Installed base monitoring for PSS business models: experiences from the T-REX project

Factories of the Future
Public Private Partnership

T-REX
INNOVATIVE STRATEGIES FOR RENOVATION AND REPAIR IN MANUFACTURING SYSTEMS

LIFECYCLE EXTENSION THROUGH PRODUCT REDESIGN AND REPAIR, RENOVATION, REUSE, RECYCLE STRATEGIES FOR USAGE&REUSAGE-ORIENTED BUSINESS MODELS

F. Peysson, D. Léon, C. Mozzati, R. Aras, JB. Léger

PREDICT

Content

- Short Presentation of PREDICT
- Values, Services, Practices, Models and Objectives driving T-REX
- T-REX Activities and Results
  - Fleet Management platform and services
  - Machinery Use Case
  - Robot System/Automation Use Case
  - Transportation/Industrial Vehicle Use Case

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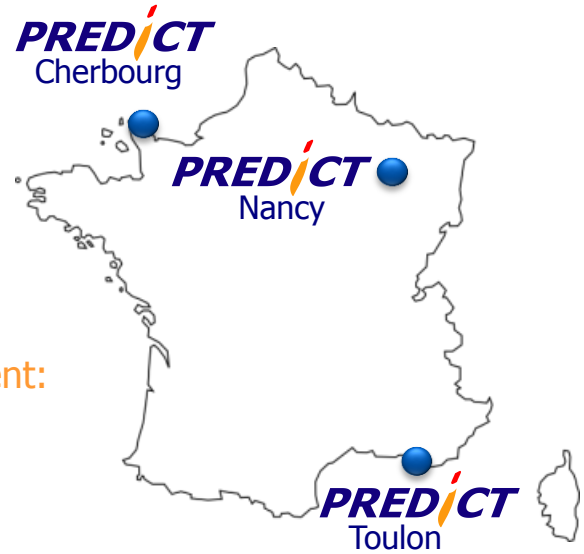
PREDICT®

Anticipate & Save®

Prognostics & Health Management

Management

- ✓ CEO: Dr. Jean-Baptiste LEGER
- ✓ CTO: David MOREL
- ✓ CSO: Pr. Benoit IUNG



Business

- ✓ Digital Technologies for Prognostic & Health Management:
  - ⇨ Realtime Monitoring
  - ⇨ Prognostic / Anticipation
  - ⇨ Health Management
  - ⇨ Investigation

Key Figures

- ✓ Investment in RTD: > 7 M€
- ✓ Equity: ~1 M€
- ✓ Treasury: ~400 k€
- ✓ Sales: 1,25 M€
- ✓ People: 14 Engineers

LORN TECH

PREDICT : Key Facts

10 000+
Monitored equipment

Industrial

10+ years
Of operation

Reliability

1 000+
Users

Efficiency

3-6
Months

Payback

15-25%
Increase of production

Performance

30-45%
Less downtime

Profitability

PREDICT "Vertical" Solutions

CASIP Engineering

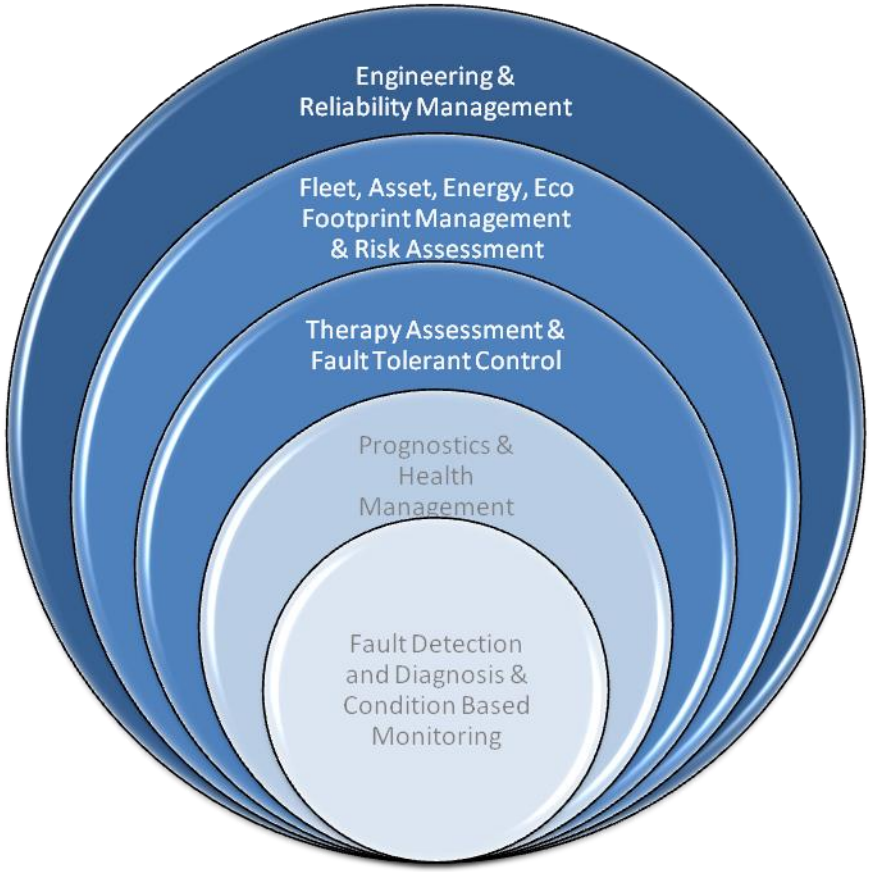
- Function / Flow
- HAZOP / FMECA
- FTA / RCA
- Reliability Analysis

KASEM

- Therapy Assessment
- Fleet Wide Monitoring
- Health Management
- Diagnosis / Investigation / Prognosis

CASIP

- Fault Localisation
- Fault Isolation
- Fault Detection
- Condition Monitoring

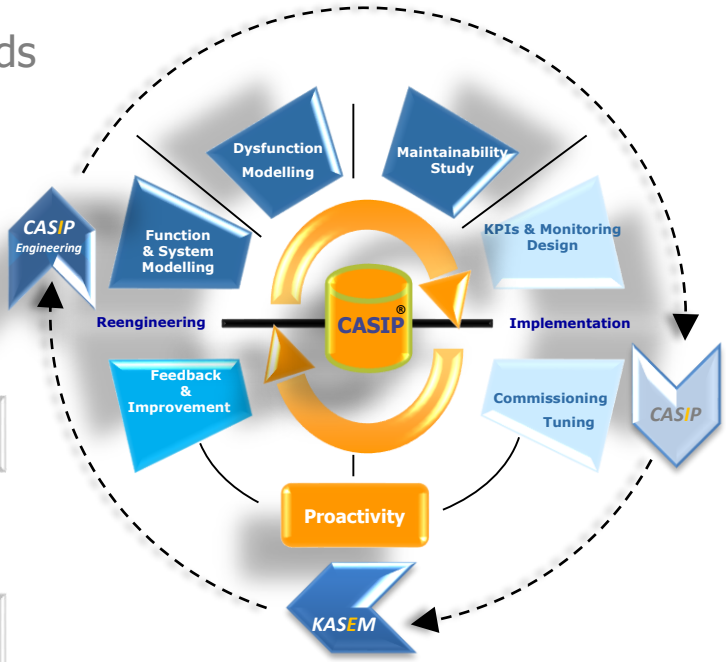


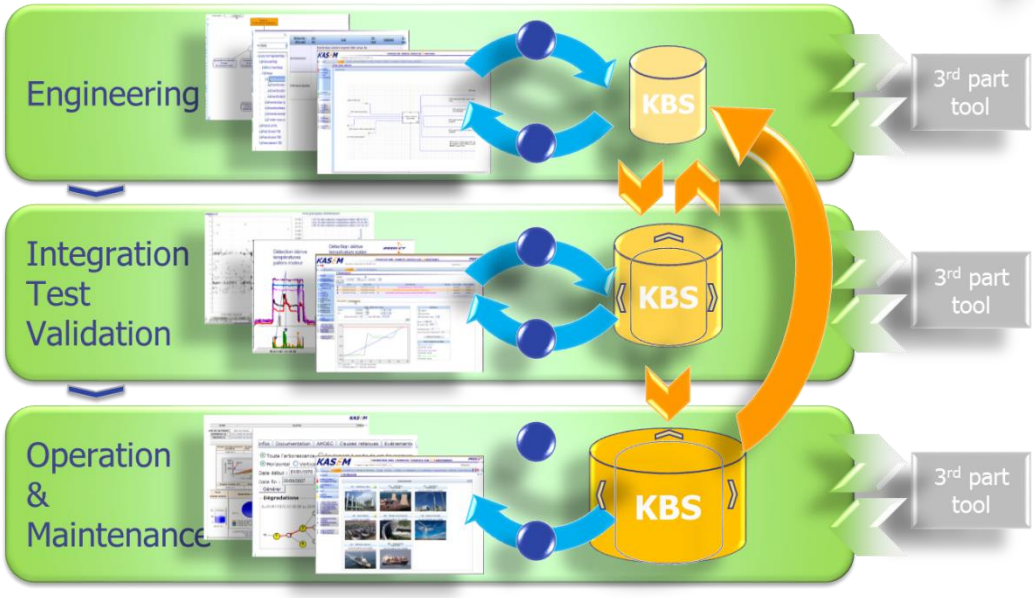
PREDICT Solutions Foundation

System Engineering to structure Knowledge and to increase Efficiency of Diagnostics, Prognostics, Health Management and Proactive Therapy.

Set of Integrated Concepts and Methods

- ✓ help in the knowledge expression,
- ✓ organise and structure knowledge,
- ✓ further operation, feedback and improvement.





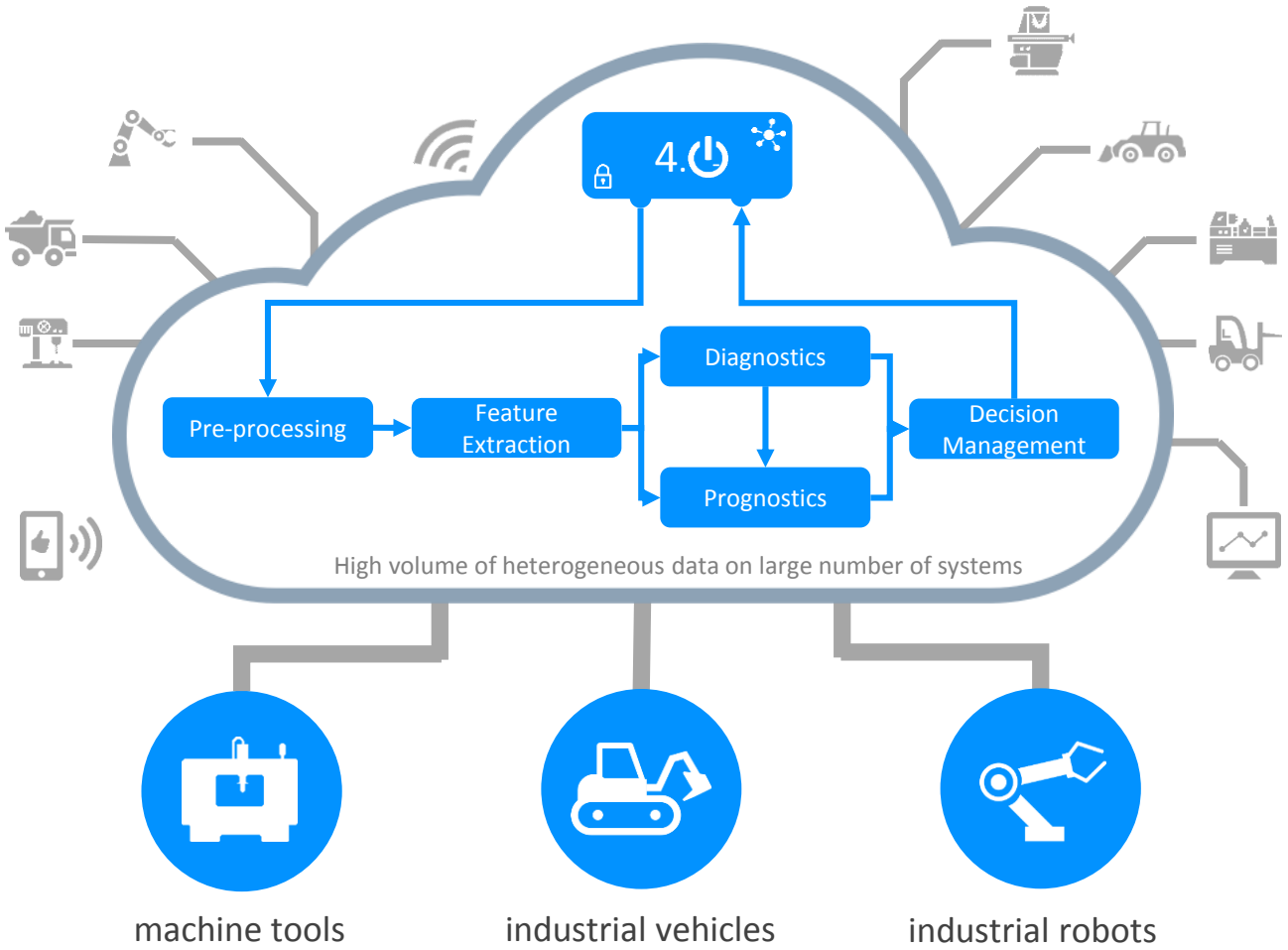
LabCom PHM-Factory

PHM FACTORY

Consolidate
Development of advanced and generic PHM algorithms

Expand
Adaptable engineering for fast deployment of PHM solutions

Explore
Embed these solutions on industry 4.0 targets



Towards new PHM solutions based on the **I**ndustrial **I**nternet **O**f **T**hings

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New Usage / New Services / New Business

UNIVERSITÀ DEGLI STUDI DI BRESCIA

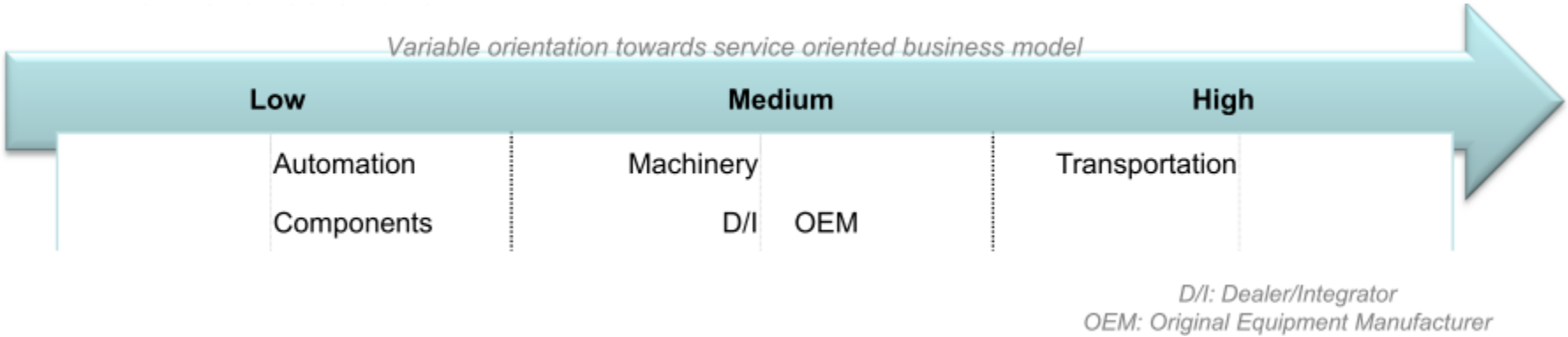
- How business models of companies that operate in capital goods sector such as machinery (machine tools), automation (robot systems) and transportation (forklifts trucks) are configured?

- Which are the main drivers/obstacles toward the implementation of usage-oriented business models?

Customer value sources – general findings

UNIVERSITÀ DEGLI STUDI DI BRESCIA

- Main sources of value for customers are product performance, and product productivity.
- Moderately to quite important are product expected lifetime, customer image enhancement, customer minimization of operational risks, brand reliability.
- Moderate importance of value generated through minimization of customer maintenance efforts.

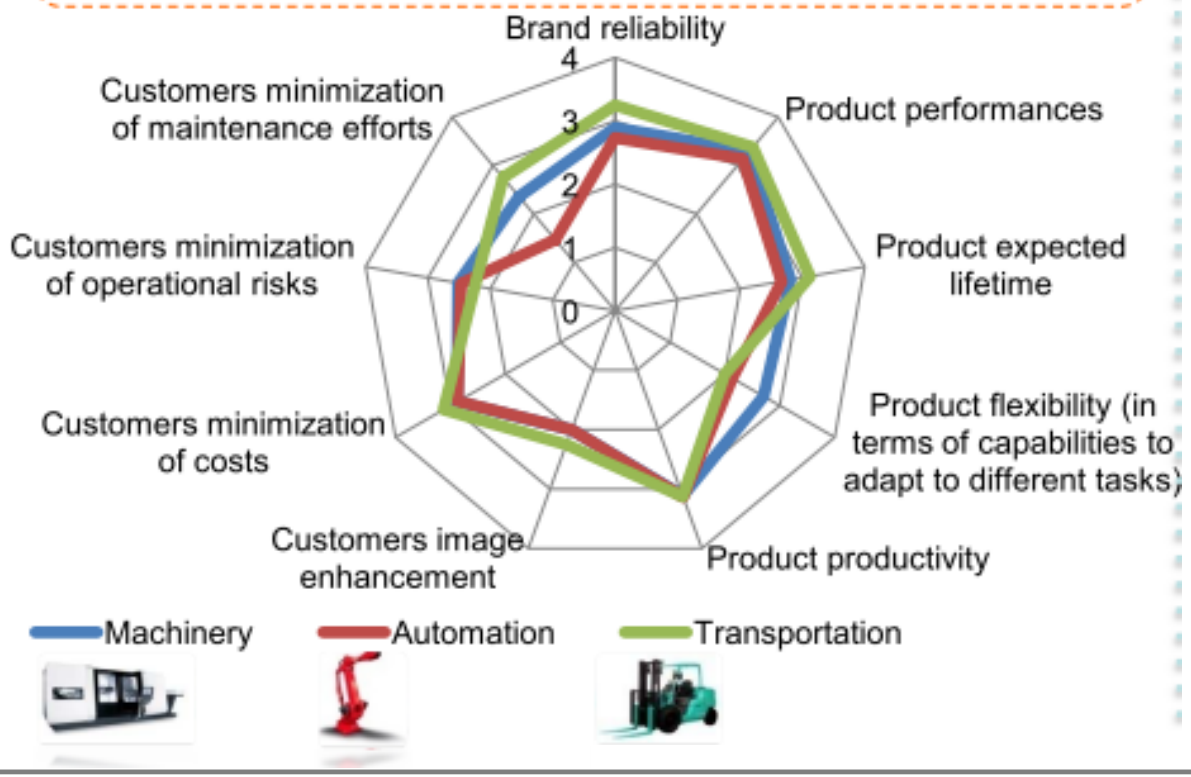


Customer value sources

UNIVERSITÀ DEGLI STUDI DI BRESCIA

Domains

Transportation: more customer oriented.
Machinery: more focused on flexibility.
Automation: less oriented towards maintenance.



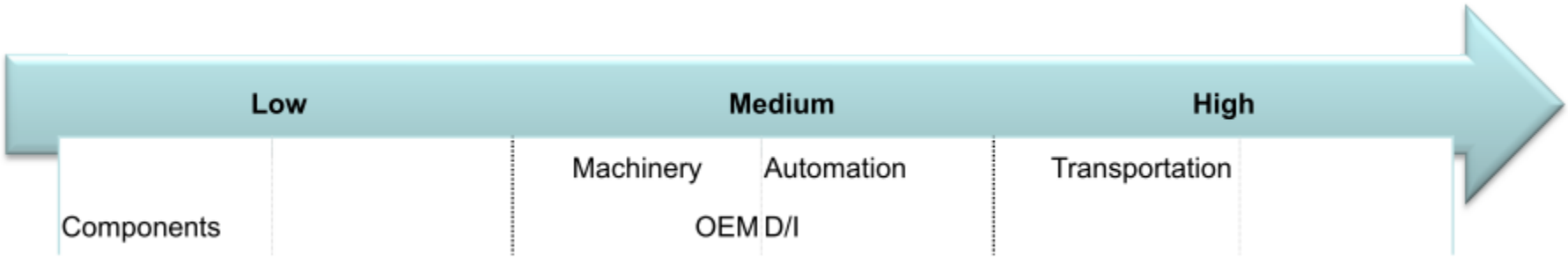
0 – Not at all
1 – Slightly
2 – Moderate
3 – Quite high
4 – Extremely high

Service offering – general findings

UNIVERSITÀ DEGLI STUDI DI BRESCIA

- Basic services are extensively offered (documentation, repair, spare parts, basic training),

- Advanced services are sometimes offered (advanced training, remote monitoring and product remote diagnosis, product upgrade/retrofit, warranty extension and maintenance contracts).

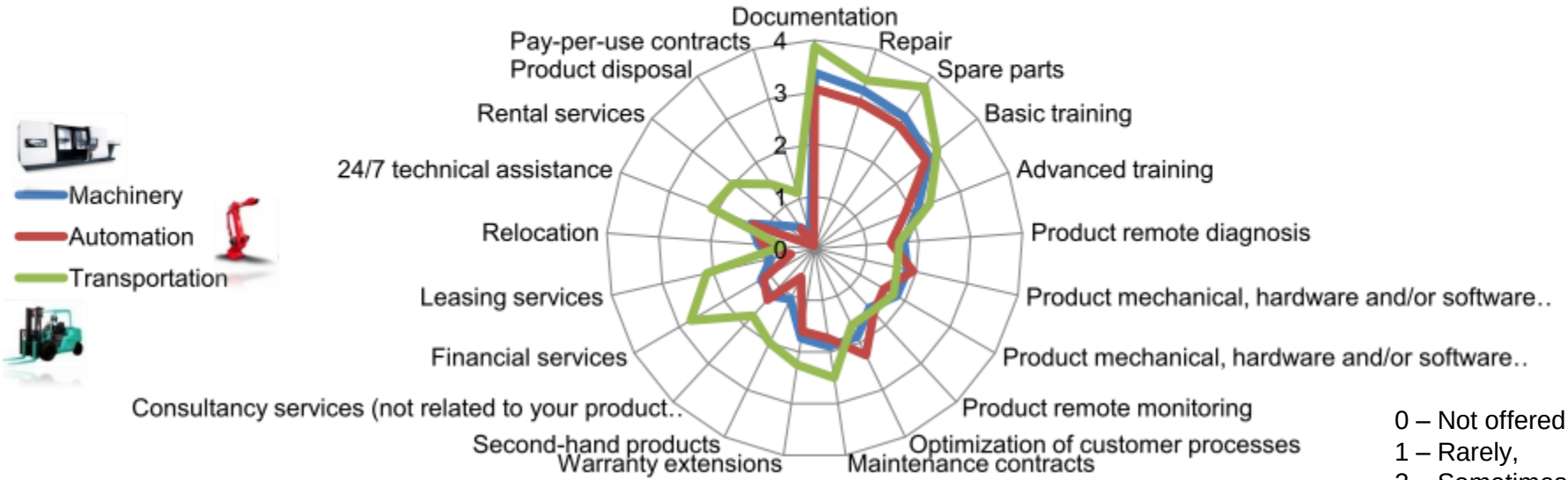


Service offering

UNIVERSITÀ DEGLI STUDI DI BRESCIA

Domains

Automation: Advanced services related to optimization of customer processes are sometimes offered.
Transportation: Some advanced services as financial services, leasing, second-hand services and rental are offered.



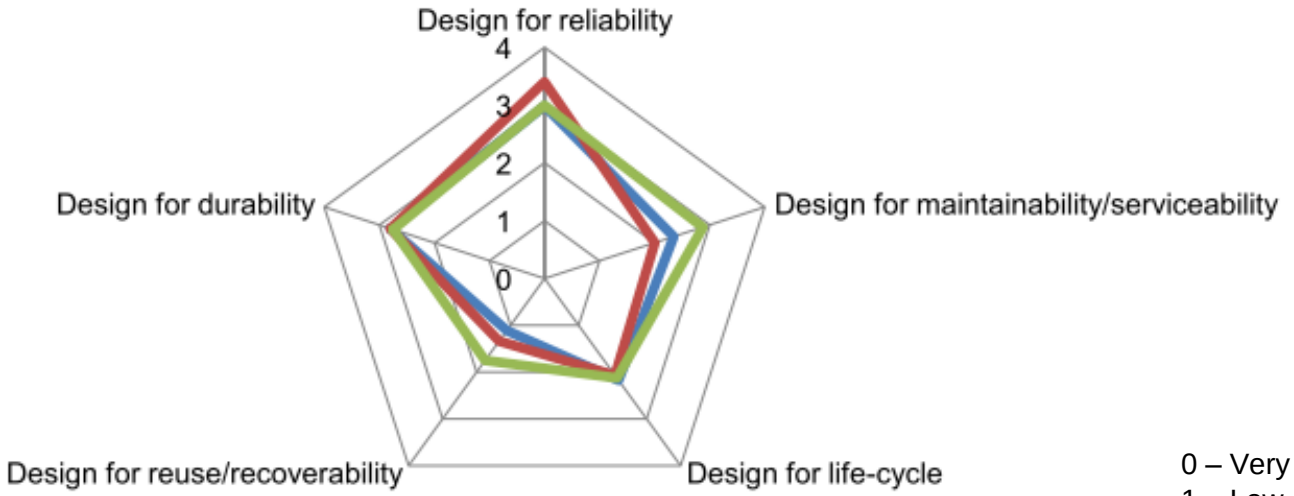
0 – Not offered
1 – Rarely,
2 – Sometimes
3 – Often
4 – Always

Adoption level of Design for X

Università degli Studi di Brescia

Domains

Transportation: High experience in the design for maintainability/serviceability and also medium experience in the design for reuse.



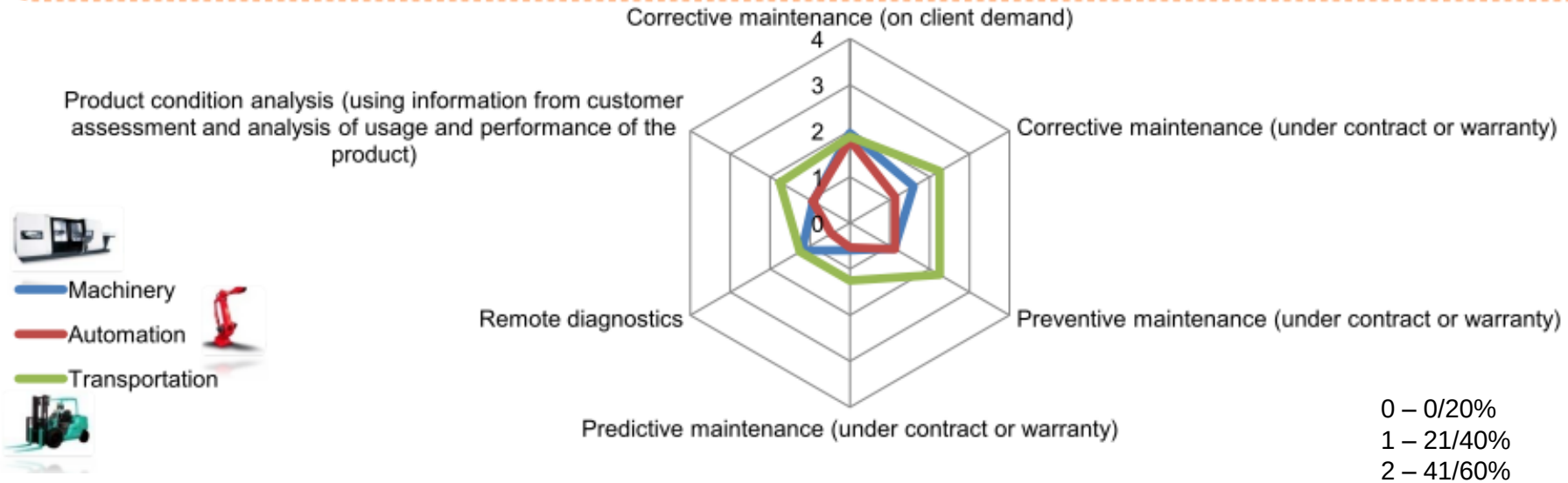
0 – Very low
1 – Low
2 – Medium
3 – High
4 – Very high

Fleet operation and maintenance practices

UNIVERSITÀ DEGLI STUDI DI BRESCIA

Domains

Machinery: companies perform predictive maintenance activities on less than 20% of their installed base.
Automation: companies perform remote diagnostics and predictive maintenance activities on less than 20% of the installed base
Transportation: companies perform preventive and corrective maintenance activities (under contracts or warranty) in average on 60% of their installed base and product condition analysis on 50% of their product.



0 – 0/20%
1 – 21/40%
2 – 41/60%
3 – 61/80%
4 – 81/100%

Revenue model

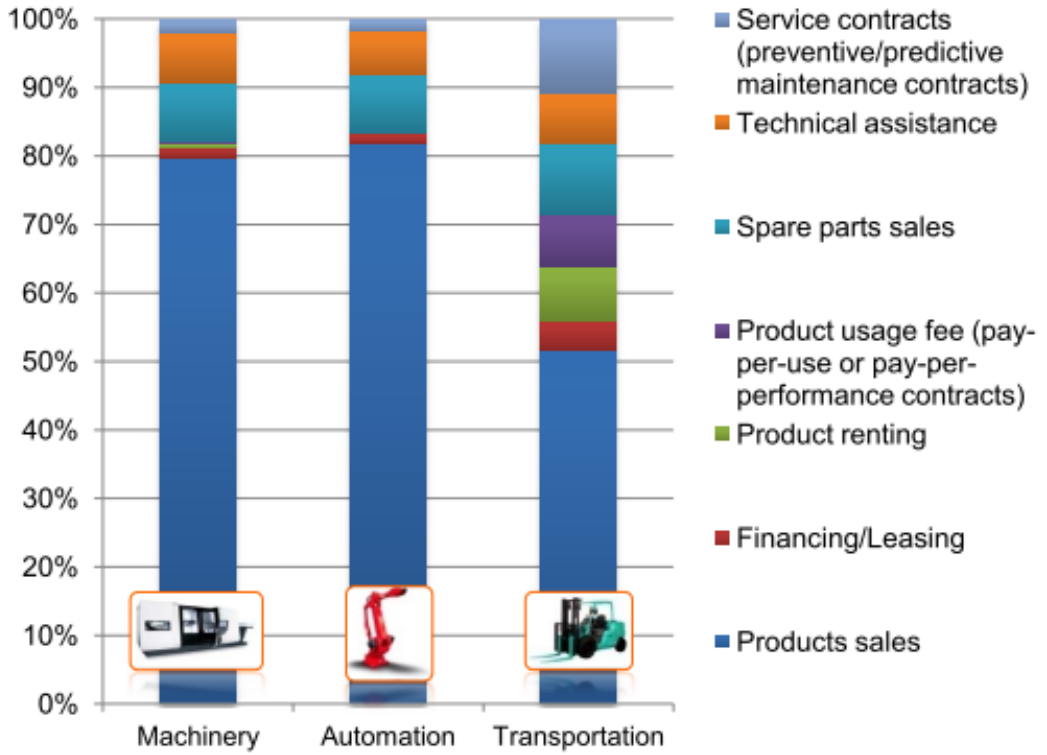
UNIVERSITÀ DEGLI STUDI DI BRESCIA

Domains

Machinery: Services represent only 20% of companies turnover. Service contracts and financing/leasing represent less than 2% each. Renting and pay-per-x contracts don't generate revenue.

Automation: Services represent less than 20% of the companies turnover. Service contracts and financing/leasing represent less than 2% each. Renting and pay-per-x contracts don't generate revenue.

Transportation: Service represent about 50% of companies turnover. Service contracts represent the main sources of service-related revenues (about 11%). Financing/leasing contribute to the total turnover for around 5%, renting and pay-per-x contracts for around 8% each.



Main findings

UNIVERSITÀ DEGLI STUDI DI BRESCIA

Fleet operation and maintenance practices are carried out by companies on less than 50% of their installed base, generally through direct field engineers.

Remote diagnostics, product condition analysis, preventive and corrective maintenance activities are even less diffused, below 30% of the installed base.

Objectives

1. Design and **implement embedded or distributed systems to** be able to **capture the use** and **assess the state of health, using** power based information (and others), obtained from **sensory system** or **evaluation technologies** of power, load, current, temperature, vibrations,... **and** from machine/system **accessible data**.

2. Provide the **Fleet-Wide** Asset **Health Management platform** (FW-AHM) that supplies the related business services.
   a. The platform should support innovative features and technology to provide **fleet-wide monitoring, diagnostic and health** management services and delivers the required data **and information for the operation and related maintenance strategy optimization** services.
   b. The platform will act as a hub of technology, providing the end-user with the different business services at different level: i.e. product dealers, users or third party maintenance service providers.

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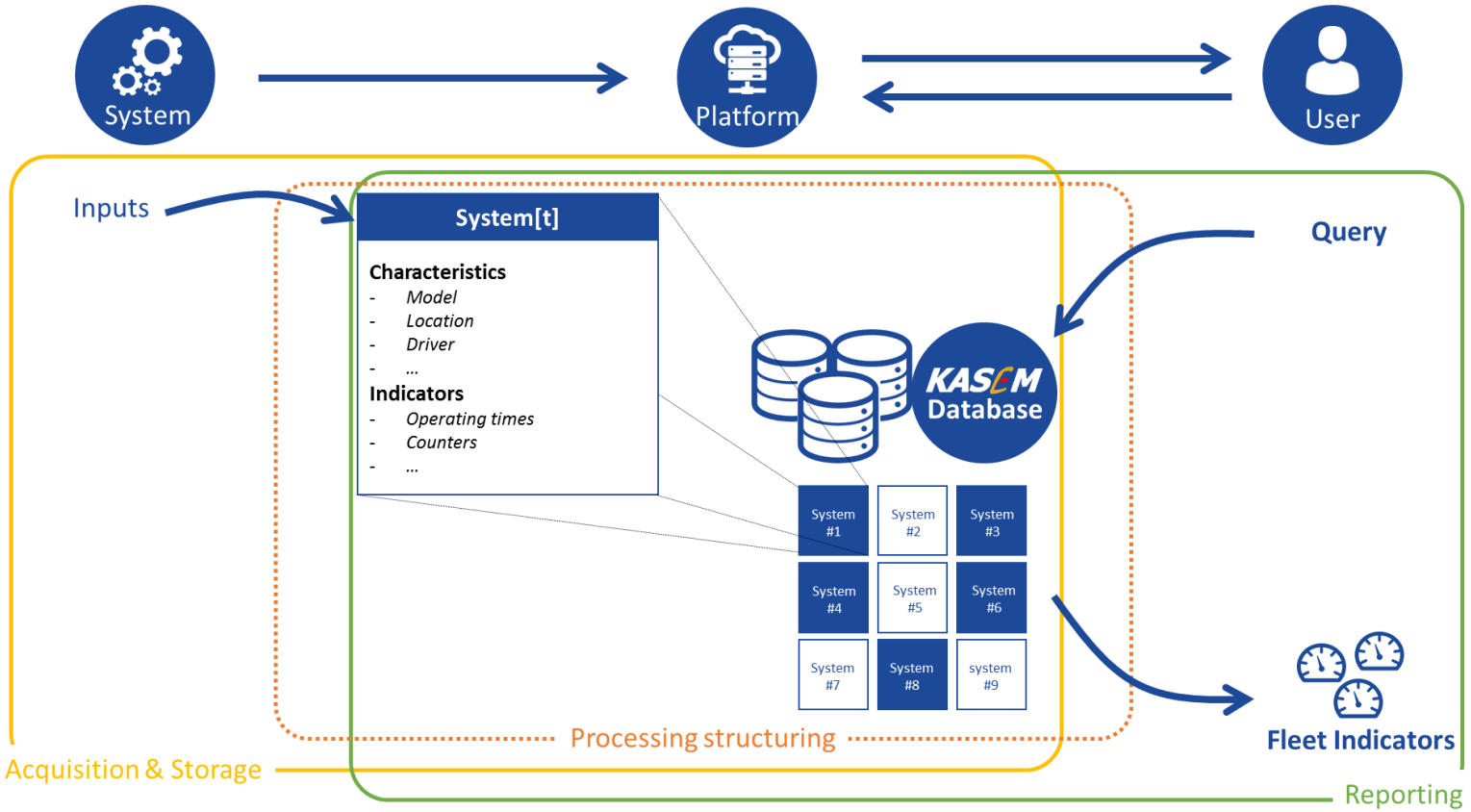
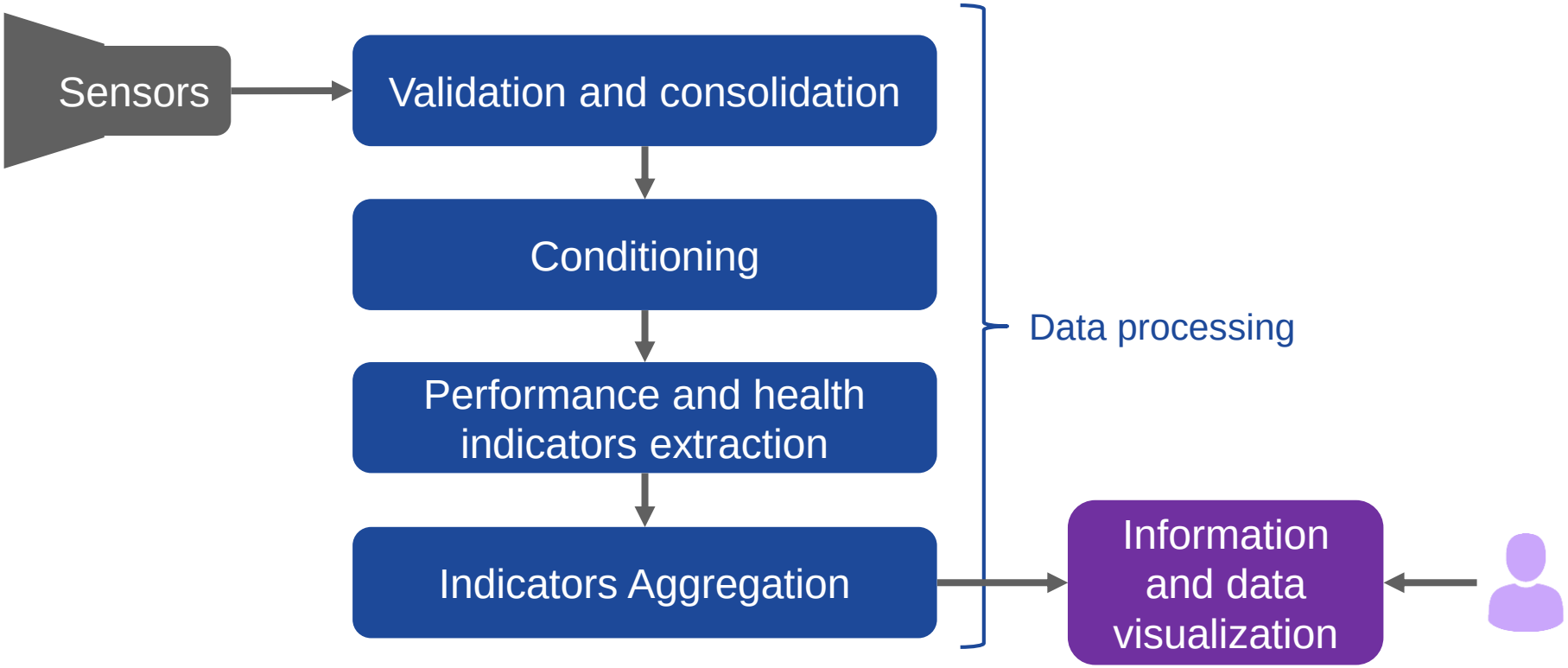
Fleet Management platform and services



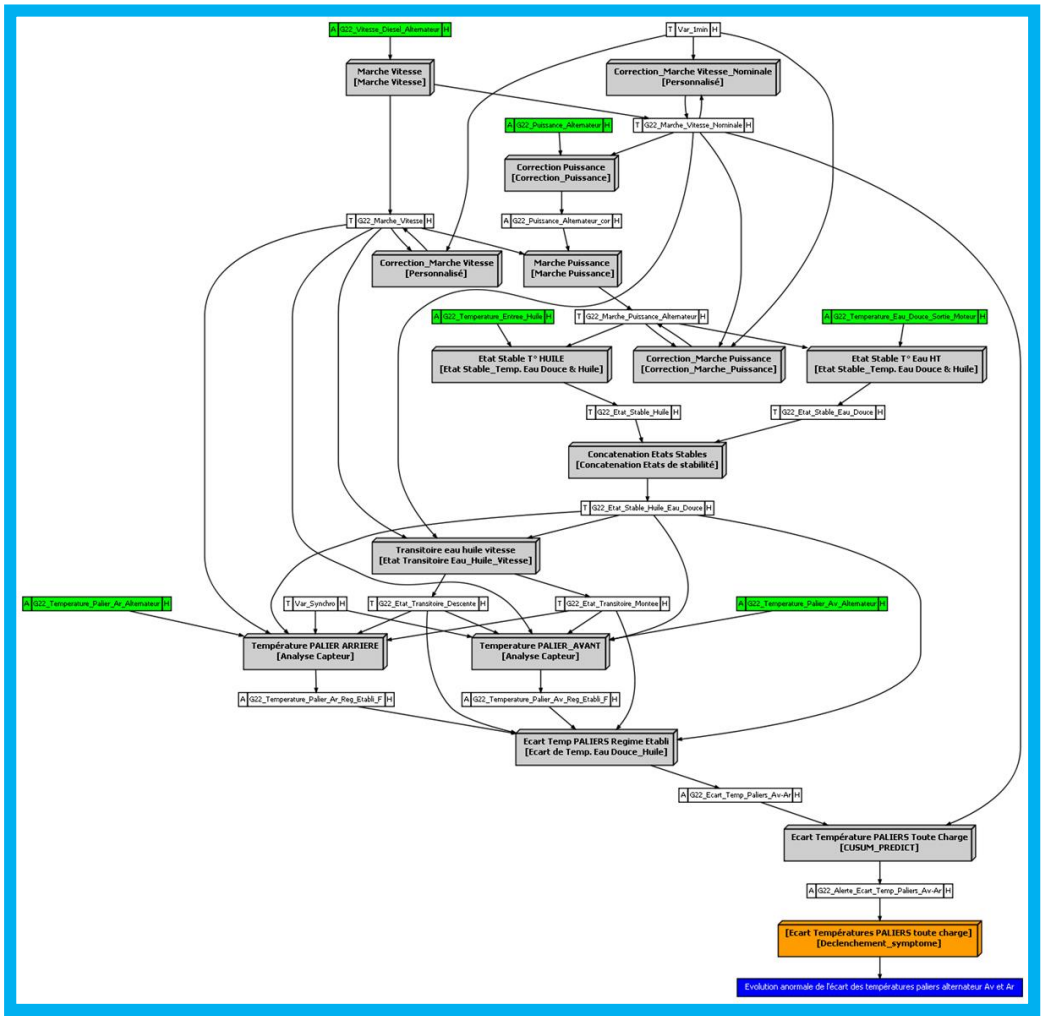
Processing structuring

- From raw data to users information



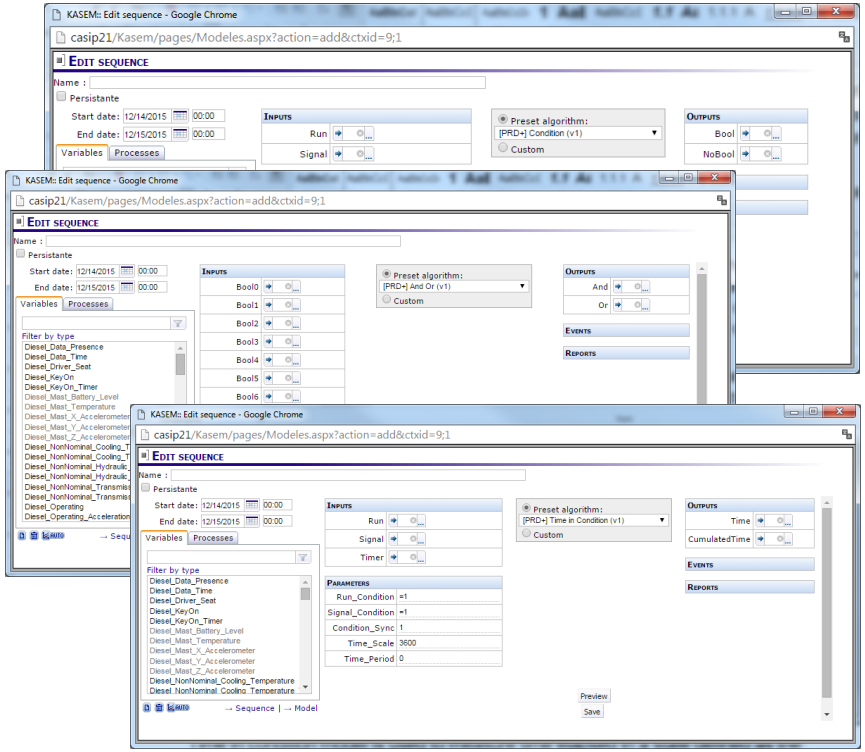
Example of data treatment sequence

- Sequence
- Acquisition data
- Treatement
- Calculated variables
- Symptom
- Alert



Compute “bottom” level indicators Generic KASEM® algorithms

- Evaluate condition
- Perform mathematical operations
- Perform logical operations
- Count a phenomenon occurrence
- Evaluate time or cumulated in some conditions…

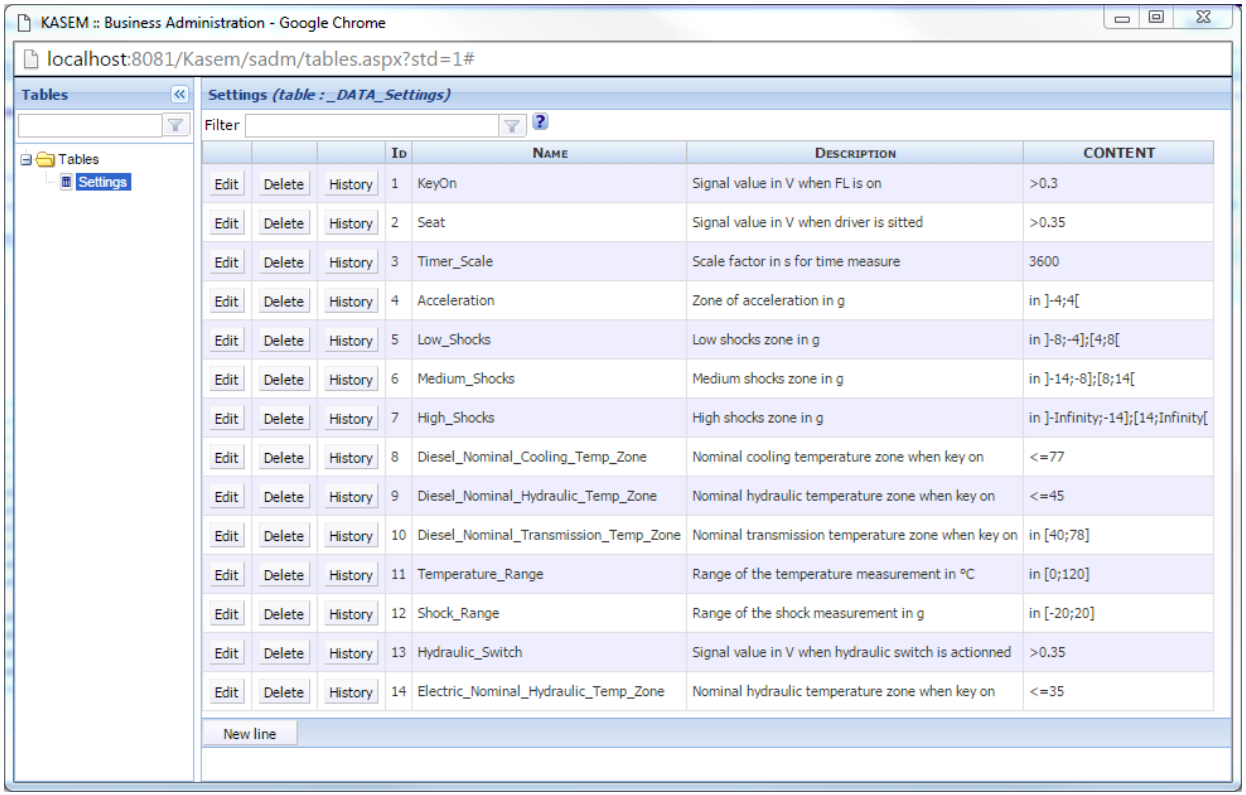


→ Algorithms with a high level of parametrization

Compute “bottom” level indicators Generic KASEM® algorithms

Example

Application parameters are centralized in a table and customized by experts



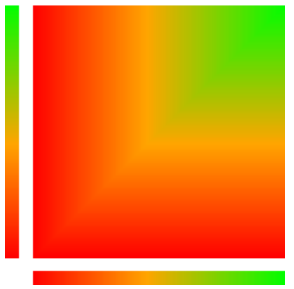
			Id	Name	Description	CONTENT
Edit	Delete	History	1	KeyOn	Signal value in V when FL is on	>0.3
Edit	Delete	History	2	Seat	Signal value in V when driver is sitted	>0.35
Edit	Delete	History	3	Timer_Scale	Scale factor in s for time measure	3600
Edit	Delete	History	4	Acceleration	Zone of acceleration in g	in]-4;4[
Edit	Delete	History	5	Low_Shocks	Low shocks zone in g	in]-8;-4];[4;8[
Edit	Delete	History	6	Medium_Shocks	Medium shocks zone in g	in]-14;-8];[8;14[
Edit	Delete	History	7	High_Shocks	High shocks zone in g	in]-Infinity;-14];[14;Infinity[
Edit	Delete	History	8	Diesel_Nominal_Cooling_Temp_Zone	Nominal cooling temperature zone when key on	<=77
Edit	Delete	History	9	Diesel_Nominal_Hydraulic_Temp_Zone	Nominal hydraulic temperature zone when key on	<=45
Edit	Delete	History	10	Diesel_Nominal_Transmission_Temp_Zone	Nominal transmission temperature zone when key on	in [40;78]
Edit	Delete	History	11	Temperature_Range	Range of the temperature measurement in °C	in [0;120]
Edit	Delete	History	12	Shock_Range	Range of the shock measurement in g	in [-20;20]
Edit	Delete	History	13	Hydraulic_Switch	Signal value in V when hydraulic switch is actionned	>0.35
Edit	Delete	History	14	Electric_Nominal_Hydraulic_Temp_Zone	Nominal hydraulic temperature zone when key on	<=35

New line

Compute “top” level indicators Aggregation principle

- Aggregation is the “merging” several indicators in one.
- Principle

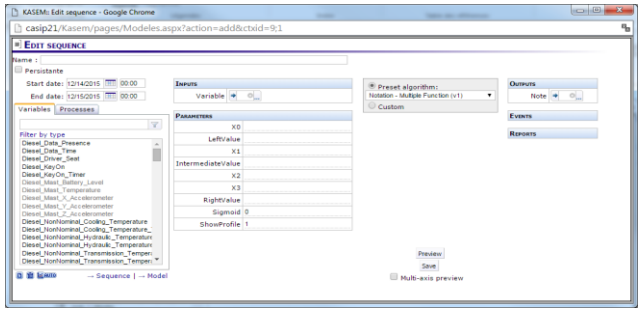
1. Notation phase
   - To be merged indicators need to have the same “scale”
   - Give a mark between 0 and 1 at each indicator
2. Aggregation, merging phase
   - Based on operators that represent expert knowledge
   - Result is a global mark between 0 and 1

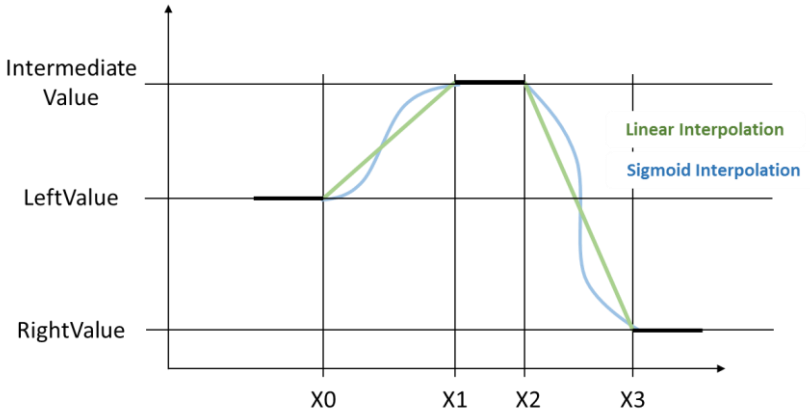


Map example of
Max Connector aggregation operator

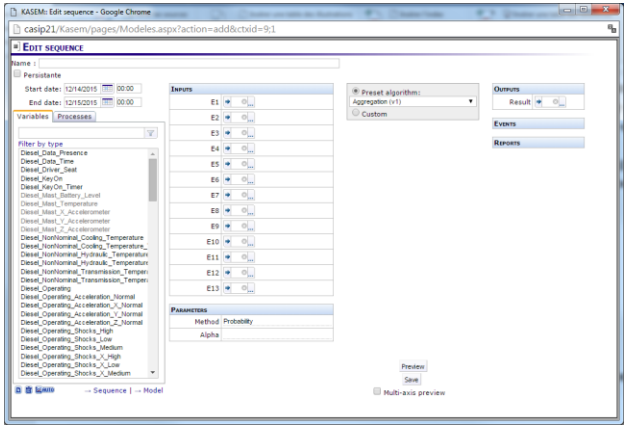
Compute “top” level indicators Generic KASEM® algorithms

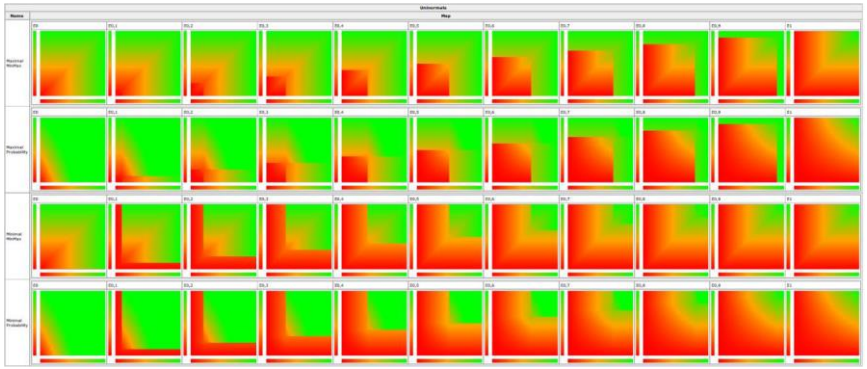
- Notation algorithm





- Aggregation algorithm

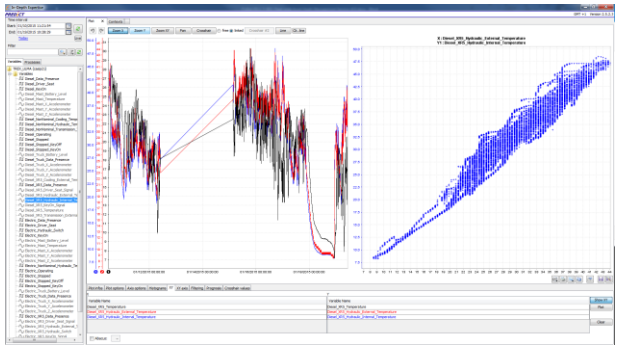




KASEM® - Data Visualization service

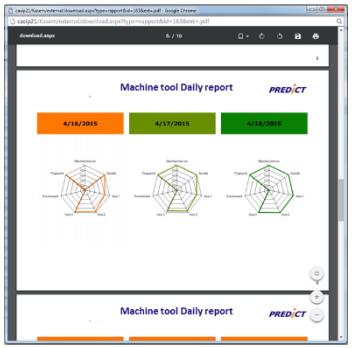
- All the tools and ways to communicate a clear and efficient information to the users (statistical graphics, plots, information graphics, tables and charts)

E-Visualization



Visualize historical raw and computed data set as well as real time information

PDF Report



Data screenshots on specific period

Dashboards / Custom. HMI

Show specific dynamics views based on real time data information

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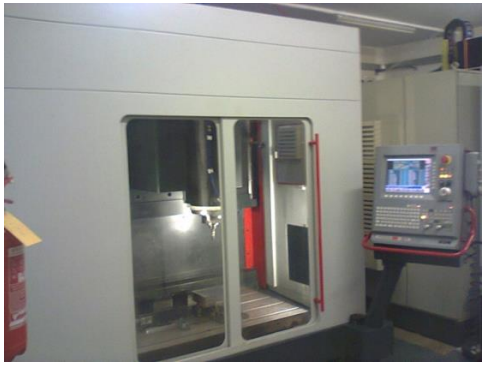
Machinery use case

- Real environment
  - Machine tool in headquarters' workshop
    - DL155
    - Equipped with a traditional OMLAT spindle



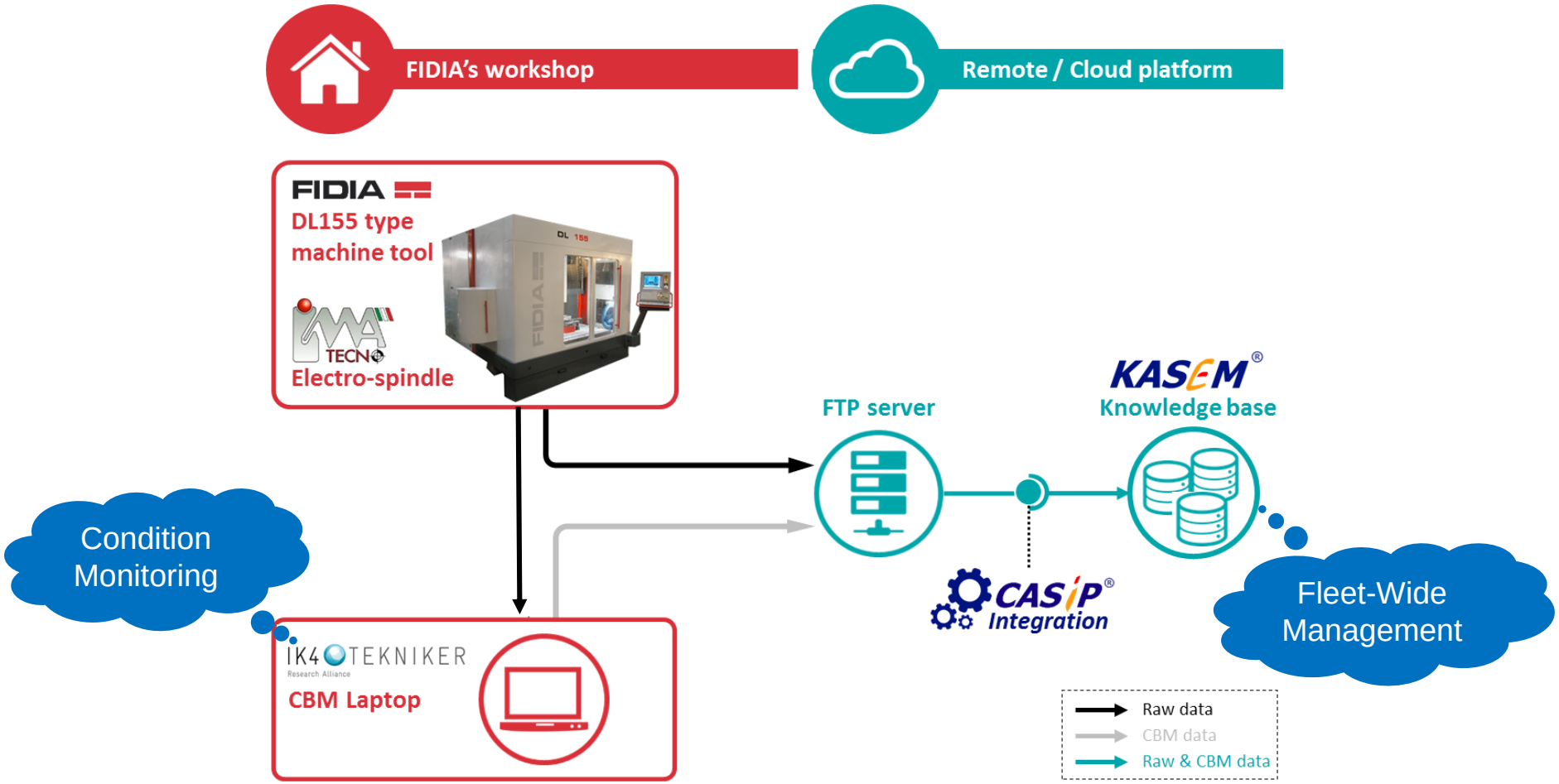
FIDIA

Machinery use case

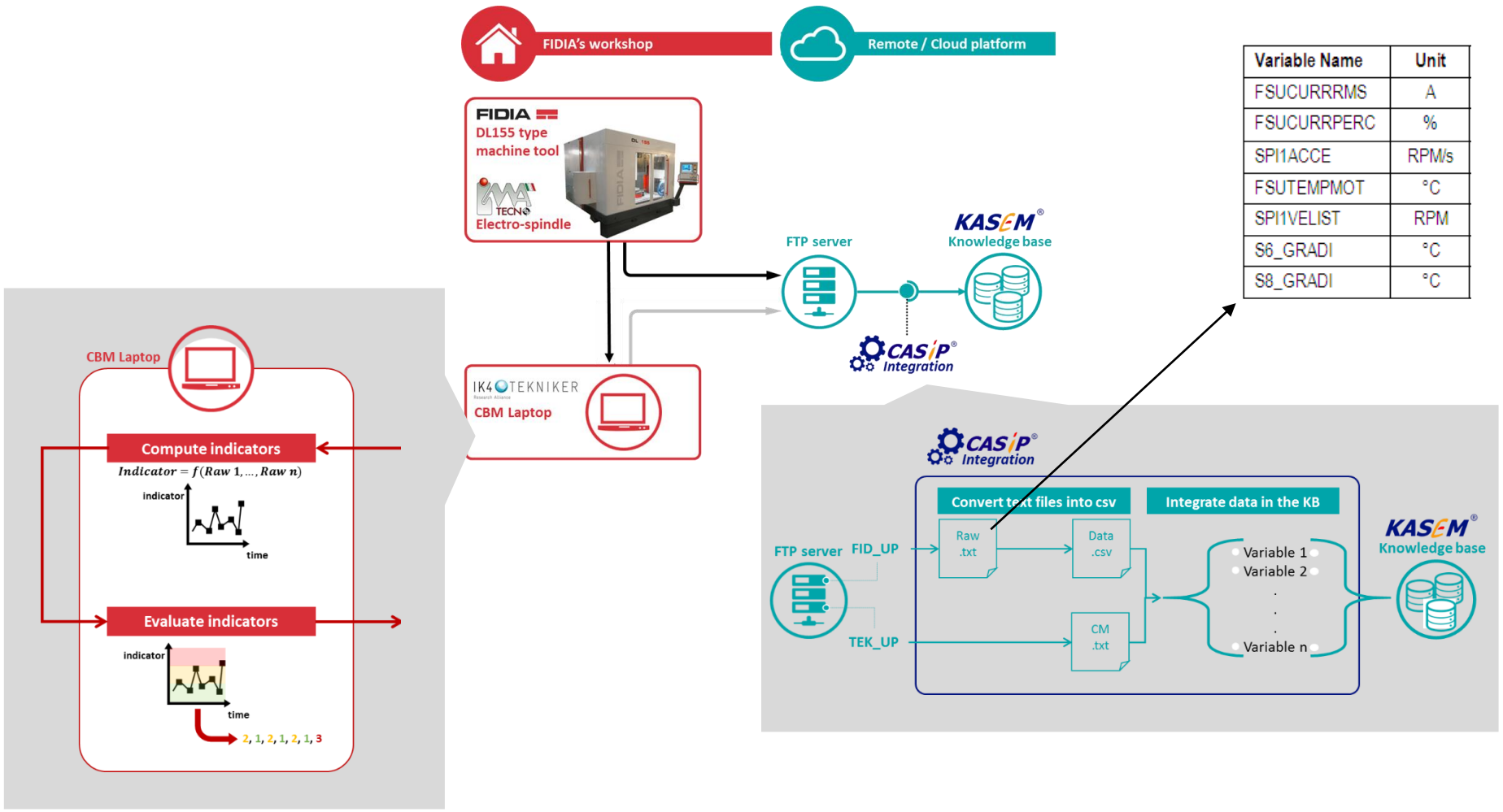
- Real environment
  - Test bed in Pinerolo production plant
    - Equipped with IMATECNO electro-spindle
    - Connected to FIDIA CNC

- Possibilities of virtual environment

Machinery use case - Platform



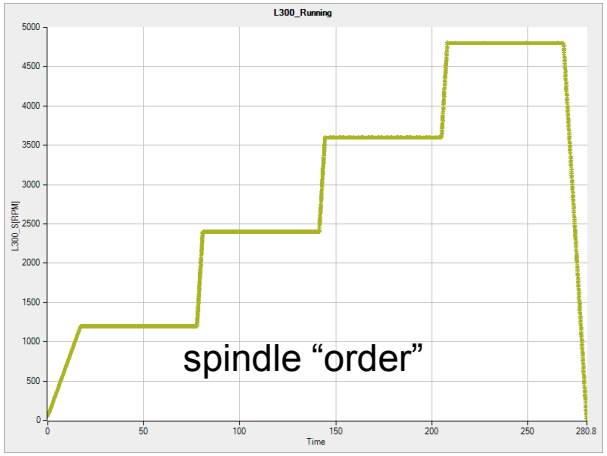
Machinery use case - Platform

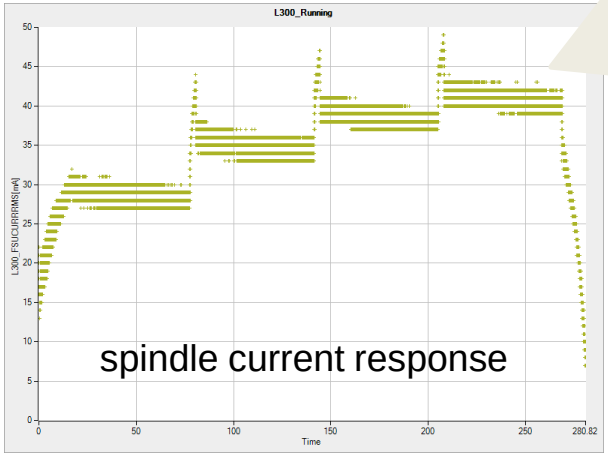


Variable Name	Unit
FSUCURRRMS	A
FSUCURRPERC	%
SPI1ACCE	RPM/s
FSUTEMPMOT	°C
SPI1VELIST	RPM
S6_GRADI	°C
S8_GRADI	°C

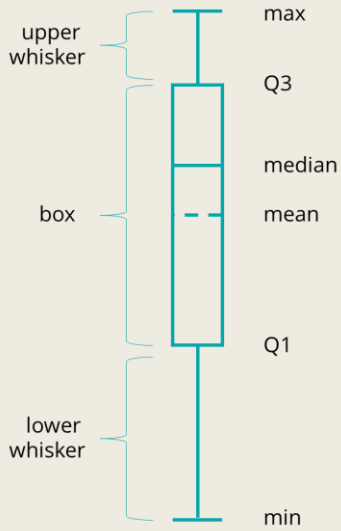
Machinery usage – Data Visualization

- Collection of maintenance test sessions only
  - Periodical tests that only few minutes (≈ 5)
  - Consist of a sequence of constant level spindle speed
- PDF report after each test session
- Test sessions example on L300

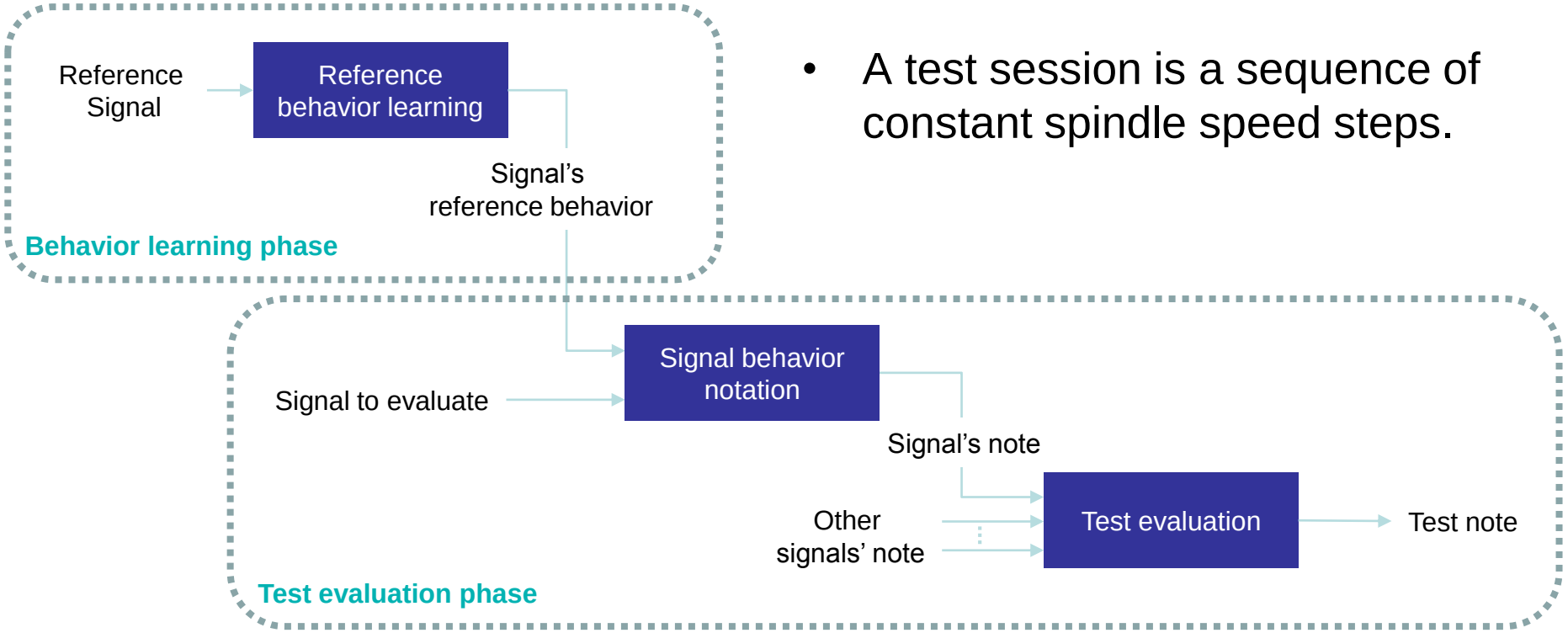




Boxplot representation:

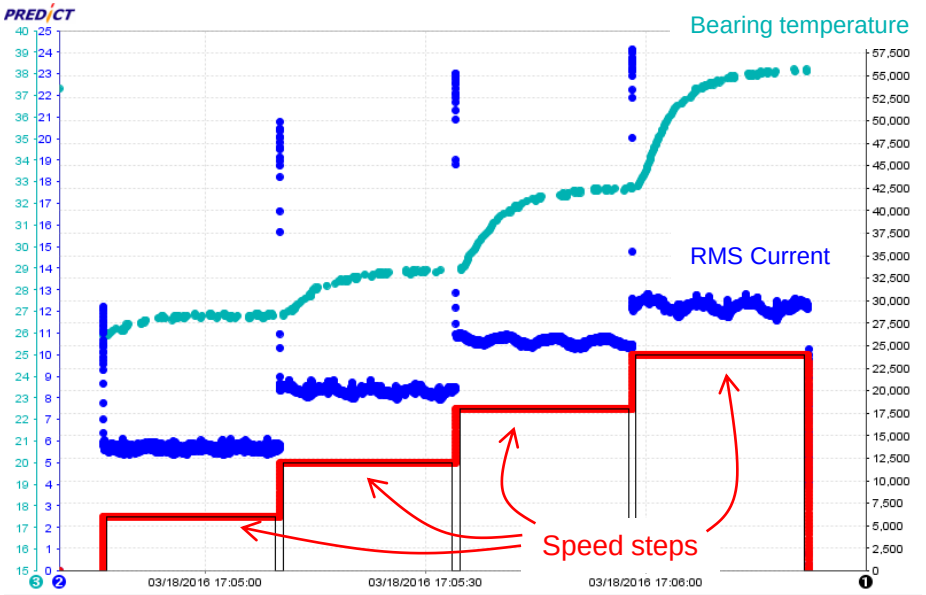


Machinery use case: tests evaluation principle



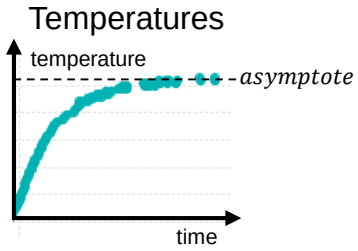
- A test session is a sequence of constant spindle speed steps.

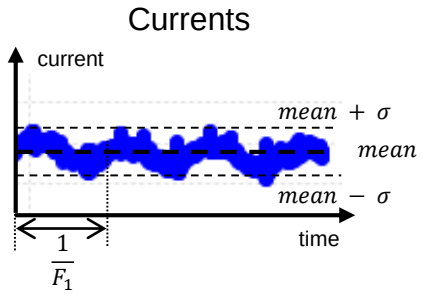
Machinery use case: Behavior learning phase



		Variable Name	Unit	Description	Count	Min	Max
1	❶	TestBed_Step		TestBed_Step	8	0	24,000
2	❶	TestBed_SP1VELIST		TestBed_SP1VELIST	40,717	1	24,026
3	❷	TestBed_CURRRMS		TestBed_CURRRMS	44,159	0.3	24.14
4	❸	TestBed_S6_GRADI		TestBed_S6_GRADI	317	25.9	38.2

- Two types of signal's behavior, spindle speed step dependent, to learn.

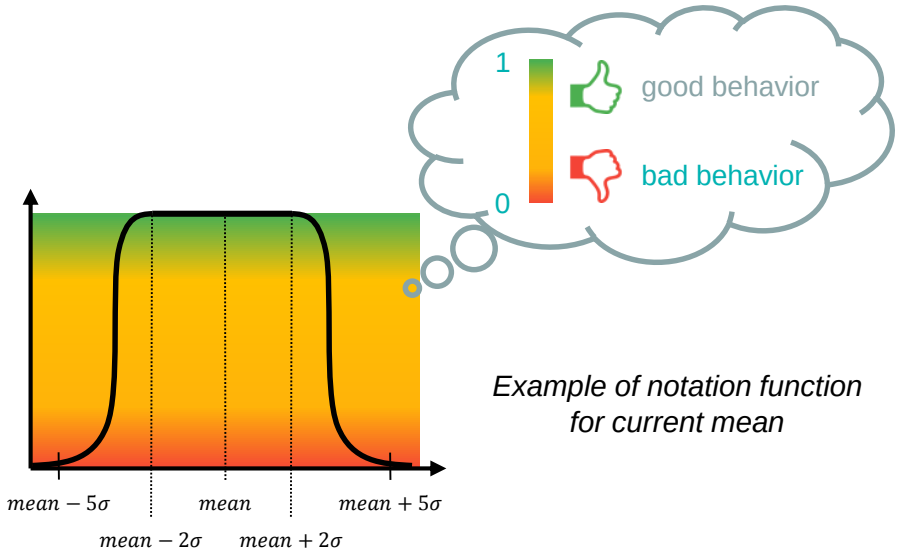




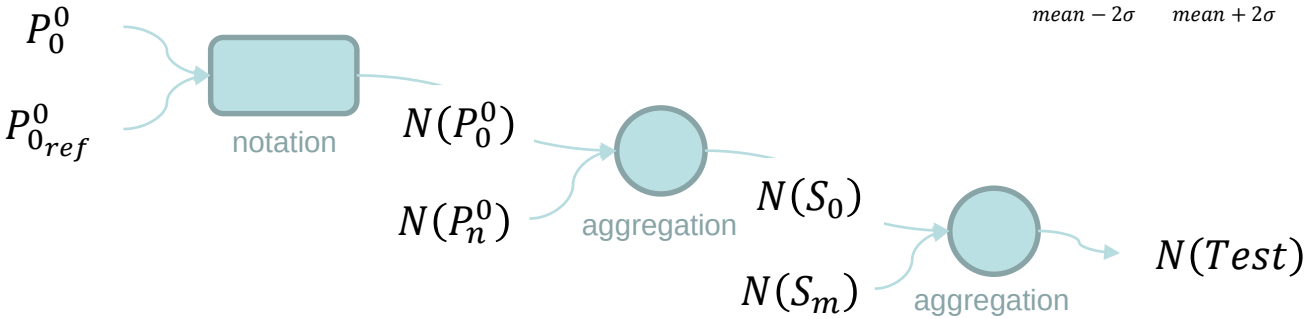
- For a given speed step, behavior is characterized by a set of parameters:
  - ☑ Temperatures : asymptote's mean.
  - ☑ Currents : mean, standard deviation, first and second harmonics' amplitude and frequency.

Machinery use case: evaluation phase

- Evaluate behavior parameters with notation function based on references statistics.
- Aggregate parameters note
- Aggregate signals' note.



Example of notation function for current mean



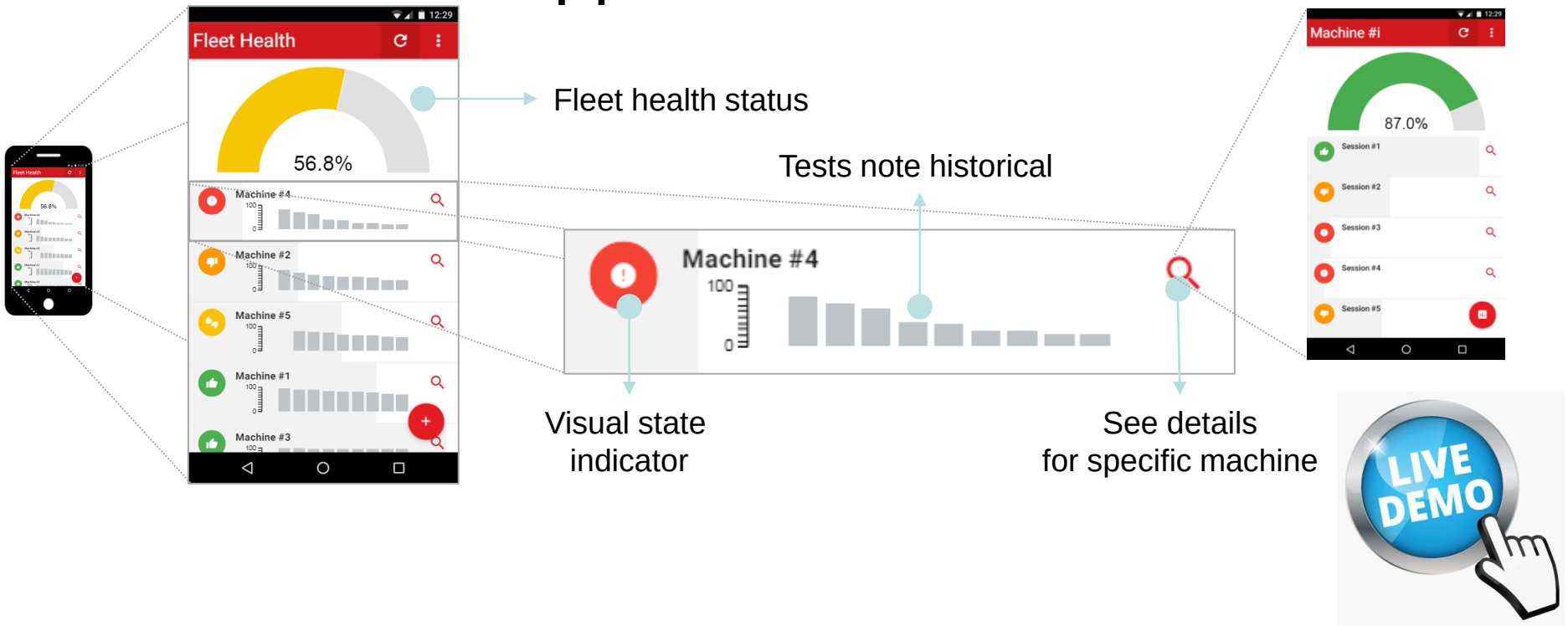
P_i^j: Parameter i of the signal j

S_j: Signal j

$N(e)$: Note of e

Fleet-wide tests follow-up

- Mobile web application



Content

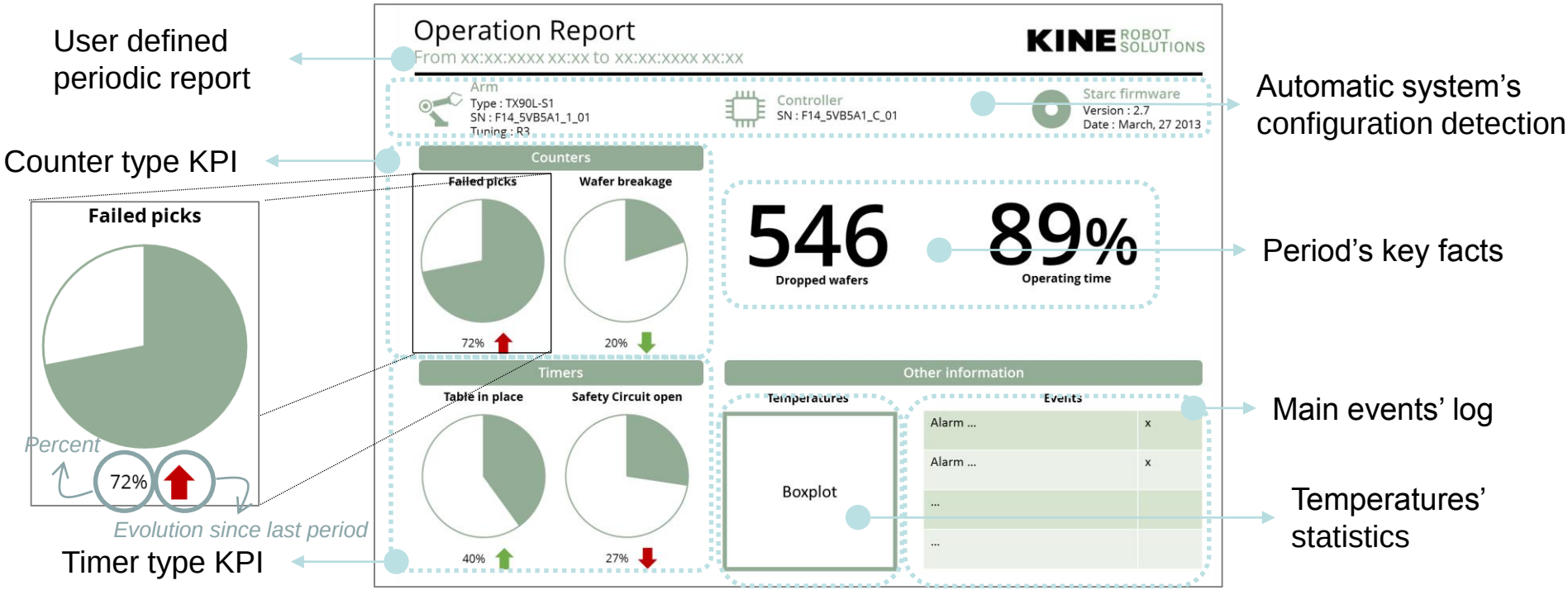
- Short Presentation of PREDICT
- Values, Services, Practices, Models and Objectives driving T-REX
- T-REX Activities and Results
  - Fleet Management platform and services
  - Machinery Use Case
  - Robot System/Automation Use Case
  - Transportation/Industrial Vehicle Use Case

Robot System usage – Data Visualization

- Reporting services
  - Daily PDF report on robot performances
    - Comparison between several production day

- Customized KASEM® HMI and Dashboard to fit with KINE business

KINE Operation report



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Industrial Vehicle usage – Data Visualization

- Reporting services
  - Provide easy access
    - to real time forklift trucks indicators
    - To daily updated ERP information
  - Customized KASEM® HMI to fit with ULMA business

ULMA Carretillas Elevadoras

Transportation use case

- Test fleet is composed of 10 forklift trucks
  - 5 forklift trucks in CIE facilities
    - 2 electrics: Mitsubishi FB25N MC 80V
      - Two batteries + esenergia's smart pulse
    - 3 diesel: Mitsubishi FD25NTD MC
  - 5 other forklift trucks
    - 2 electrics
    - 3 diesel

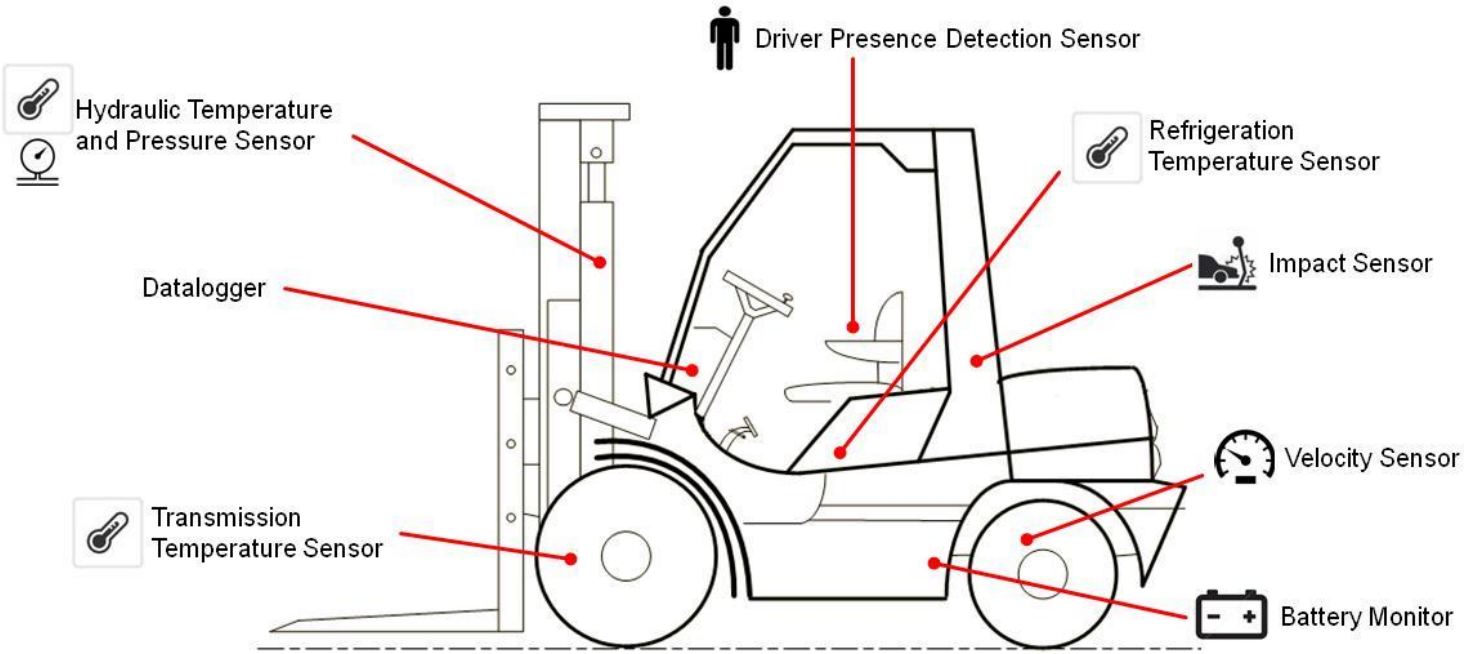
ULMA Carretillas Elevadoras

FB25N MC 80V

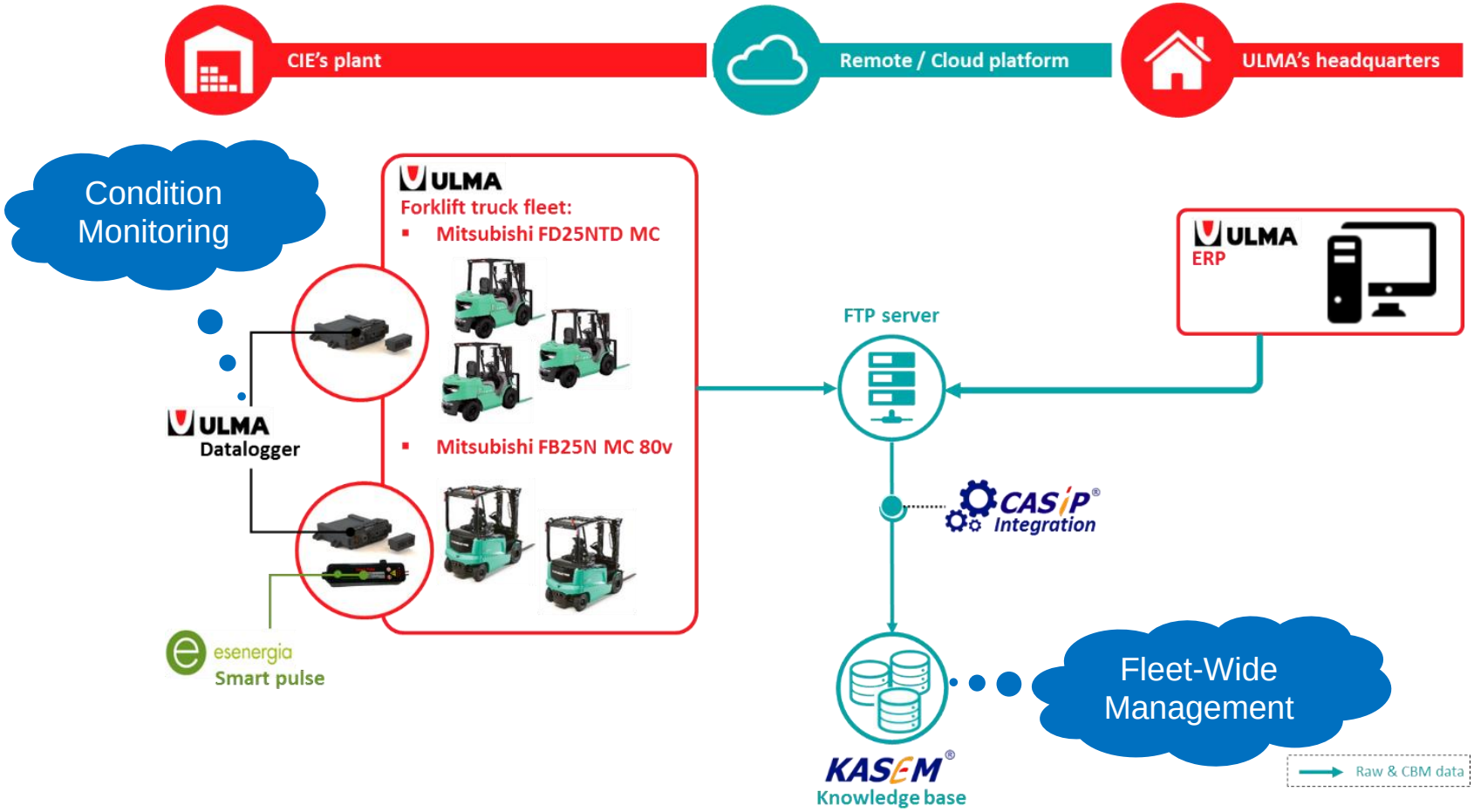
FD25NTD MC

ULMA Carretillas Elevadoras

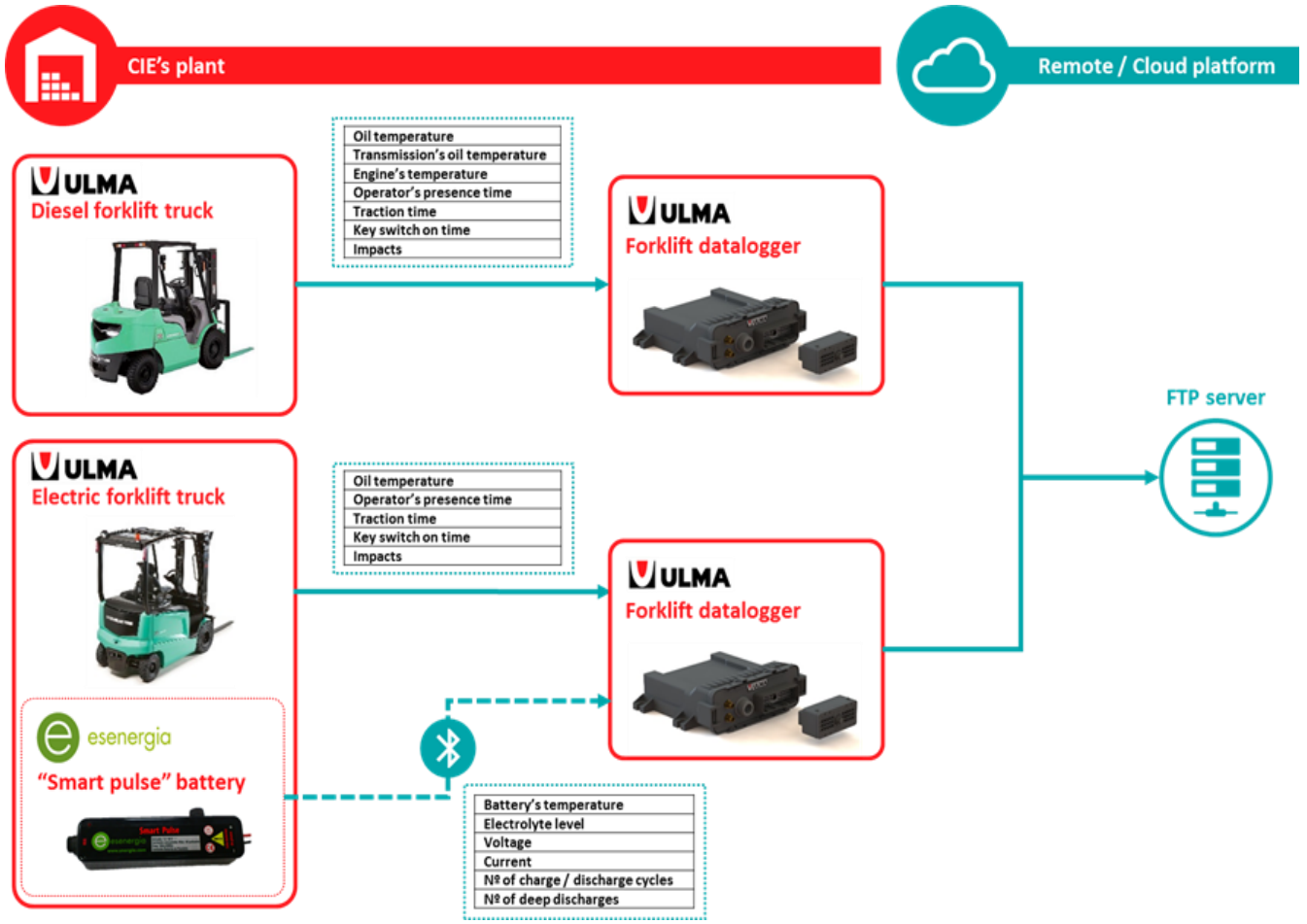
FORKLIFT TRUCK MAIN SIGNALS



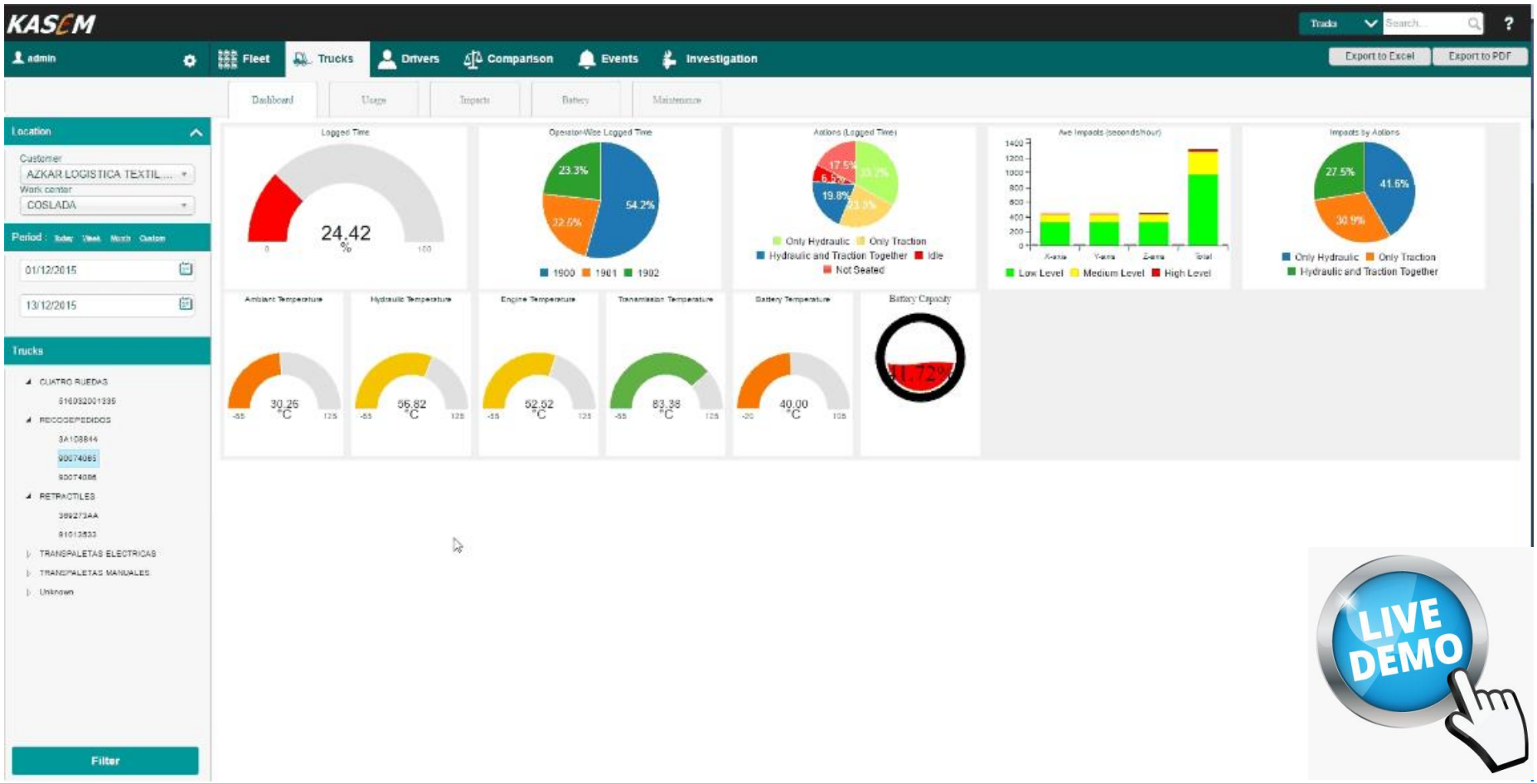
Transportation use case - Platform



Transportation use case - Platform



Transportation use case
Fleet Dashboard



T-REX Consortium

IK4 TEKNIKER
Research Alliance

PREDICT

KINE ROBOT SOLUTIONS

ULMA
Carretillas Elevadoras

FIDIA

CIE Automotive

esenergia

TECNO
MECHANICAL TECHNOLOGIES

Fraunhofer
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PREDICT