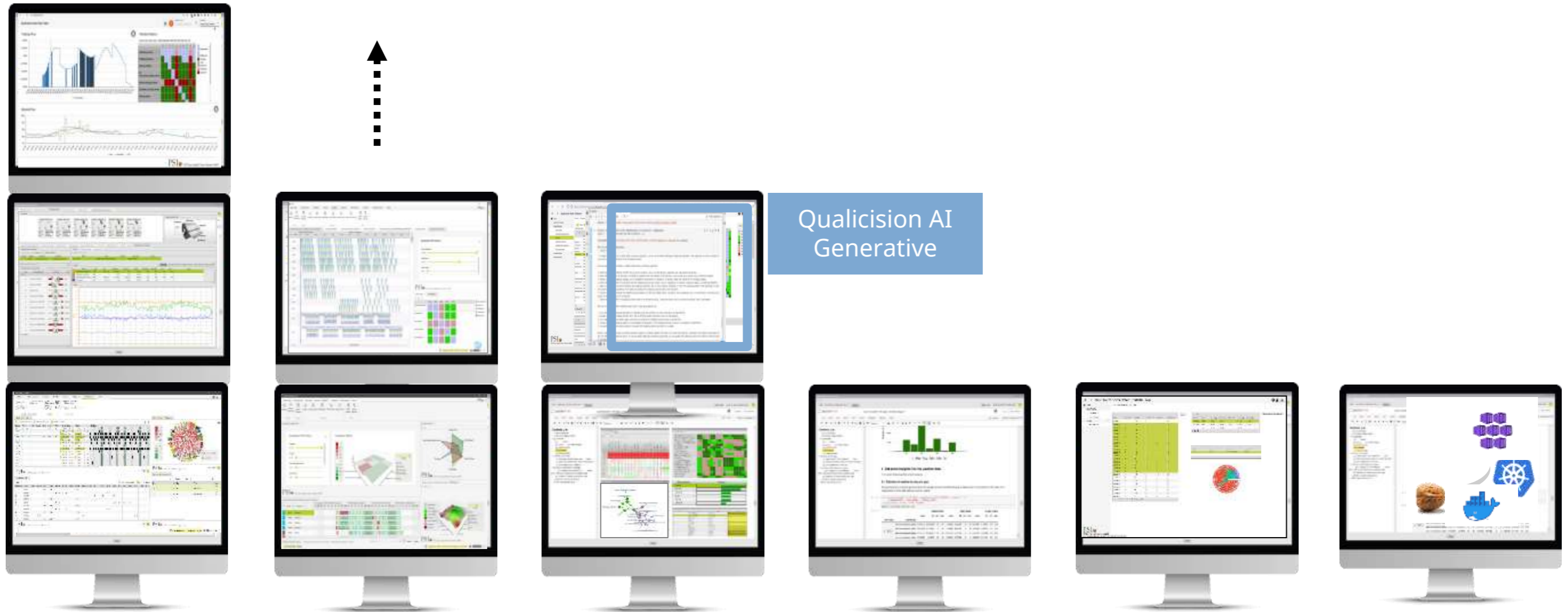
Innovation 2023: Qualicision—A2 Asks and Answers with Generative AI

- **Query: How to support industry application by using Qualicision?**
- **Answer Qualicision AI Generative:** By implementing Qualicision technology as a software system for intelligent decision-making, and process optimisation across industrial sectors.

- **Query: If I have to schedule a large quantity of orders based on arbitrary properties how should I proceed?**
- **Answer Qualicision AI Generative:** To do this, you first need to specify which property is most important. You can then determine an ideal workplace for that order by applying certain rules (e.g., “if the operation has the earliest desired deadline”). If the order can be completed at that time and place, it will be scheduled there. All other orders are ordered according to their importance. At this point, it is important to note that the sequence planning in finite capacity scheduling is only based on some rules which make use of various algorithms or heuristics. It is not a complete algorithm for solving the problem; for example, the heuristic for determining the most important operation cannot be found in any textbook about operations research.
- Source: PM_2015-03_Smart_Face_EN.pdf, PM_2015-01_PSIpentaLeitstand with Qualicision_EN.pdf, PM_2009-01_VC_Corporation_EN.pdf, PM_2018-02_Predictive Optimization with Deep Qualicision_EN.pdf

- **Query: What to do if I have a dataset with many duplicated entries?**
- **Answer Qualicision AI Generative:** The Deep Qualicision AI Framework provides a solution. It allows for automatic detection of duplicates through an unbiased, robust methodology based on similarity metrics. This approach is also possible when dealing with historicized data, i.e., with previously collected data. Historicized data is also included in the process by using the same methodology described above and then used to search for duplicate entries in existing databases.
- Source: PM_2020-04_Duplicate_Detection_with_DQAI_EN.pdf, PM_2020-03_Data_input_validation_with_DQAI_EN.pdf

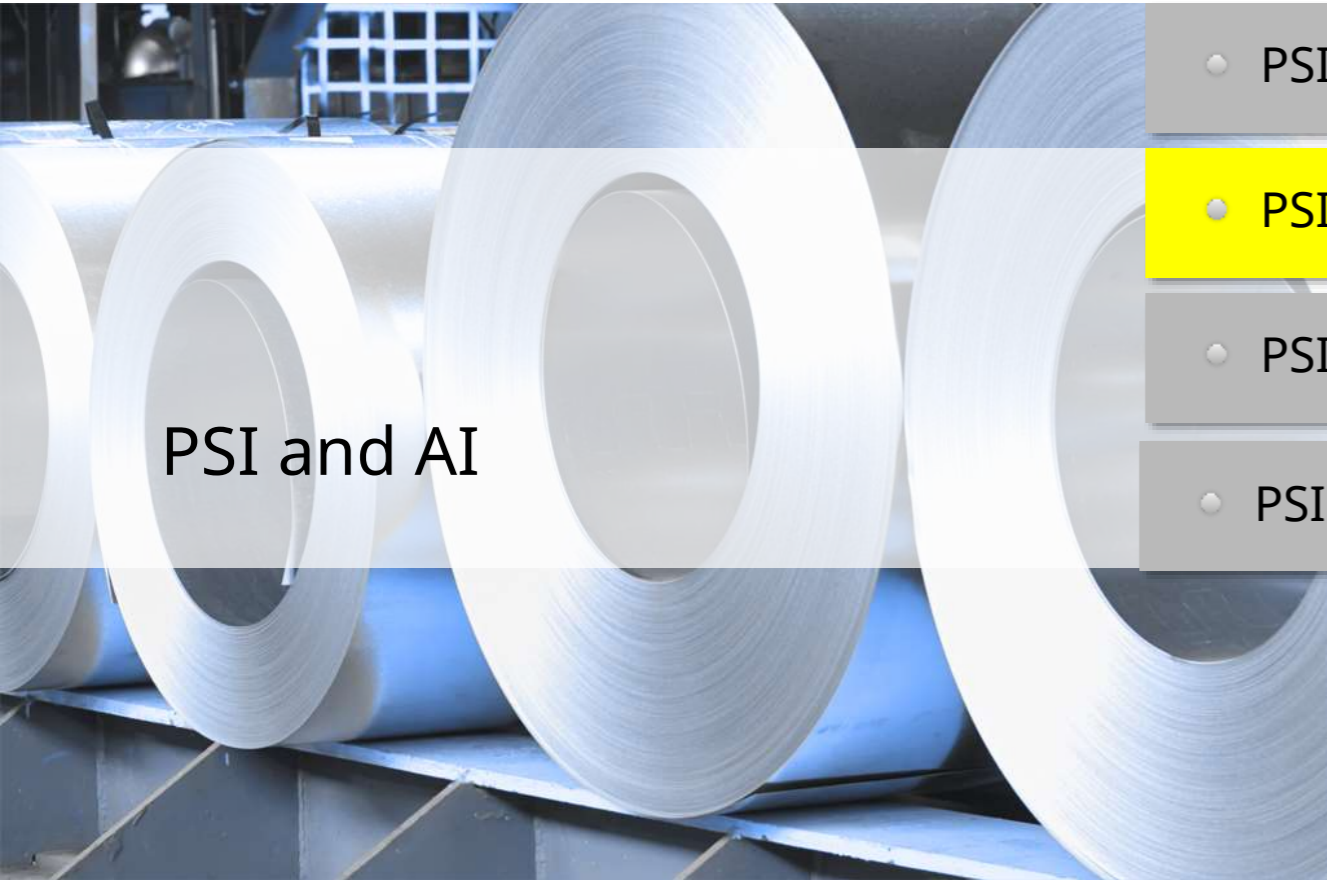
PSI Vertical Tools and Qualicision AI – Supports Management of Data Science Lifecycle



Qualicision AI
Generative

Any PSI (Qualicision AI based) Vertical Market Tool

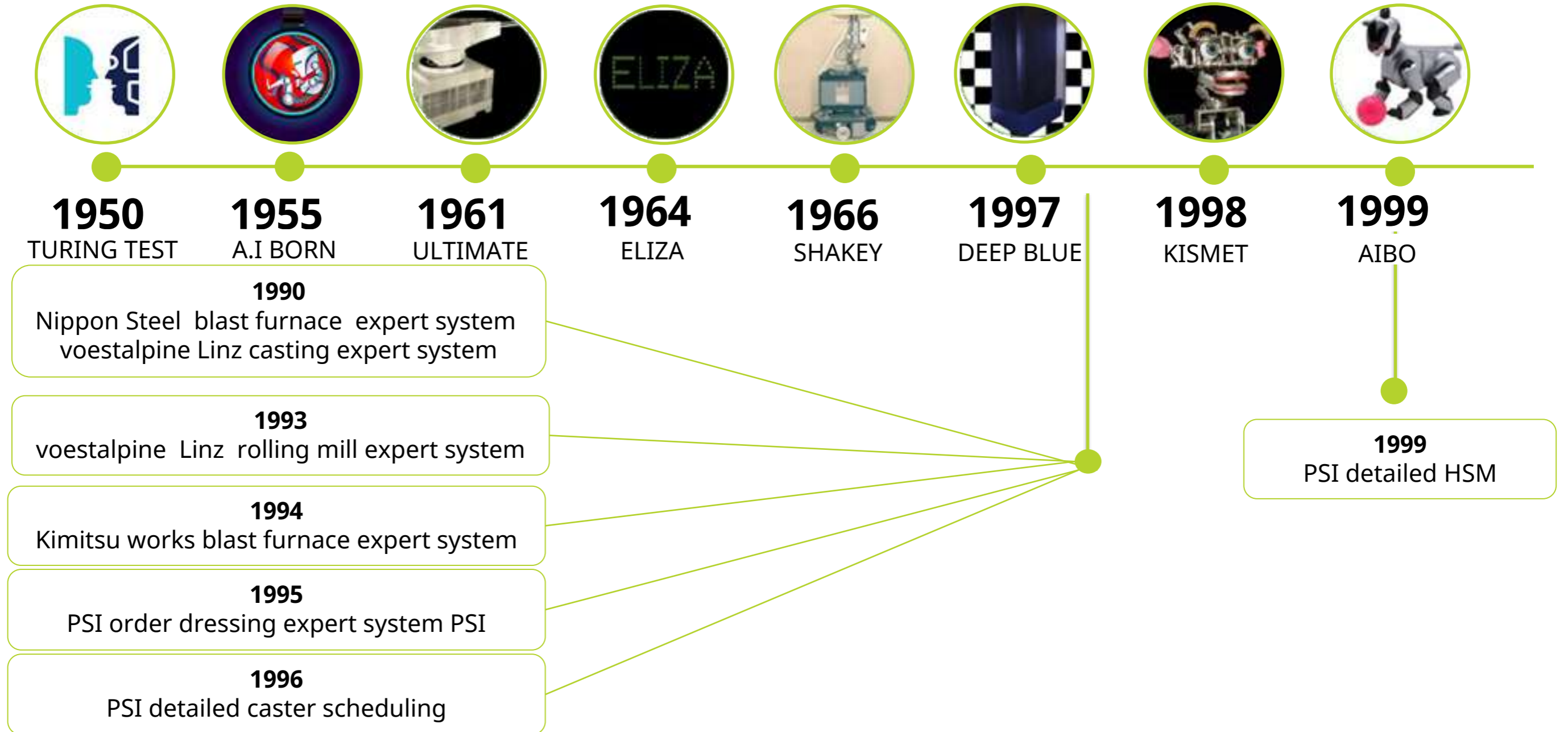
PSI Qualicision AI



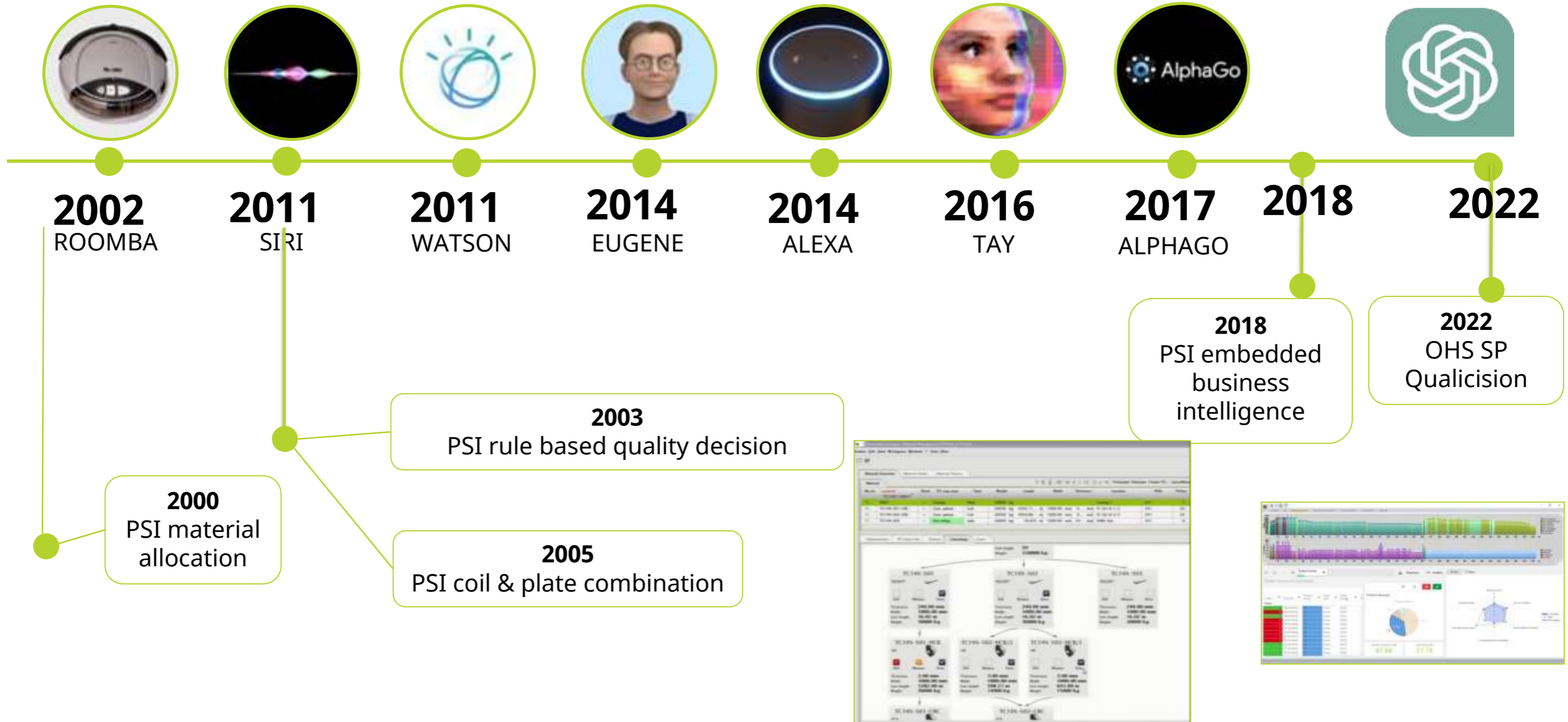
PSI and AI

- PSI and Industrial Artificial Intelligence
- PSI Metals and Artificial Intelligence
- PSI Qualicision AI
- PSI Metals and Qualicision AI

Artificial Intelligence Timeline



Artificial Intelligence Timeline



Capacity planning

needs linear
programm
optimu
between
inventor

Quality
based
confi

**Caster Scheduler uses
an A* algorithm to
define and sequence
optimal heat/slab
schedules**

er uses
ling
at Scheduler
onstraint
ning for its
scheduling
algorithm

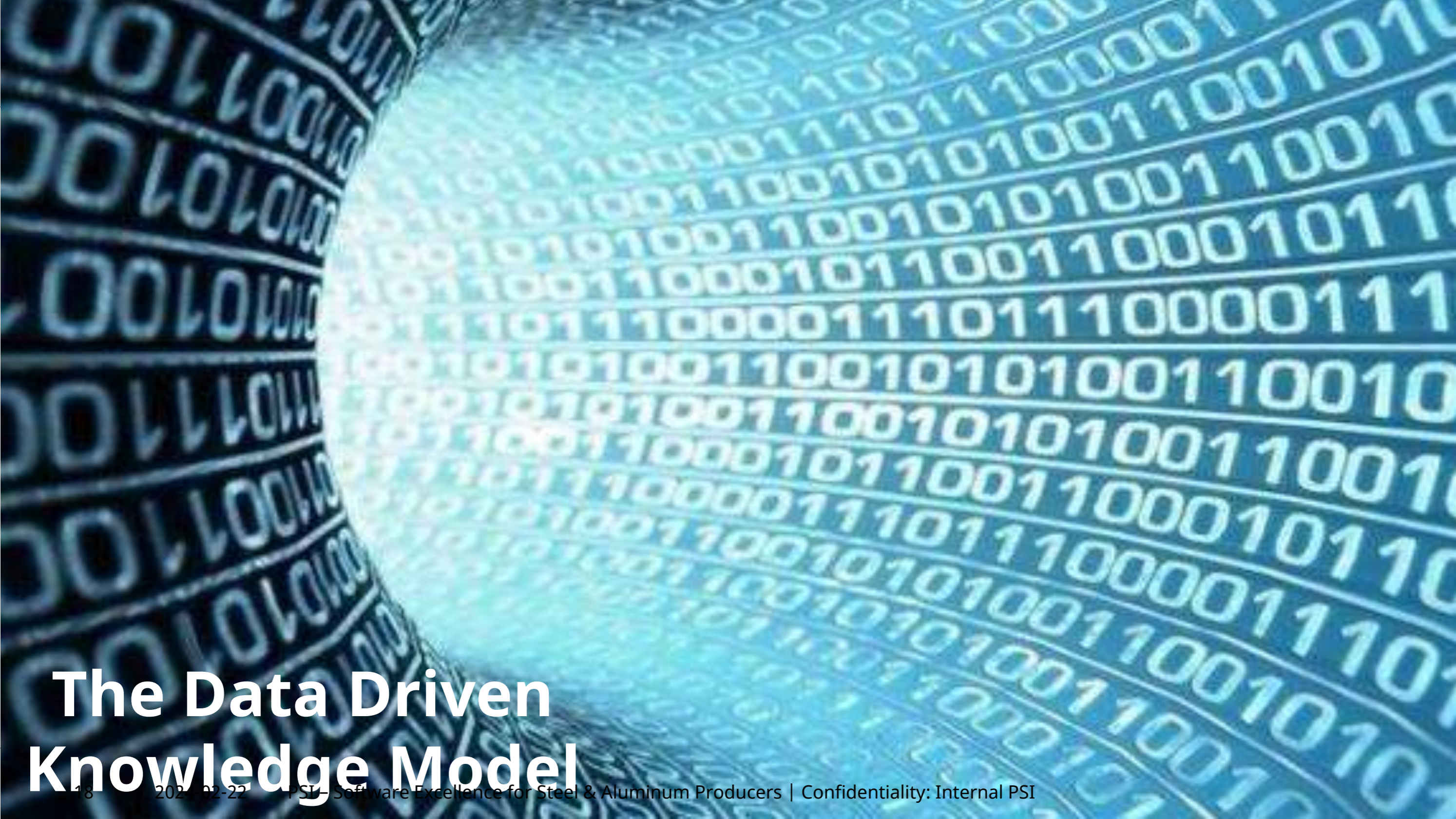
Scheduling



Production Execution & Material Logistic



**Qualicision based
green KPI s
Online Heat Scheduler**



The Data Driven Knowledge Model

Machine Learning and the data revolution

Knowledge model extraction from (data) examples

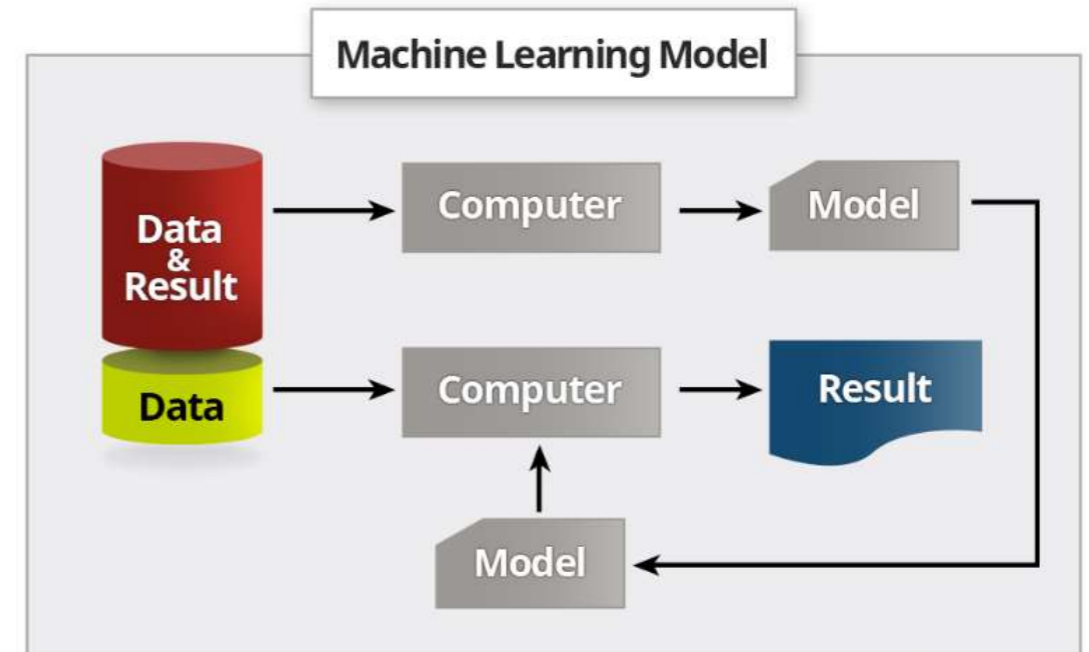
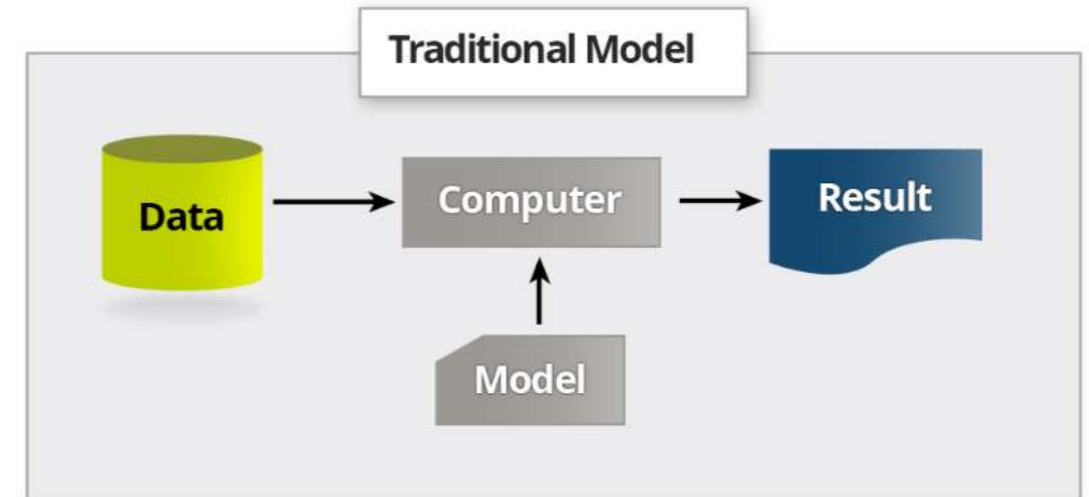
**VERY EFFICIENT
FOR**

Identification

Classification

Prediction

Regression



Quality Indicator (QI)

Definition: A *quality value* (scalar number or classifier) derived via a set of *rules* and *functions*, fed with complex *data* collected in the QPS




Raw Process Data

- Rolling force
- Coiling temperature
- ...

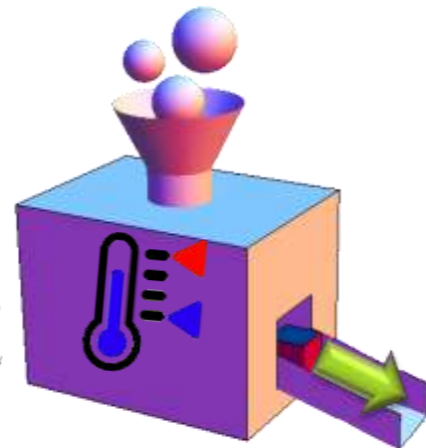
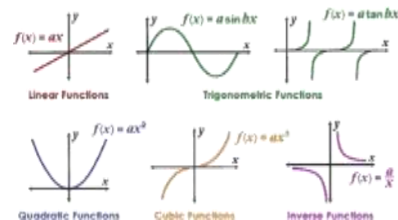
Material Data

- Thickness
- Flatness
- Surface topography
- ...

Data from previous process steps

- Casting speed
- Tundish level
- ...
- Other QI 

Rules + Functions



Quality Indicator

To be used for material and/or process evaluation

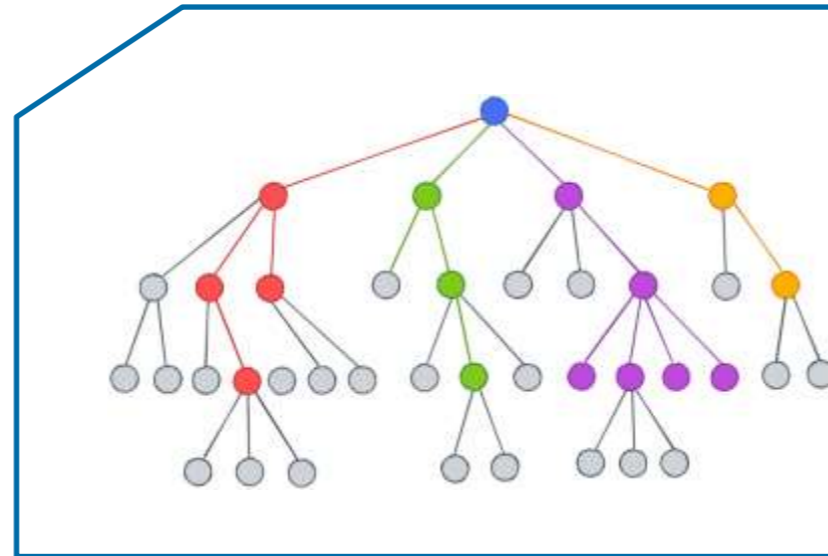


Quality Features and traditional QF modeling

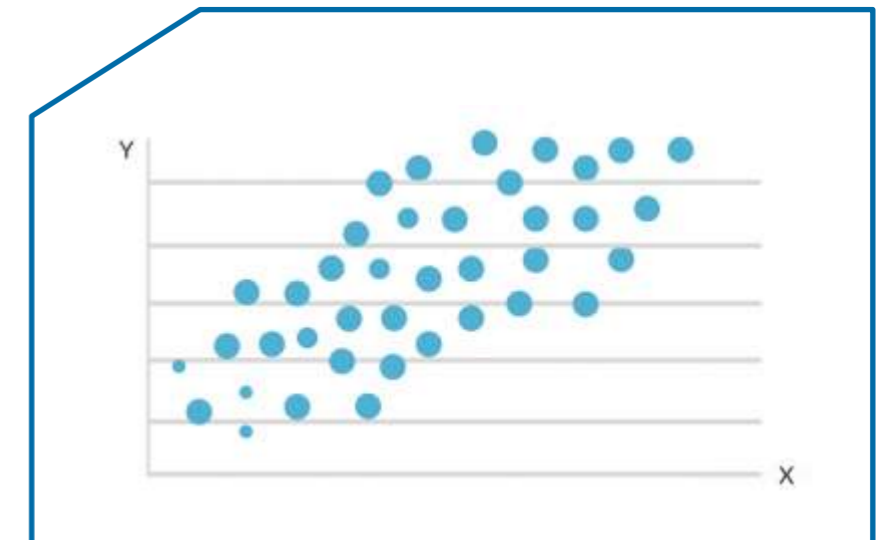
$$\text{QualityFeature}(\text{coil } n) = f \left(\text{MaterialAttributes}(\text{coil } n), \text{ProcessParameters}(\text{coil } n) \right)$$

$$v_a = \sqrt{\frac{m^2}{s^2} + \frac{Nm^2}{kg^2} kg \left(\frac{1}{m} - \frac{1}{m} \right)}$$
$$v_a = \sqrt{\frac{m^2}{s^2} + \frac{kgm}{s^2} \left(\frac{m^2}{kg^2} \right) kg \left(\frac{1}{m} - \frac{1}{m} \right)}$$
$$v_a = \sqrt{\frac{m^2}{s^2} + \frac{kgm}{s^2} \left(\frac{m^2}{kg^2} \right) kg \left(\frac{1}{m} \right)}$$
$$v_a = \sqrt{\frac{m^2}{s^2} + \frac{m^2}{s^2}} = \sqrt{\frac{m^2}{s^2}} = \frac{m}{s}$$

Calculation Model



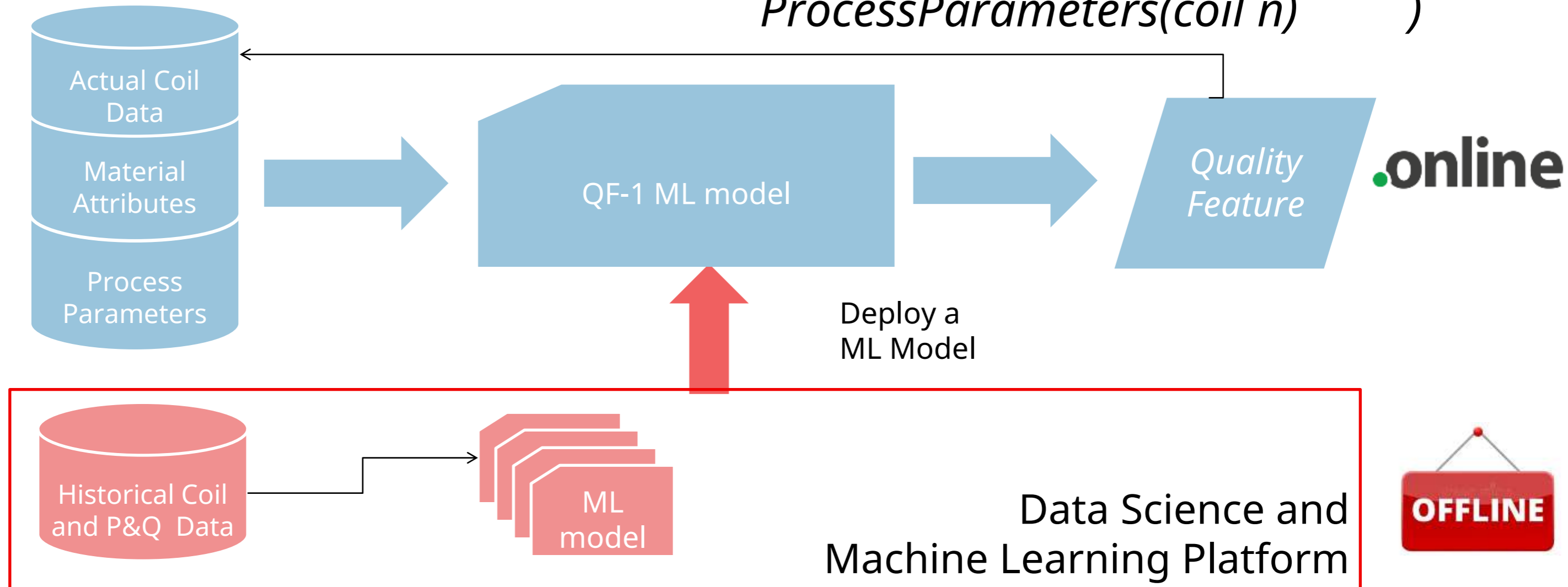
Decision Model

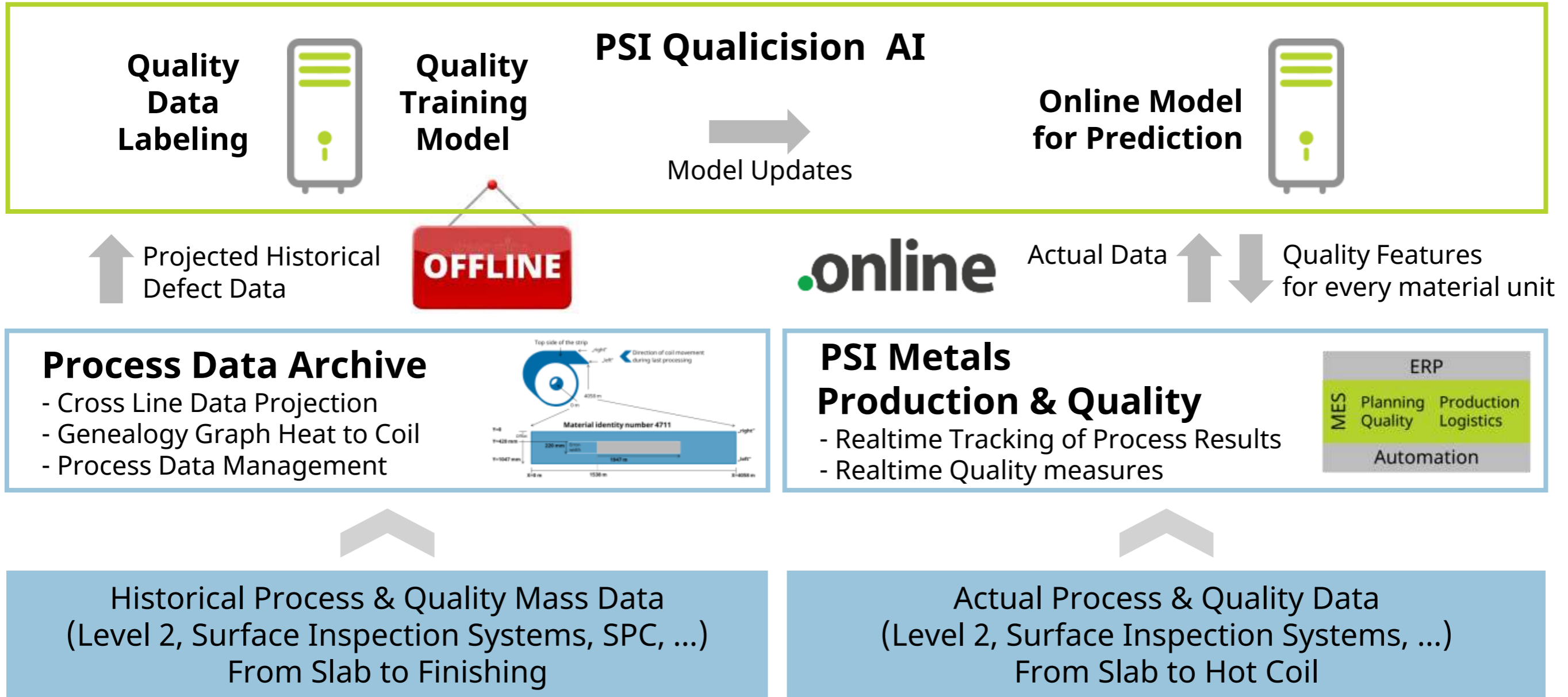


Statistical Model

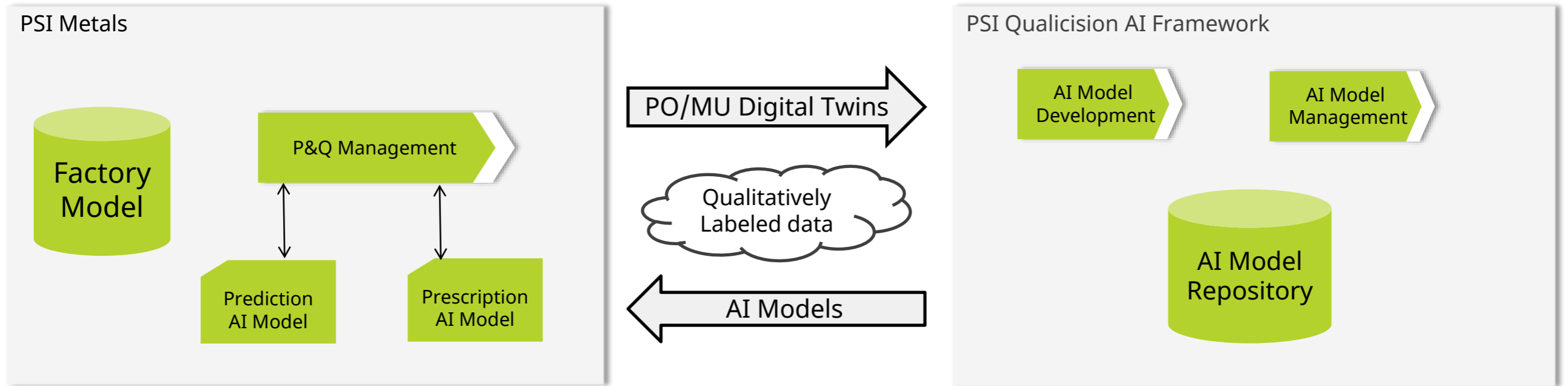
Quality Features based on ML Models

$$QualityFeature(coil\ n) = f_{ML} (\quad MaterialAttributes(coil\ n), \quad ProcessParameters(coil\ n) \quad)$$





Integrated PSImetals Quality & PSIqualicision AI Framework



PSImetals Production & Quality

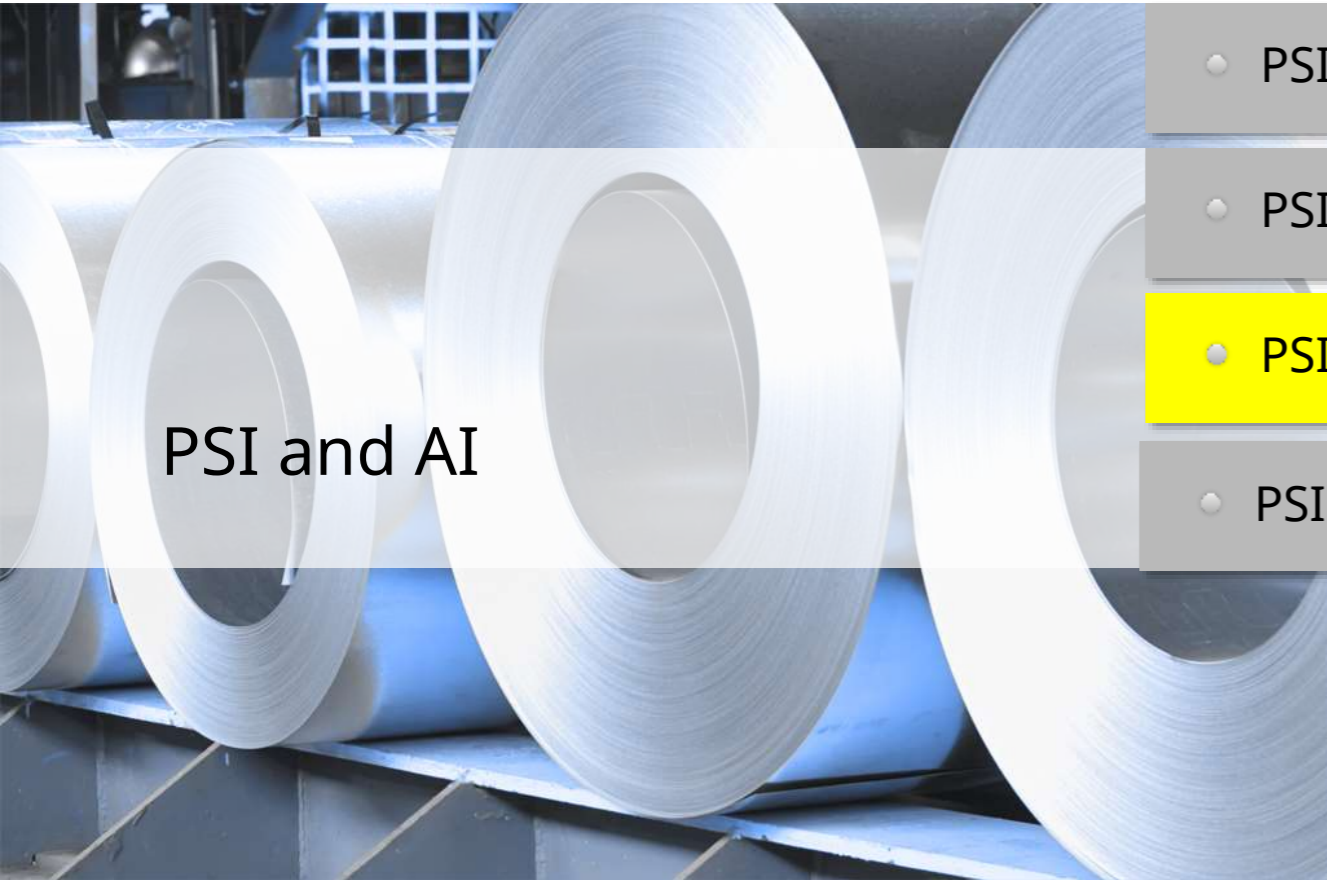
PSIqualicision AI



PSImetals & PSIqualicision AI: Comprehensive Coverage of End-To-End Processes

PSImetals

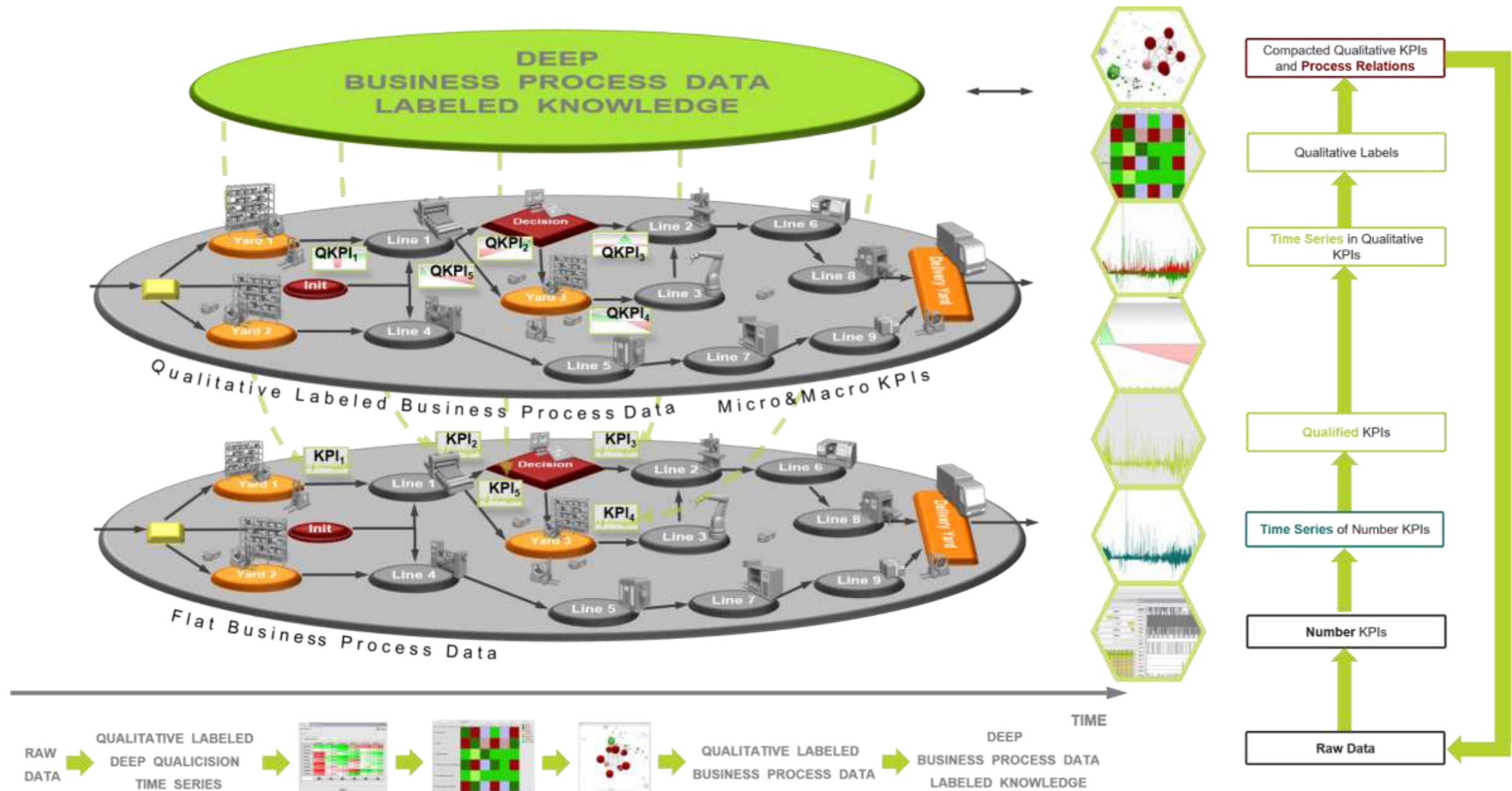




PSI and AI

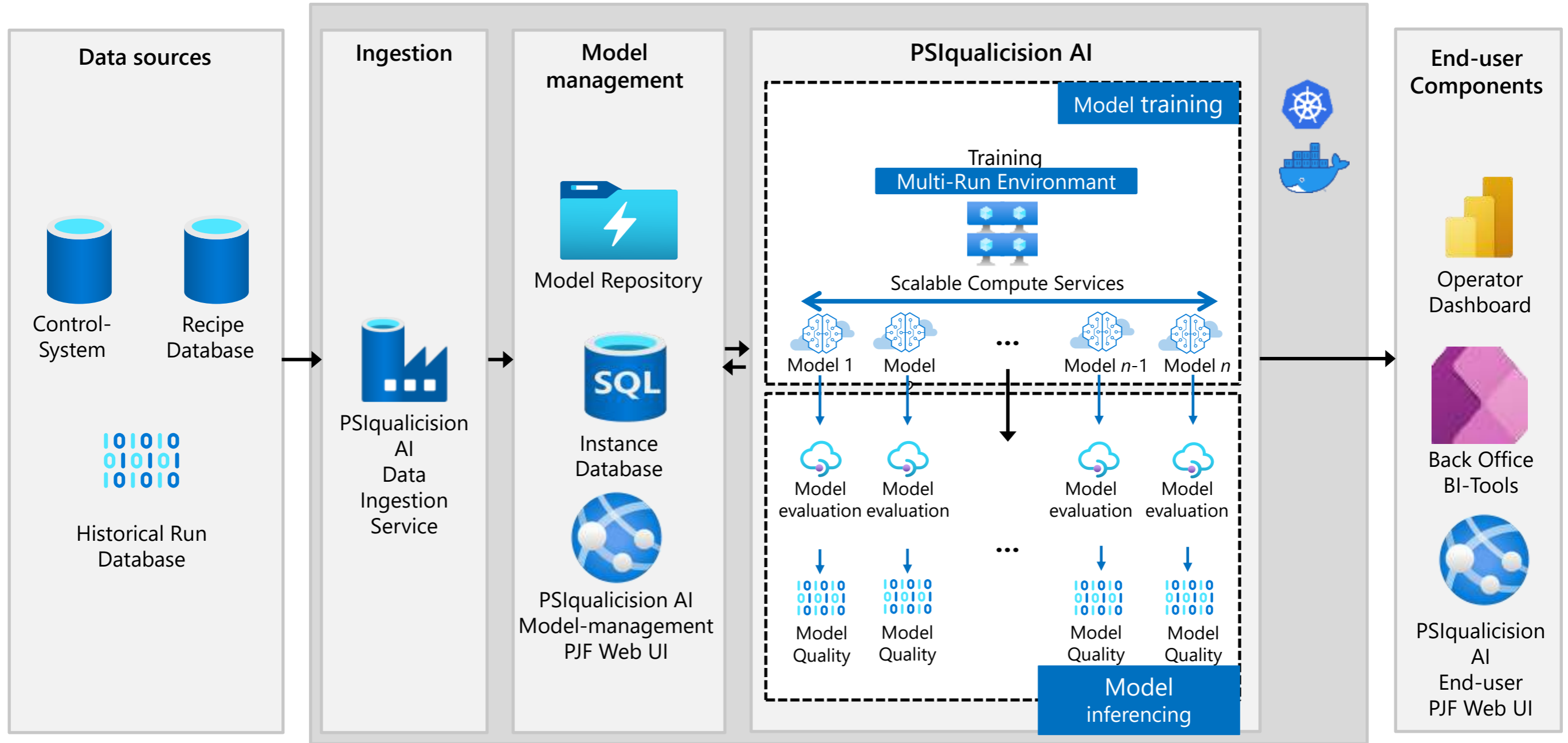
- PSI and Industrial Artificial Intelligence
- PSI Metals and Artificial Intelligence
- PSI Qualicision AI
- PSI Metals and Qualicision AI

Qualitative Labeling with Deep Qualicision AI

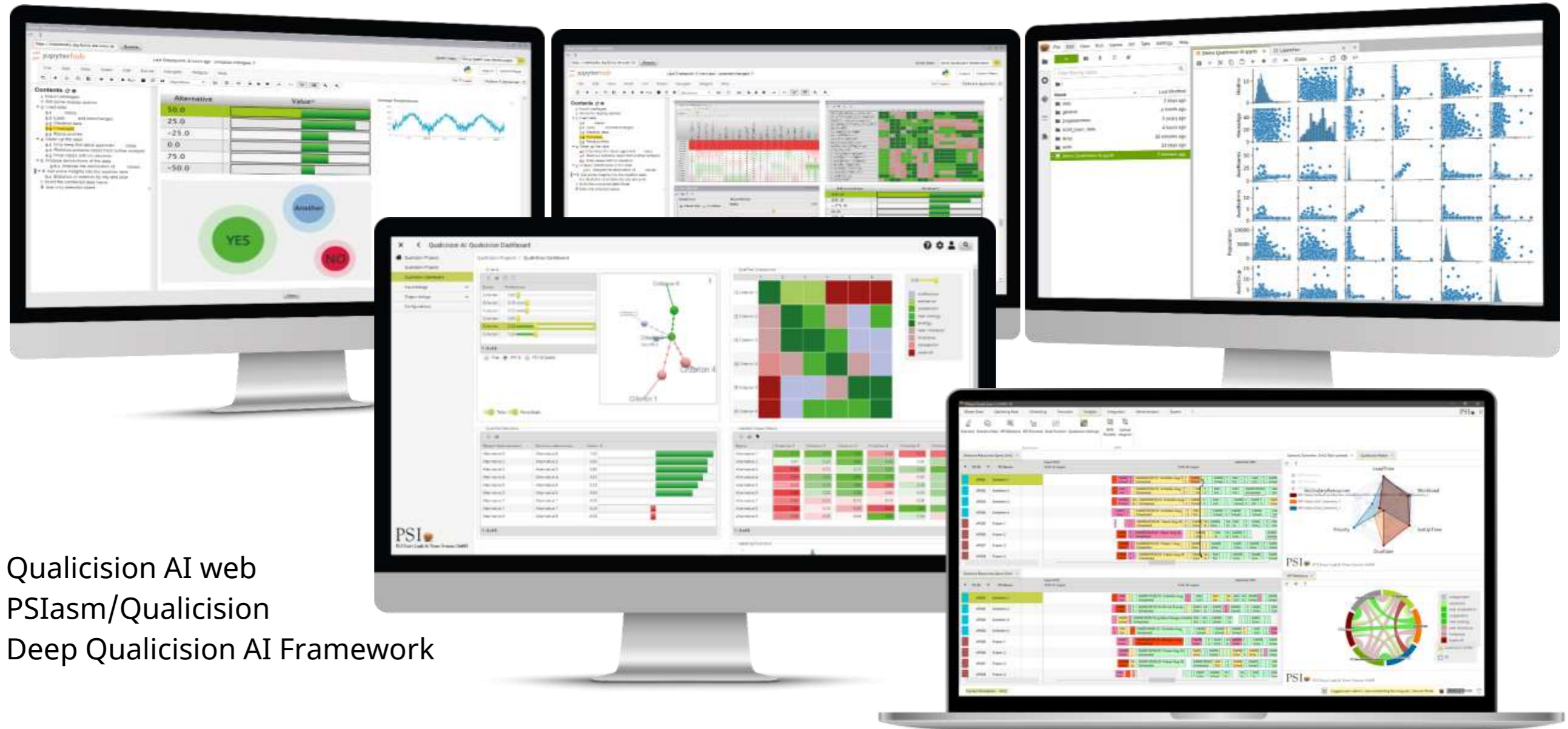


PSIqualicision AI Architecture for Industry

Customer Architecture for AI



Live Demos



- Qualicision AI web
- PSIasm/Qualicision
- Deep Qualicision AI Framework

AI-supported Harmonization of Production and Energy Consumption and Procurement



PLANNING AND SCHEDULING

Long-term planning
(S&OP)

Mid-term planning
(order and material planning)

Short-term planning
(Line planning)

Execution of time schedule
(online)



Energy grids and energy transmission

Long-term energy procurement

Mid-term energy procurement

Day trading

ENERGY PROCUREMENT



Scheduling of Production in Combination with Energy Trading—Metal Industry

PSImetals
Qualicision AI
Scheduling

click on image online article will open



PSI EM Qualicision
AI Smart Day Trader

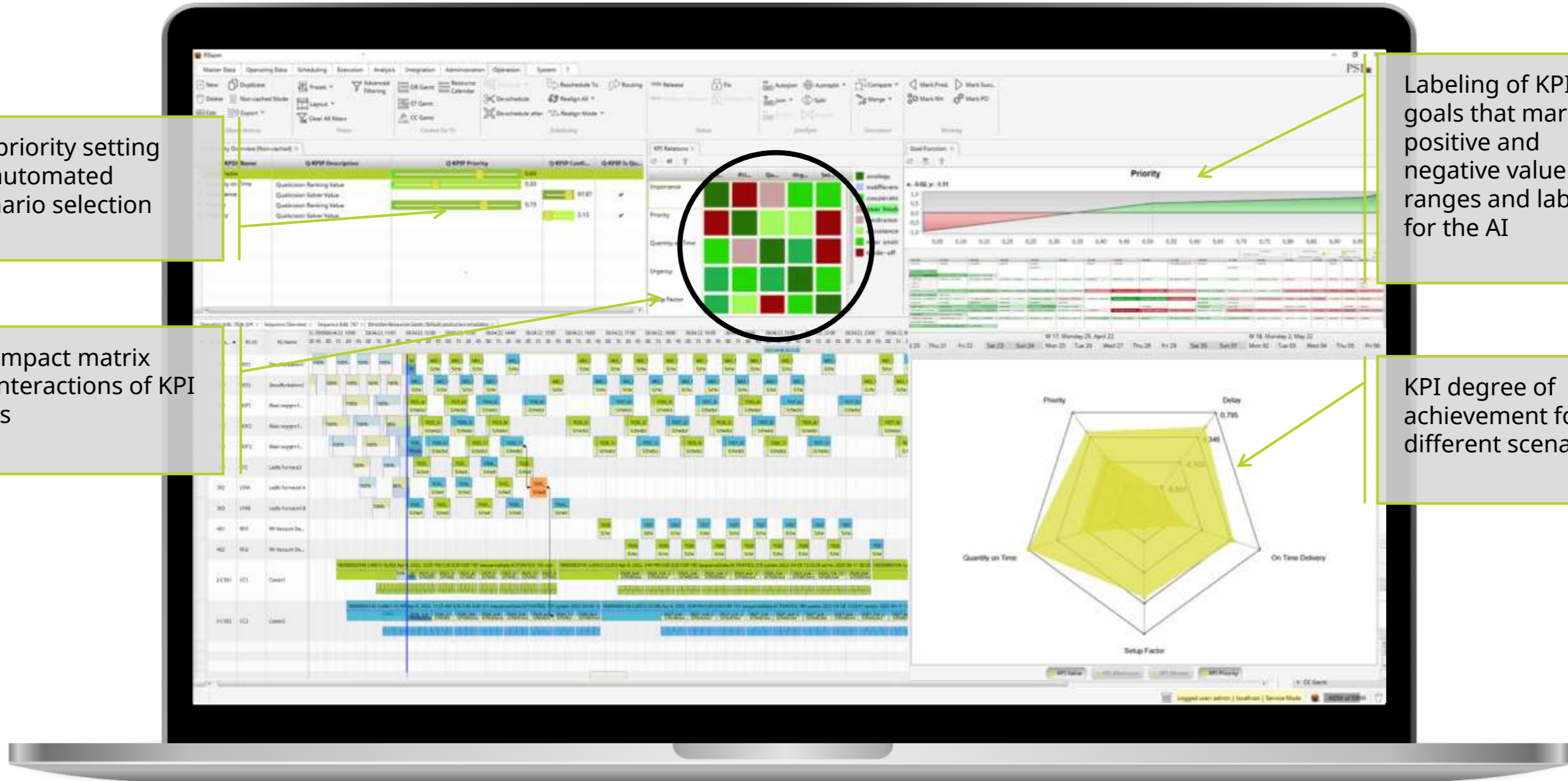
Online Heat Scheduler— KPI Dashboard to Analyze and Optimize the Balancing of Classical and Green KPIs

KPI priority setting for automated scenario selection

KPI impact matrix for interactions of KPI goals

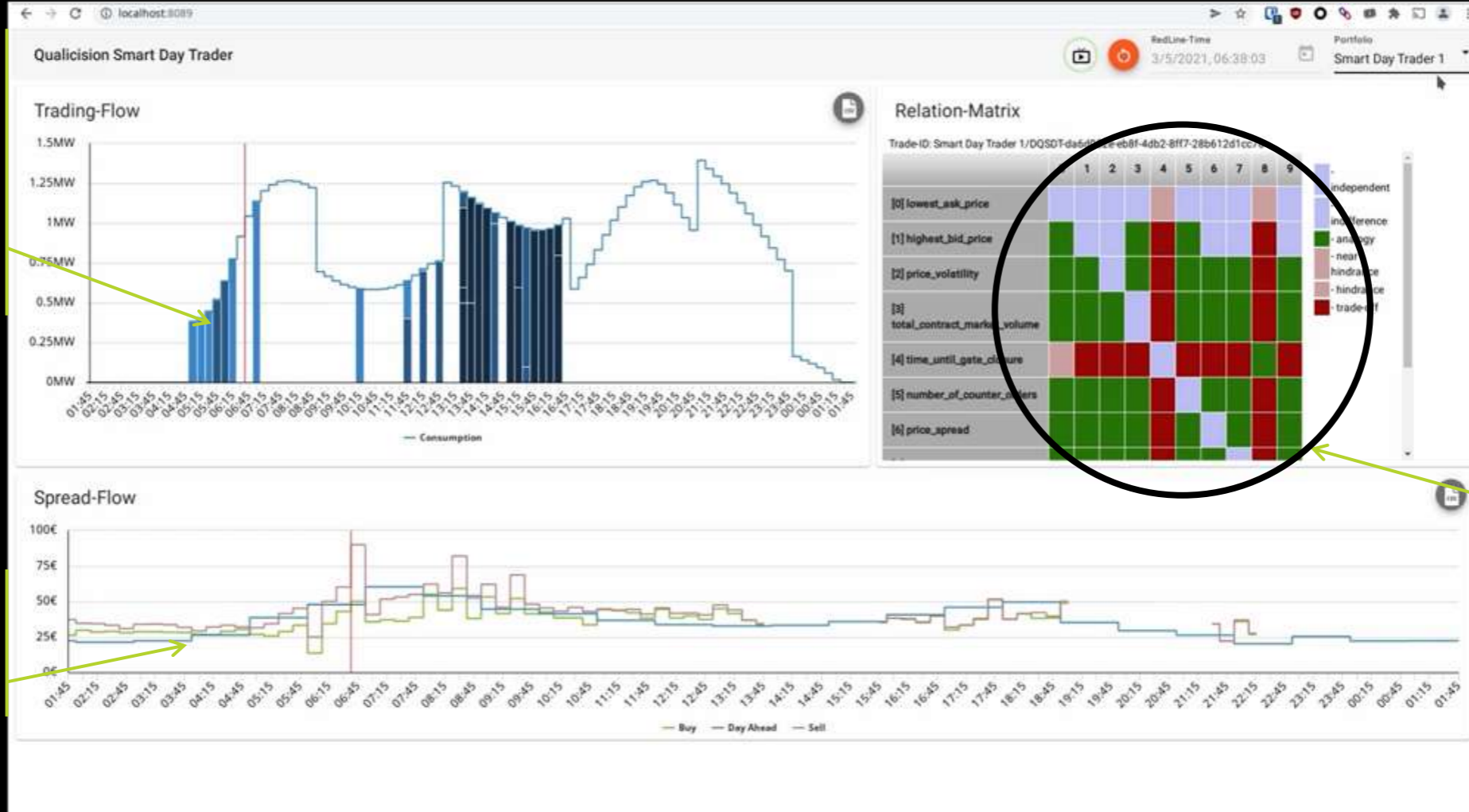
Labeling of KPI goals that marks positive and negative value ranges and labels for the AI

KPI degree of achievement for different scenarios



Green KPIs: Scheduling as a Demand Profile Provider for AI Decision Criteria for Energy Trading

Energy demand history or energy demand forecast with partially executed trades



Purchase prices, sales prices

KPI balancing in the trading process

Qualicision AI Scheduling: Alternative Scenarios

The screenshot displays the Qualicision software interface with two Gantt charts and two KPI radar charts. The top Gantt chart is sorted by priority, and the bottom one is sorted by due date. The right side features two KPI radar charts: 'Qualicision Radar' and 'KPI Relations'.

Gantt sorted by priority

Gantt sorted by due date

Qualicision Radar

- LeadTime
- Workload
- SetUpTime
- DueDate
- Priority

KPI Relations

- 19 Workload
- 4 DueDate
- 7 LeadTime
- 10 Priority
- 13 SecondaryResources

Legend for KPI Relations:

- independent
- assistance
- near cooperation
- cooperation
- near analogy
- near hindrance
- hindrance
- trade-off

AI Technologies of PSI Group for Production Industry



Online Heat Scheduling

- parallel processes
- Transition periods time critical
- resource scheduling by AI-based optimization



Predictive Quality

- Reduce & avoid defects in advance by using AI
- Self-tuning quality control business process
- Process Control in Process Industry



Production

- Material availability based on optimized inventory
- Long campaigns due to equal diameters and alloys
- setup times and processing times



Sequencing

- Sequencing based on
 - physical order properties
 - workload-oriented production times
 - flex resources with AGVs as PSI swarm production



Logistics

- Anomaly detection and improvement of planning quality by AI
- Evaluation of shipment data to generate multi-criteria transport tariffs

...

AI Technologies of PSI Group for Energy Industry



Operation Management

- Asset management
- AI-based planning and dispatching
- Maintenance, incident, crisis, shift management



Grid status

- Intelligent security applications
- AI algorithms for pattern detection
- Visualization grid status



Transport

- Predictive grid control by AI technology
- Consideration and balancing of technical evaluation criteria



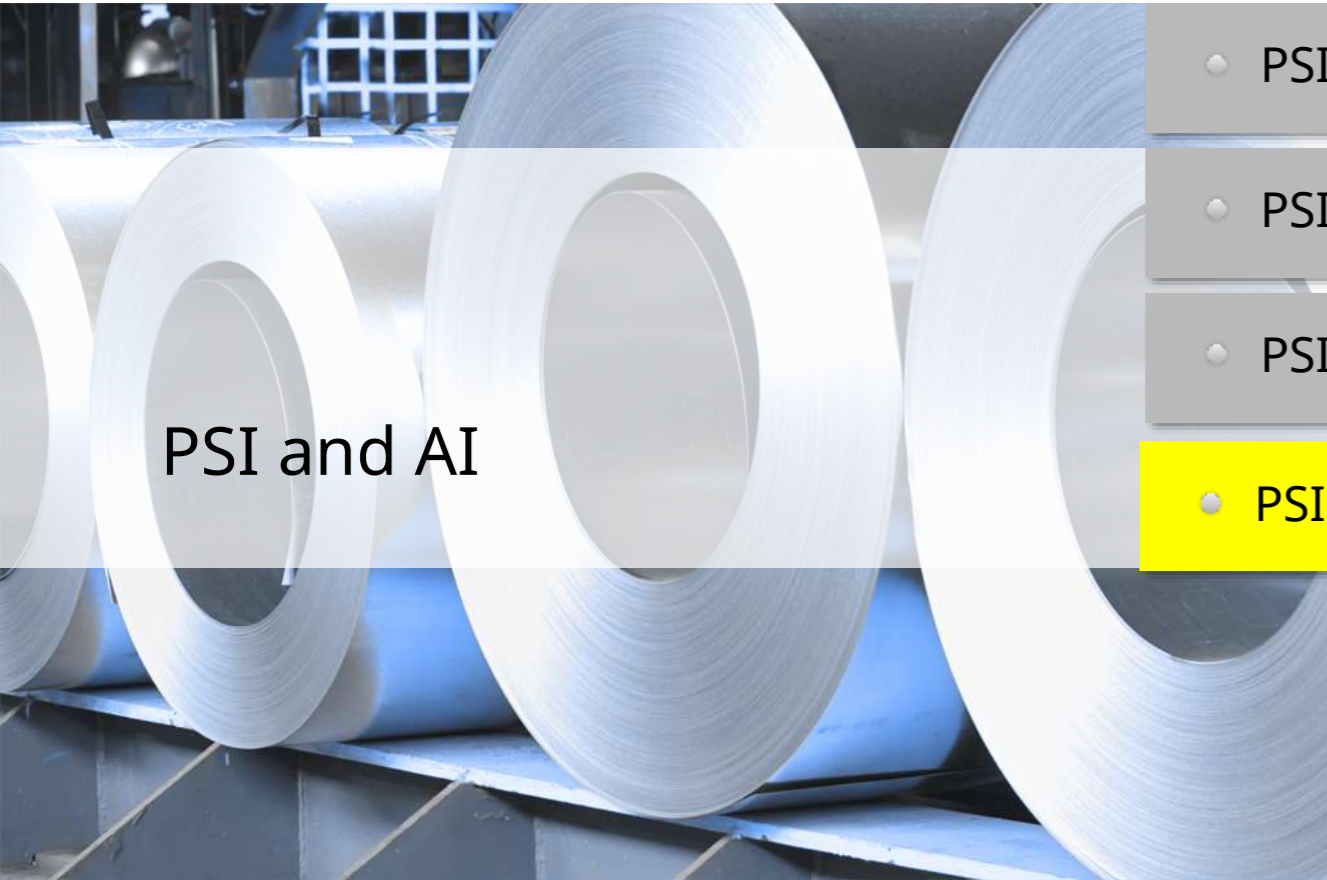
Grid guidance

- Active grid operation guidance with AI
- Sustainable integration of decentralized renewable energies
- Realization of powerful load infrastructures



Trading

- Trade decisions by Explainable AI
 - Intuitive Handling of KPI and trade preferences
- ...



PSI and AI

- PSI and Industrial Artificial Intelligence
- PSI Metals and Artificial Intelligence
- PSI Qualicision AI
- PSI Metals and Qualicision AI

Production Management and Machine Learning Potential

Demand and Order data

- Delivery time prediction
- Lead time prediction/Correction
- Supplier classification

Planning and scheduling data

- Plan quality & feasibility
- Schedule quality & feasibility
- Plan KPI & Schedule KPI

Equipment Data

- Percent Reactive Maintenance
- Maintenance Cost/Replacement percentage
- Overall Equipment Effectiveness
- Mean Time Between Failure
- Time Until Failure

Quality Data

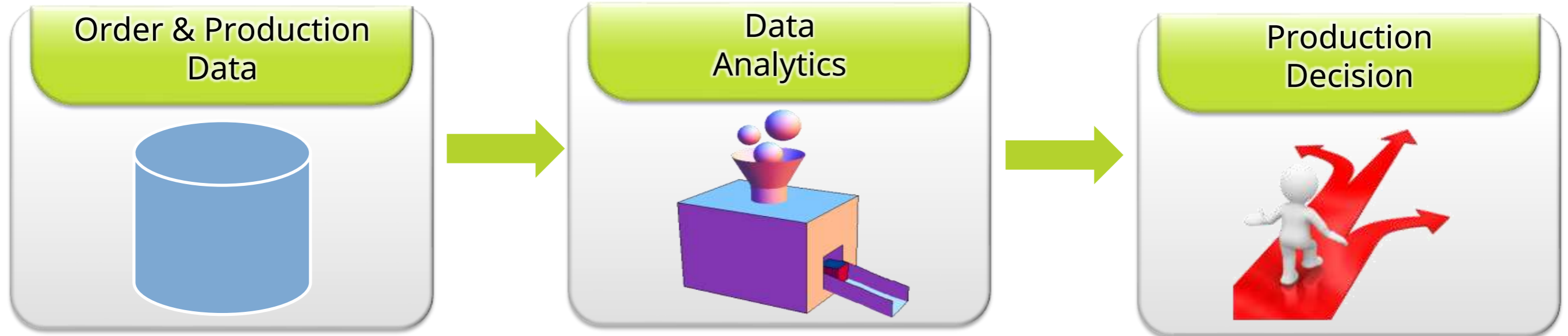
- Quality Indicators
- Test & Defect KPIsd
- Root cause correlation

Yard data

- Inventory Turn Time
- Composition Mix Status
- Overload/Underload KPIs
- Movements KPIs

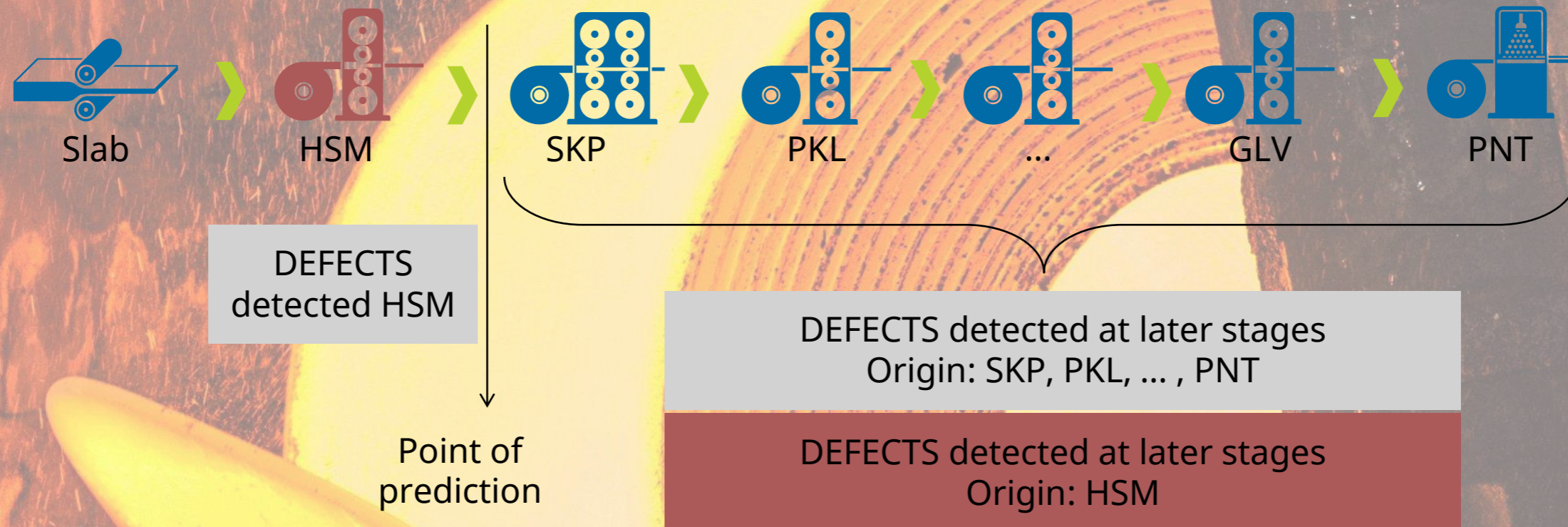
Material Unit Data

- Defect detection
- Defect prediction
- Order Assignability/Popularity
- Quality Classification



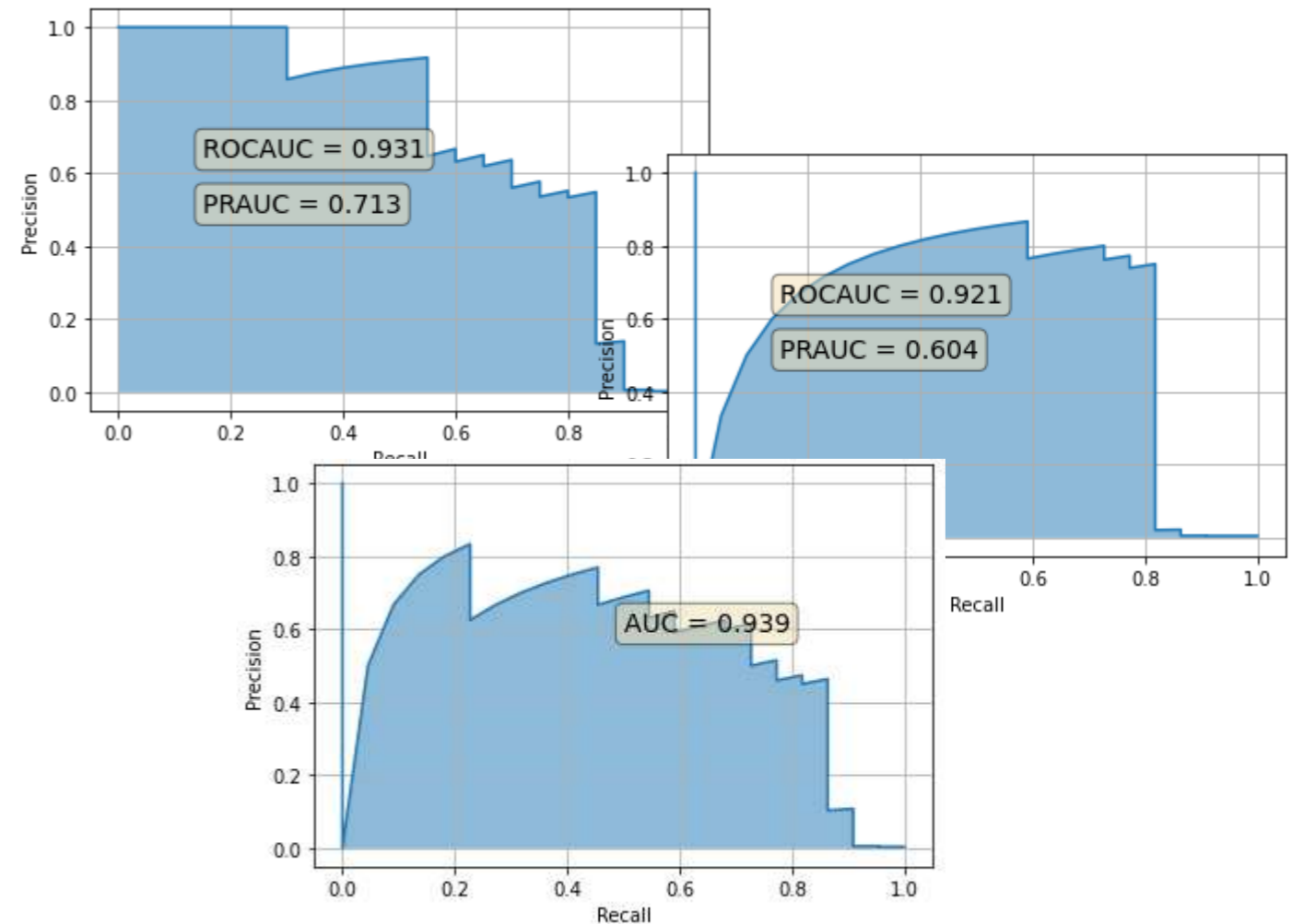
Predicting defects originated in HSM

- Model predicts the probability of a defect that **originates** in HSM but is **detected** at ANY later stage
 - So-called „hidden defects“ – created at HSM but only detected at later stages in the process
 - Based on material characteristics and furnace / HSM characteristics when material exits HSM
- Defects could be originated and detected at Casting stage



Predictive Quality for coil defect detection - results

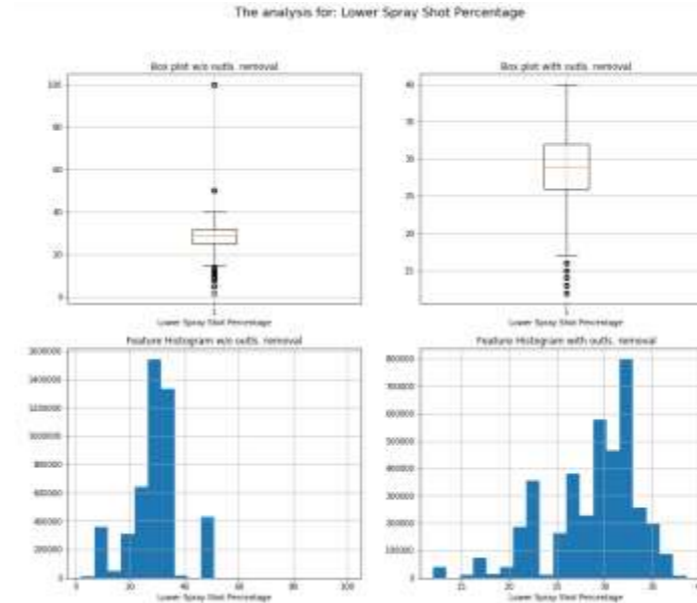
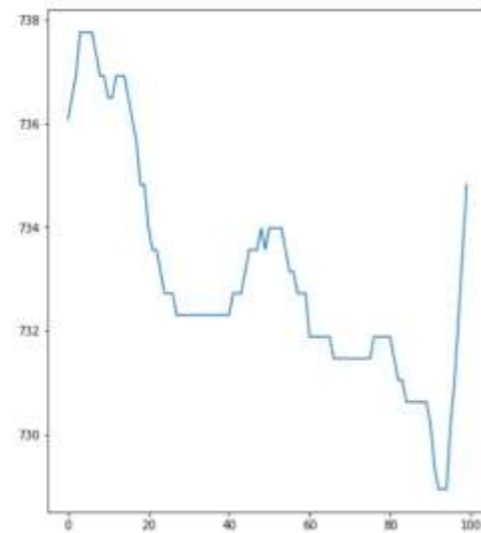
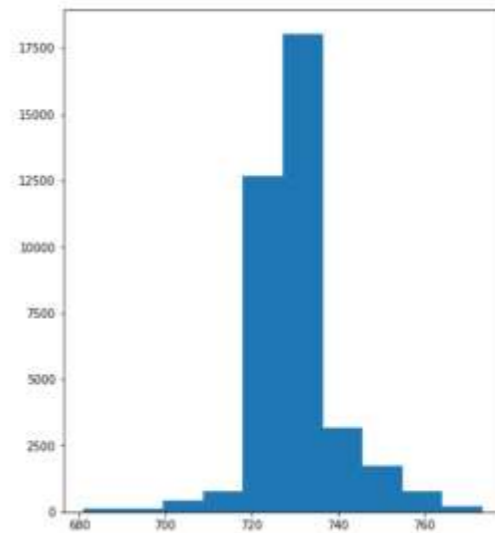
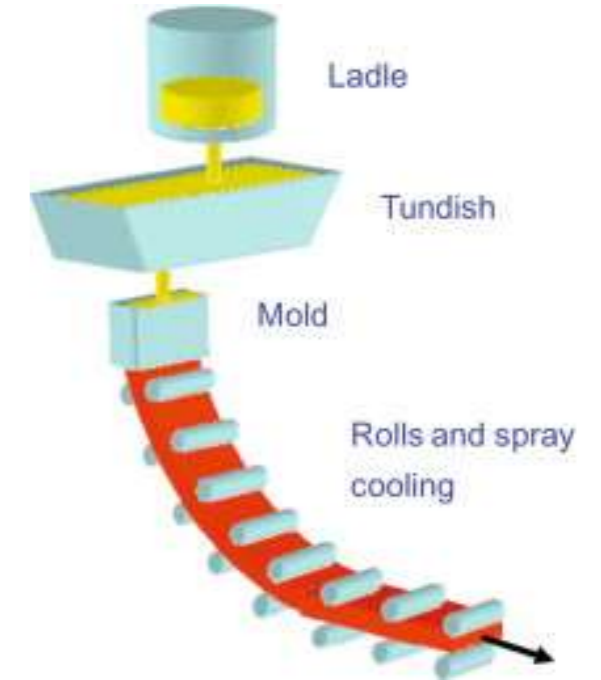
- The results have been obtained with RNN(static+dynamic) and Gradient Boosting methods
- Both static and dynamic features have been considered
 - static features: material/coil meta-information
 - dynamic features: selected sensor time series
- Satisfactory AUC result: 0.931, 0.939, 0.921
- Obtained accuracy: > 95%



Continuous casting process

Root cause analysis coil defects based on machine learning

- Similar use case, but the data is gathered at the level of continuous caster
- Aluminum production
- Slow coil casting process



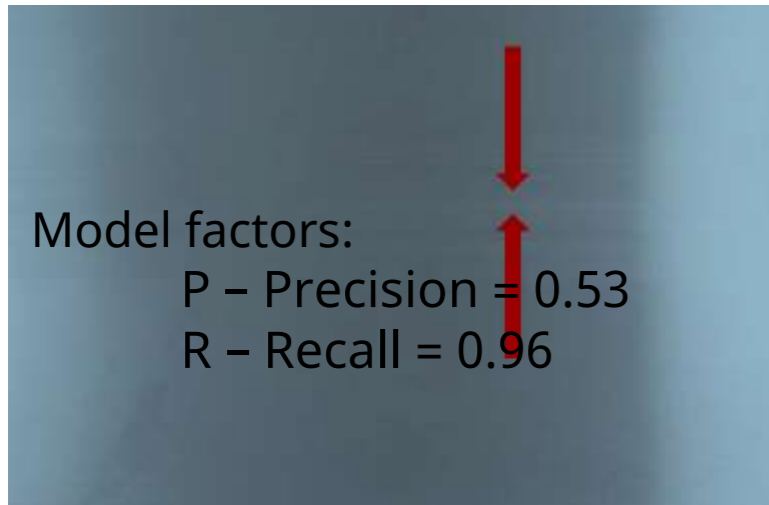
<https://www.sciencedirect.com/topics/engineering/continuous-casting>

Defect reduction at Al. Producer using Prediction Models

DEFECT TYPE

Scuff Types

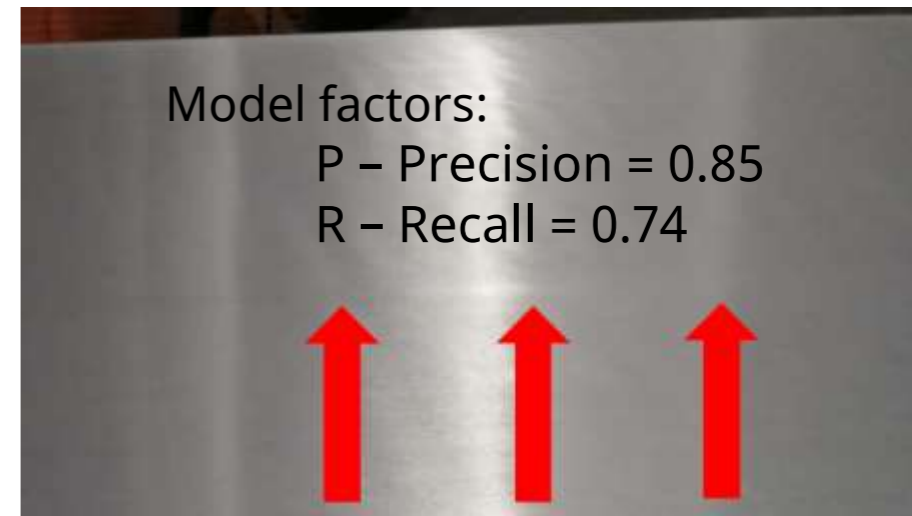
Type scuff mark is a surface defect that occurs as thin lines parallel to the casting direction. Possible defect causes: small distance between the tip lip and the roller surface.



DEFECT TYPE

E-band


E-band defects are surface defects in the cellular structure lined up on the plate surface. Possible defect causes: insufficient grain refiner feed, very high casting temperatures, low tior level




Defect type	Recall	Precision	B-TP [\$]	C-FP [\$]	Profitability/coil	Occurence/year	OneYear
Case 1	0,48	1,00	4 750,00	1 200,00	2 280,00	200	456 000
Case 2	0,74	0,85	4 750,00	1 200,00	3 335,00	200	667 000
Case 3	0,83	0,79	4 750,00	1 200,00	3 690,50	200	738 100

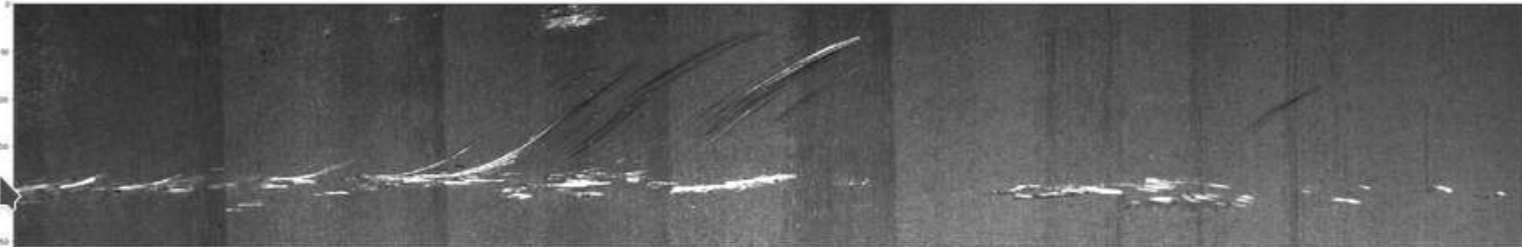
The Convolutional Neural Network: defect detection

- CNN model correctly marks large spot as a defect
- There are additional areas marked as defects
- Perhaps outperforms the reference segmentation

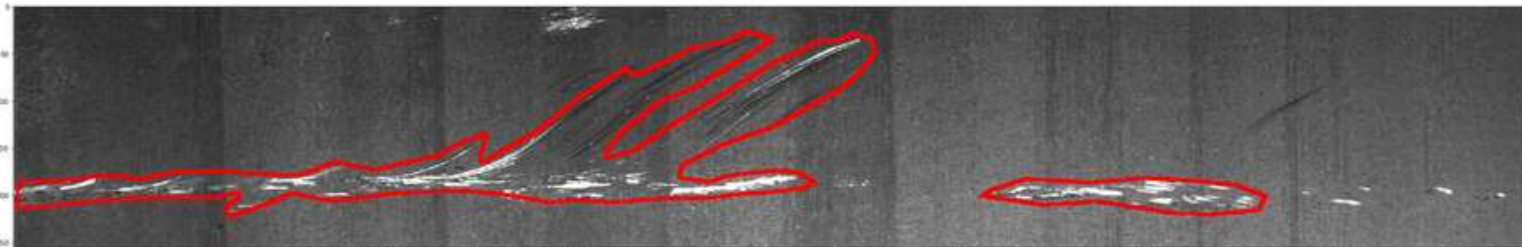
 Reference label
(human being)

 CNN model detection

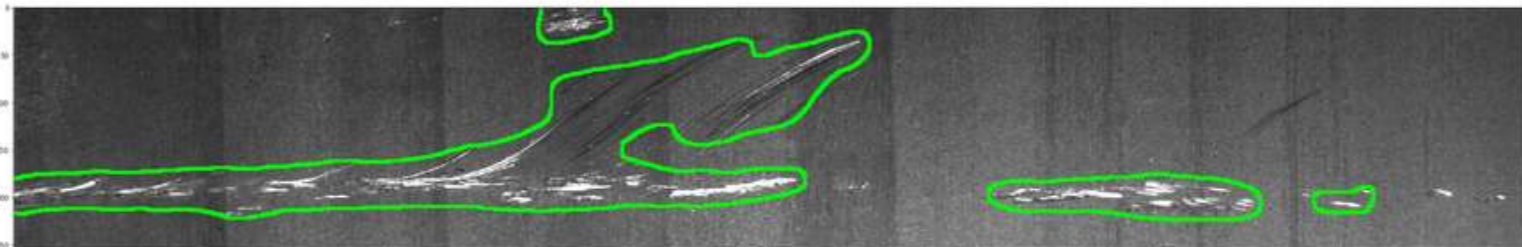
original



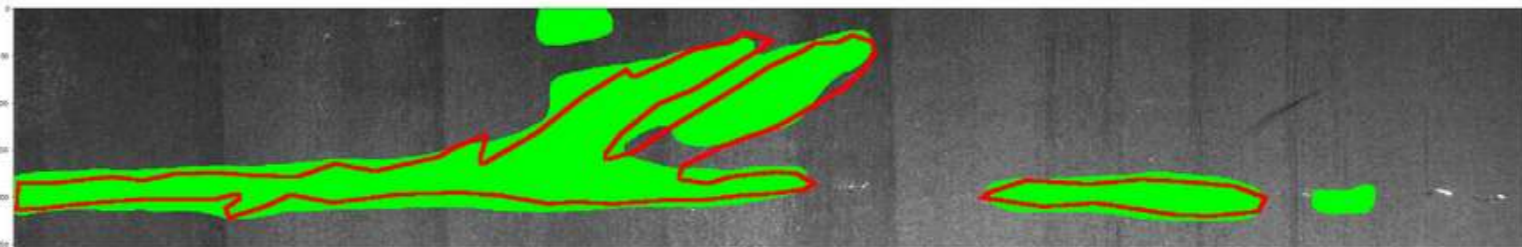
defects labeled by human being (ground truth)



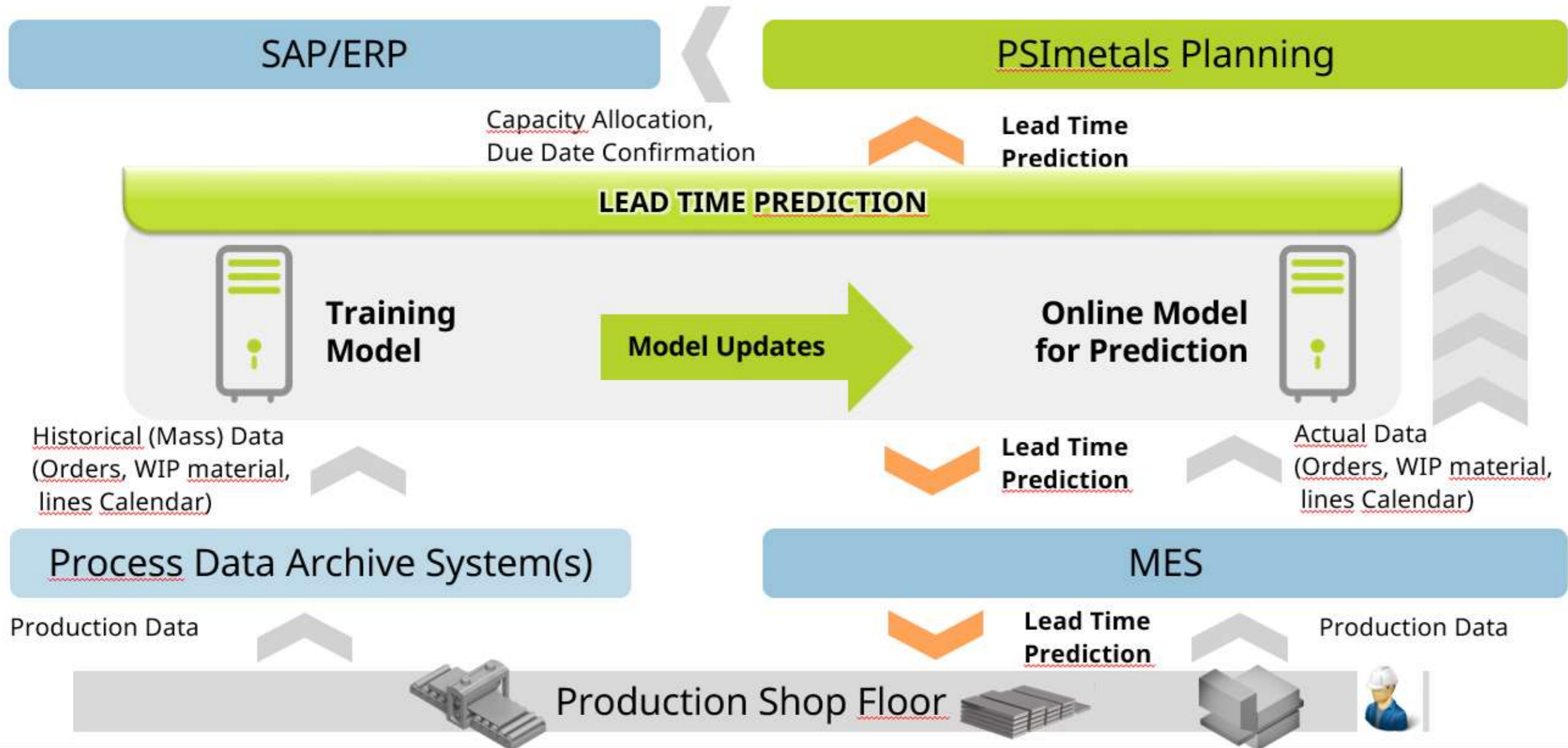
defects detected by PSI CNN-based approach



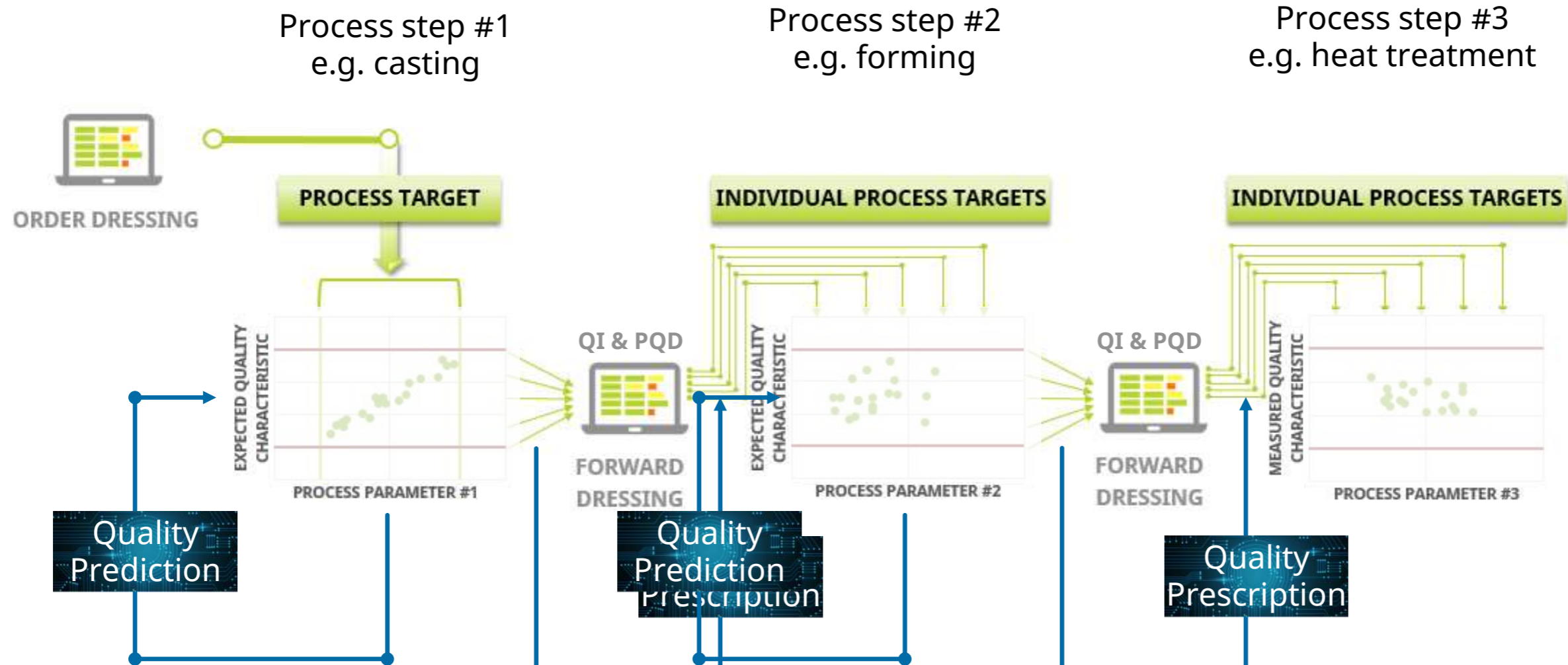
ground truth + CNN-based approach



Delivery Time and Lead Time prediction

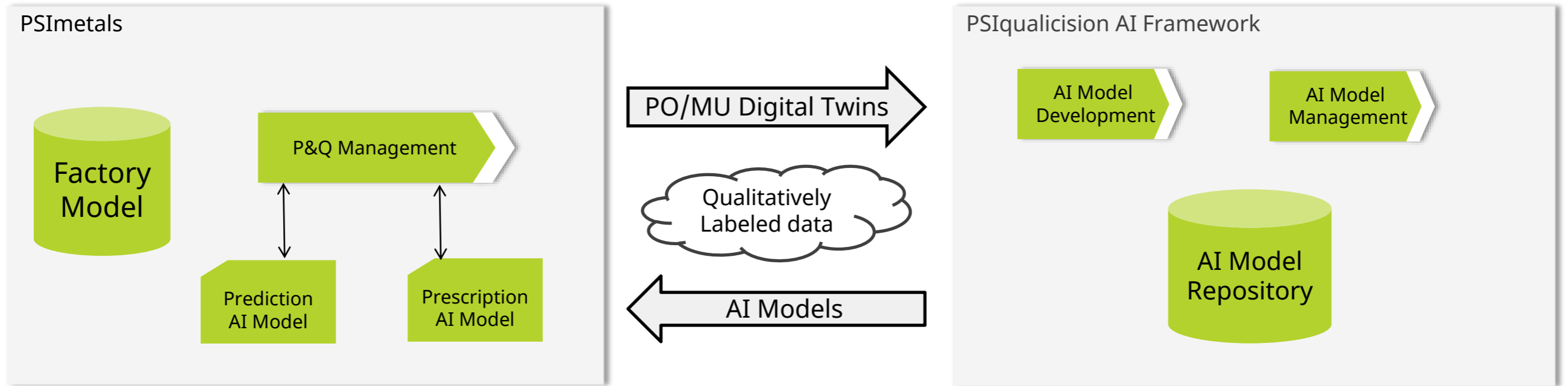


How can PSImetals integrate ML algorithms?



Integrating predictive and prescriptive models into PSImetals Quality enables closed-loop, reactive dynamic process optimization for best quality control.

Integrated PSImetals Quality & PSQualicision AI Framework

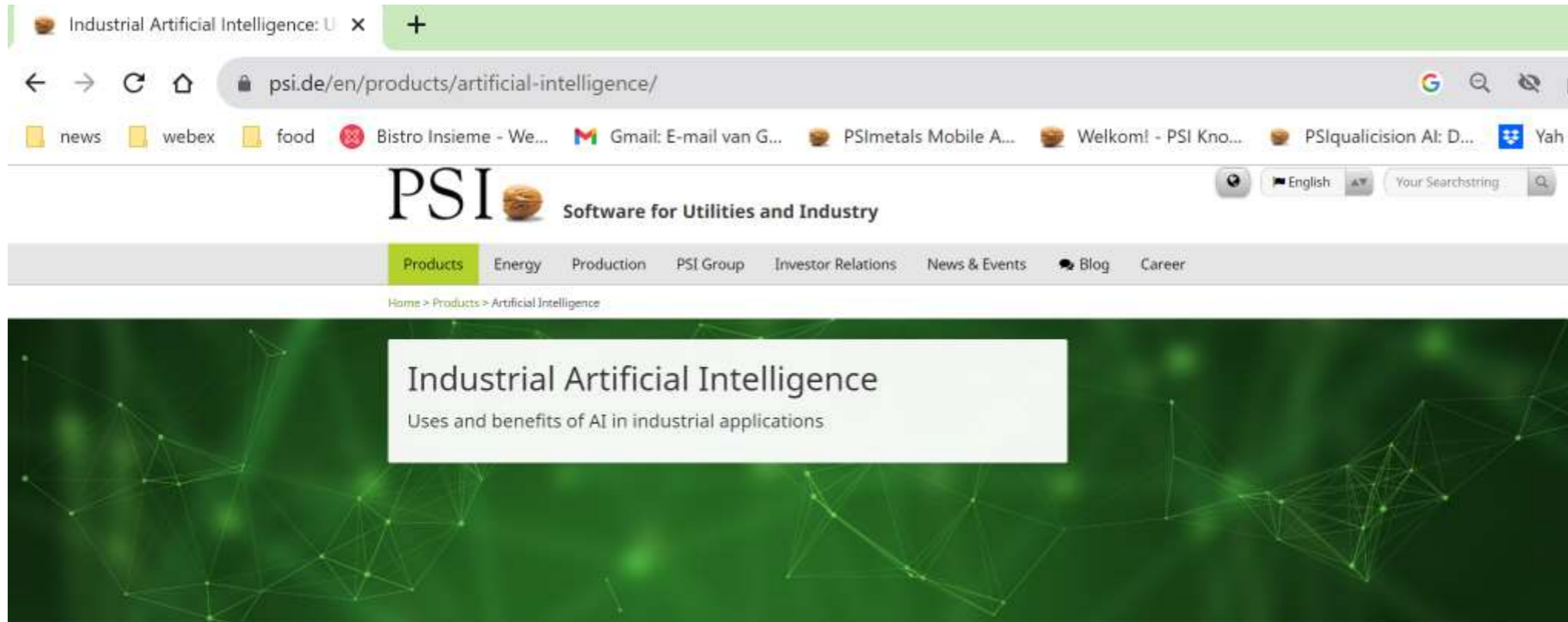


PSImetals Production & Quality

PSQualicision AI



PSI and Artificial Intelligence



Companies use **Industrial Intelligence** to gain significant advantages over their competitors. By cleverly combining various AI methods, they can

- ✓ **continuously save time and costs,**
- ✓ **optimize and automate routine processes,**
- ✓ **increase productivity and efficiency,**
- ✓ **improve sustainability and**
- ✓ **make faster and better decisions.**



Why to Change?

A paradigm shift in the way we source, produce, market, sell and provide support & service



Collaboration in supply chain (horizontal digitalization) for superior demand visibility

Standardization of data exchange & compatibility

Information Security

© World Steel Association

PSI for Aluminium

Production - Smelter

- MES Functions - capturing all measurement and production data – integrated downstream for casting and rolling or extrusion
- Supply Chain Optimization

Energy

- Energy consumption
- **Balancing** energy with providers
- **Peak harmonization**
- **Forecasting** Energy – provision and consumption

Anodes

- **SPC** to see the energy consumption
- **Forecasting** change of anodes –use of ML
- Equipment management for anodes

Planning

- **Alloy and Charge** calculation and optimization – integrated with planning
- tapping process – especially downstream required for casting incl. **Tapping Decision**
- together with energy
- **Crucible Management**
- **Transport Management**
- Supply Chain **Optimization**
- **Integrated Planning – cross plant and production**

Quality

- **Quality data** – chemical analysis
- Process Control
- **Quality Decision**
- **Quality Indicators**
- Predictive quality
- SPC – by pot for various values (Temperature, electricity, time, etc.)
- **Predictive maintenance**
- **Predictive Quality**

Production Downstream

- Casting
- Rolling or Extrusion – **process manufacturing**
- Processing – **discrete manufacturing**

Yard Management

- Yard Optimization
- Crucible Management
- Piece Tracking
- Transport Management Optimization

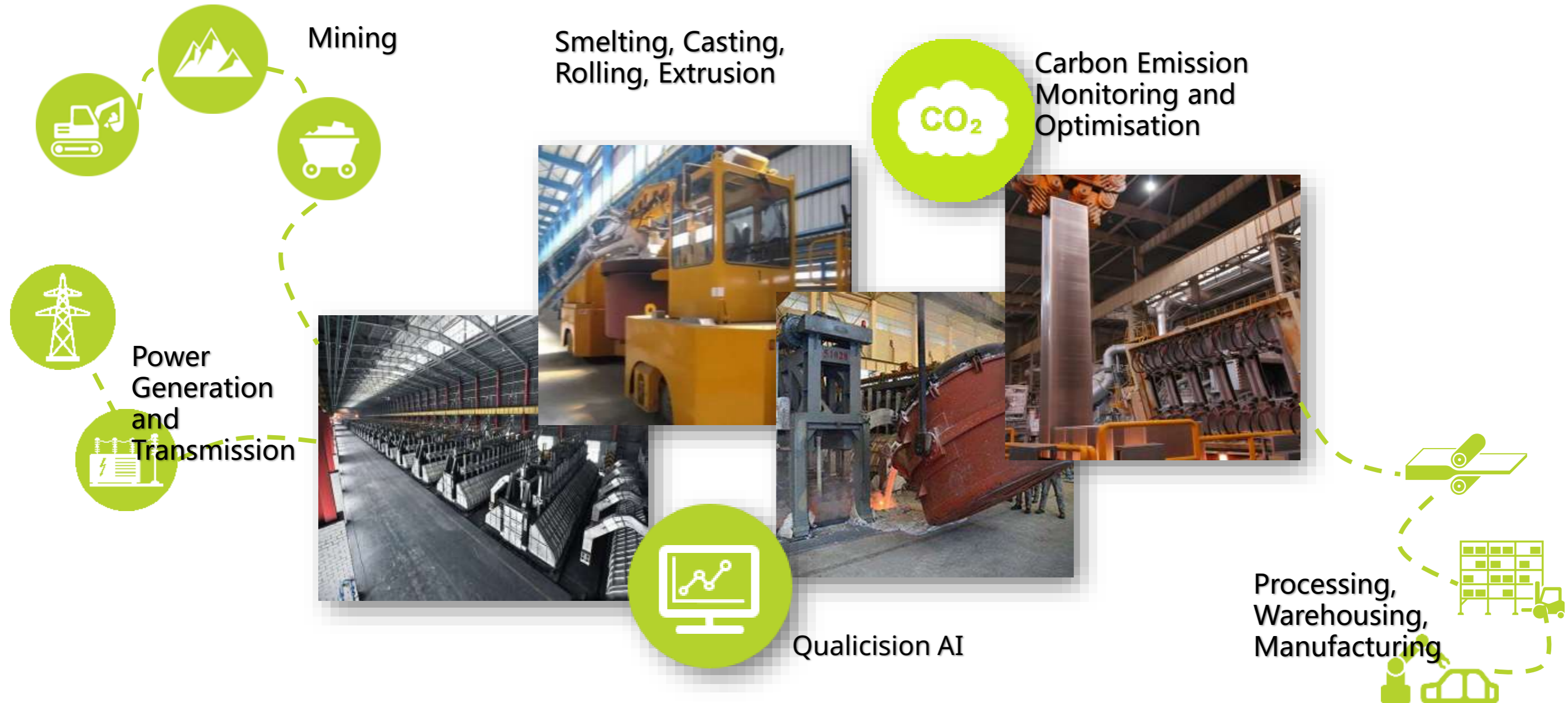
Equipment Management

- **Mold** Management
- **Die** Management
- **Roll** Management
- **Anode** Management
- **Crucible** Management

Consulting

- **Industry 4.0**
- Planning & Production Management

PSI – Intelligent Solution for the entire value chain



MES & Planning

- Process-Production – Liquid and Solid
- Discrete Manufacturing
- Planning & Scheduling
- Order Combination and Material Planning

AI Solutions

- Qualicision AI
- Machine Learning
- Prediction Models

Planning

- Logistics & Yard Management
- Transport Management
- Crane and Fork-lift Management

Energy & CO2

- Energy Optimization
- Energy Balancing
- CO2 Planning and
- CO2 Tracking

Digitalization Requires Strength

Legal form **Corporation**
Established **1969**

2022

Employees

2.251

Sales

247.938 million €

EBIT

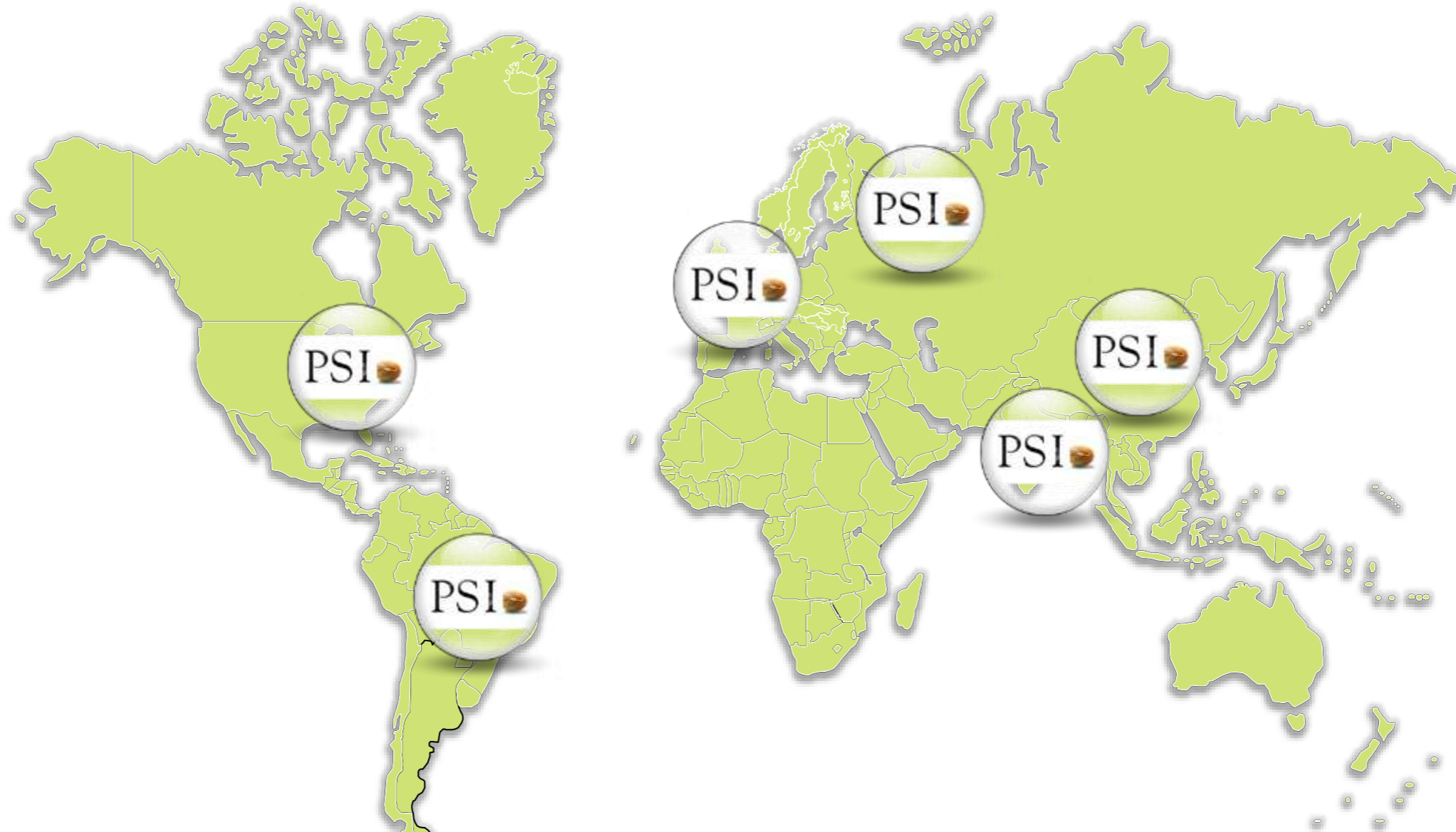
20.186 million €

Orders




















253.0 million €



World Wide Support



The Supplier for Aluminium Producers



Let's Connect!

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