TOYOTA

MATERIAL HANDLING

Predictive Maintenance in Painting Line based on Data Analytics and Machine Learning Techniques

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Webinar – BI-REX

Summary

- Toyota Group
- LTE Company Overview
- Implementation of Predictive Maintenance in Painting Line
- Operation Availability results in Painting Line
- Predictive maintenance future steps in LTE
- Predictive Maintenance in Welding Line highlights

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Corporations

- Toyota Motor Corporation
- Toyota Industries Corporation
- Hino Motors
- Daihatsu Motor
- Toyota Central R&D labs
- Toyoda Gosei
- Toyota Home Corporation
- Aisin
- Towa Real Estate
- Toyota Motor Kyushu
- Toyota Motor East Japan
- Toyota Boshoku Corporation
- Denso Corporation
- Toyota Tsuho Corporation
- Toyota Auto Body
- Jtekt Corporation
- Aichi Steel Corporation

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TOYOTA

Toyota Industries Corporation

- Total turnover € 17,1 Billion
- Total employees 66,400
- 4 business sectors

Automotive 28%

Materials Handling 67%

Textile machinery 2%

Others 3%

* Figures for FY20, employees = FY20 data

Toyota Material Handling Group

Toyota Material Handling North America

Toyota Material Handling Europe

Toyota Material Handling Japan

Toyota Material Handling China

Toyota Material Handling International

Key figures FY21

In Europe

€ 2.4 billion
total net sales

11,600
employees across Europe

86,000
factory shipment

5,600
service technicians

438,000
trucks on service agreement

4.3 million
service assignments per year

+160,000
connected trucks

Active in over **30** countries in Europe

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5 Factories
*~**11600** employees*
3 R&D Centers
*~**300** Design Engineers*

Milano, *Italy* (SIMAI)

Ancenis, *France* (TMHMF)

Bologna, *Italy* (TMHMI)

Mjölby, *Sweden* (TMHMS)

Ferrara, *Italy* (LTE)

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ABOUT OUR COMPANY

Products

10

Masts model

6 Cylinders model

6 Side-shift

Activities

R&D

Manufacturing

Customization

Turnover

107

€ Million Euro

Customers

55% TMHMI

36% TMHMF

9% TMHMS

Employees

588

Site

100.000 m2

Covered

25400 m2

Offices

1.200 m2

Our involvement

ISO 9001:2015 — **2003** Year

International Organization for Standardization ISO 14001:2015 — **2007** Year

ISO 50001 — **2015** Year

ISO TS 14067 — **Carbon Footprint** **2019** Year

International Organization for Standardization ISO 45001 — **2019** Year

LTE Maintenance history

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FY

2006

Management Renewal & Company reorganization

2007

TPS Method introduction

2008

Start of **corrective maintenance activities**

5S

2012

Training for **Preventive Maintenance** application

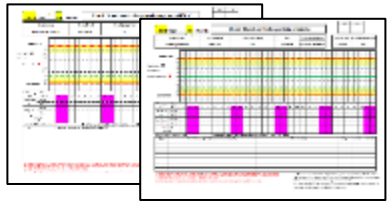
Starting of **Preventive Maintenance**

2013

Maintenance **KPIs Monitoring (MTTR MTBF OA)**

2014

TOSO Project in Painting Line



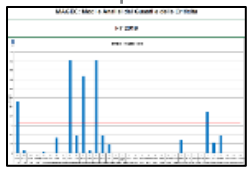
2015

Maintenance ASA ICHI

Process Control parameter Rail Line

2016

FMECA (Failure Mode Effects and Criticality Analysis) in Painting Line



Last 5 FY

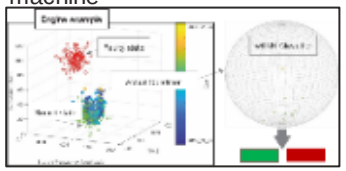
2017

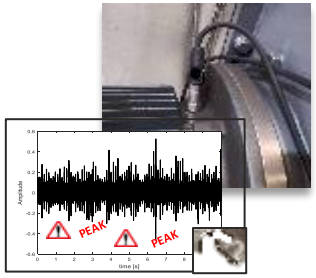
TPM activity in Rail Line

FMECA (Failure Mode Effects and Criticality Analysis) in Rail Line

2018

1° STEP Predictive Maintenance in **Painting Line** on sandblasting machine





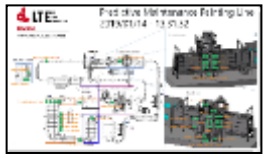
2019

Process Control parameter in Welding Line 1-2

Maintenance Dojo

2020

2° Step -Software update and passage from **Trend to Machine Learning Analysis**



Remote maintenance

Process Control parameter in Cylinder

Remote Control and Optimization of **Compressors**

Maintenance Survey

2021

Machine Learning Upgrade and **Neural Network** in **Painting Line**

Predictive Maintenance in Tack **Weld. Line 1**

Remote Control and Optimization of **Cryogenic Plant**

2022

Today

GPS Project
SMART Maintenance

Project Design

- Layout
- Devices
- Communication tools

Detailed Analysis

Data collection

- Entities, Attributes
- Spare parts
- Maintenance warehouse

Implementation of Predictive Maintenance in Painting Line

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Pilot project on Sandblasting Machine

Background:

LTE has implemented "Preventive Maintenance" after *TOSO* (Paint) project to define standards since 2014 and now started a new method, *FMECA* (**F**ailure **M**ode, **E**ffects, and **C**riticality **A**nalysis) for possible failures by "Predictive" phase.

Problems:

1.1 Set up scheduled maintenance → "Preventive maintenance" implemented.

1.2 TOSO project to standardize and monitor criteria data in each process.

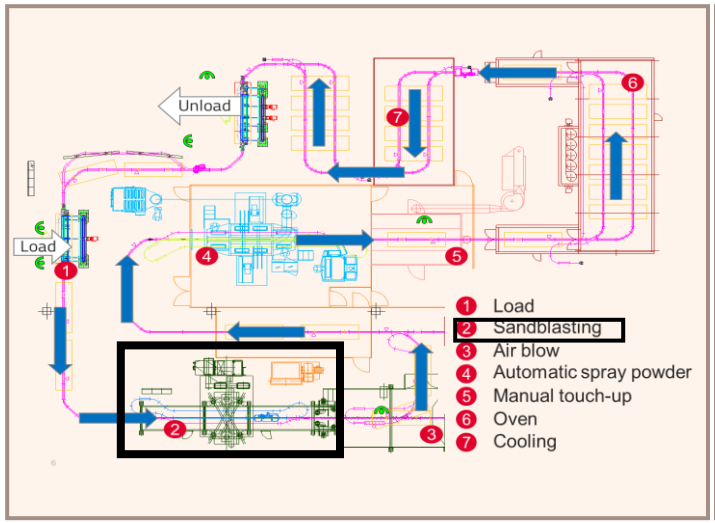
2.1 Causes breakdown for malfunction in Paint line process to find **sandblaster** has the highest relevance on downtime (40% of the downtime).

2.2 Further analysis by critical components in sandblaster to reach: Turbine, Elevator & Screw covers 80% of downtime of Sandblaster.

Focal Point:

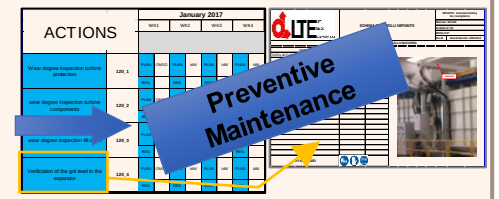
Using IoT (Industry 4.0), collecting big data to "PREDICT" possible future malfunction

1 LTE Painting Line Layout

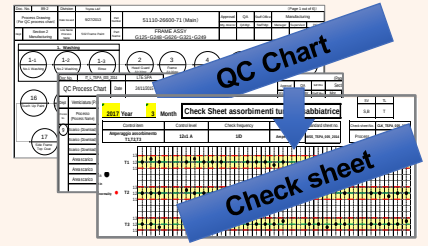


***TOSO* Project led by LTE and "Preventive Maintenance"**

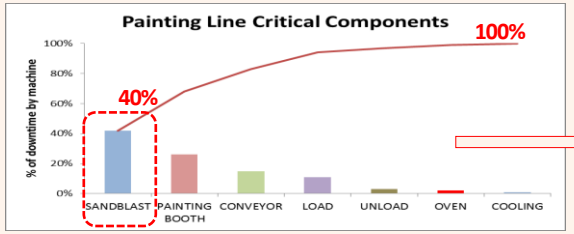
1.1 Scheduled Check — Standards



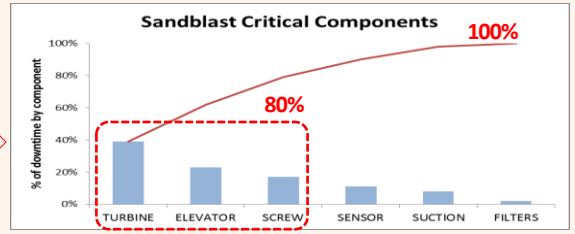
1.2 QC Process Chart → STD check sheet



2.1 **Painting Line downtime breakdown:**



2.2 **Sandblast Malfunction Breakdown:**



(BEFORE) OA 97,0% ⇢ (AFTER) OA 98,0%

NOT ENOUGH!!

Implementation of Predictive Maintenance in Painting Line

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Predictive maintenance roadmap in Painting Line

FY 2017 | 2018 - 2019 | 2020 - 2021

1˚ Step

- Predictive Maintenance on Sandblasting Machine
- Trend Analysis

TECHNICAL ASPECTS

Devices installed on the sandblaster:
- ❑ 13 current sensors
- ❑ 14 accelerometers

Trend creation & signal classification based on historic data

2˚ Step

- Predictive Maintenance on Sandblasting Machine upgrade
- Predictive Maintenance on Conveyor motors
- From Trend to Machine Learning → President's Award Theme
- Change of software architecture
- Web program generation for real time data consulting

TECHNICAL ASPECTS

Devices installed on the sandblaster:
- ❑ 5 current sensors
- ❑ 8 accelerometers

Conveyor:
- ❑ 17 current sensors

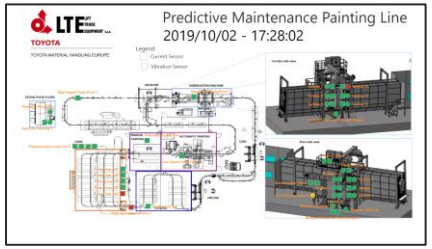
New parameters introduction and machine learning:
- Hypothesis test → vibrations
- Data classification → current

3˚ Step

- Painting Line: machine Learning upgrade
- Diagnostic feature change
- Neural network classification algorithm with 3 states

Current state

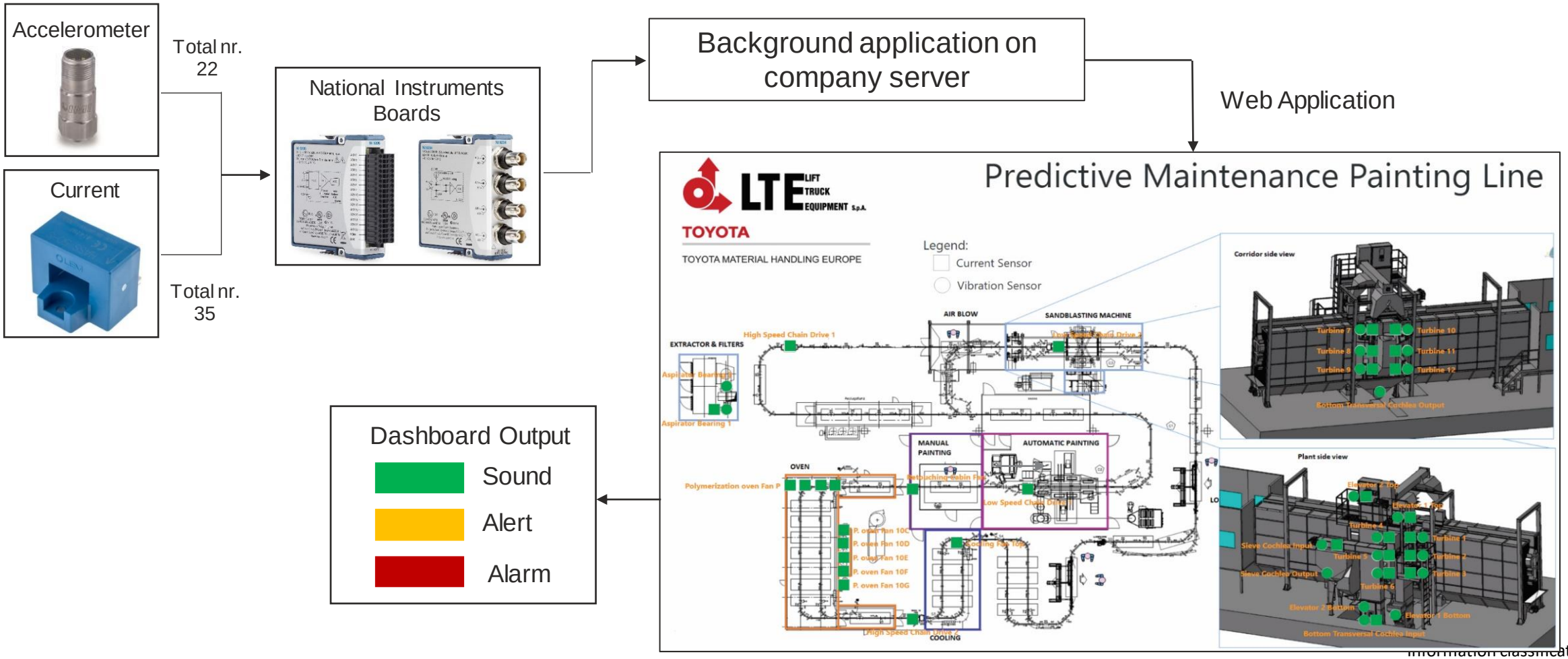
- 57 Total sensors



Painting Line condition based maintenance

A complete vibration-current monitoring system continuously acquire vibration and current signals. These signals are stored and analysed by the system that lie on a company server. Machine condition are displayed on a dedicated dashboard near the sandblasting and accessible across over company computers, also in maintenance department.

Monitoring system scheme:



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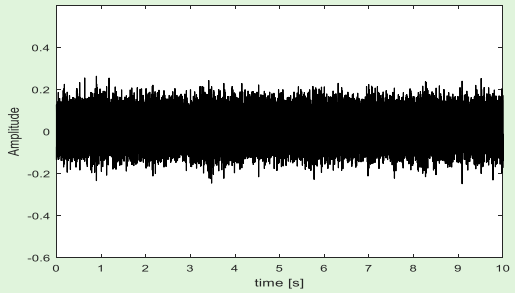
1st Step: Trend analysis on sandblasting machine

- Vibration signal is strongly linked to the condition of the mechanical components
- In complex system this could lead to several unwanted false alarms

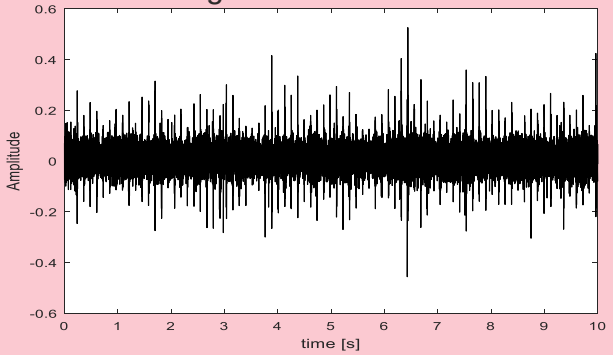
Example: bearing fault

Signal by a new bearing

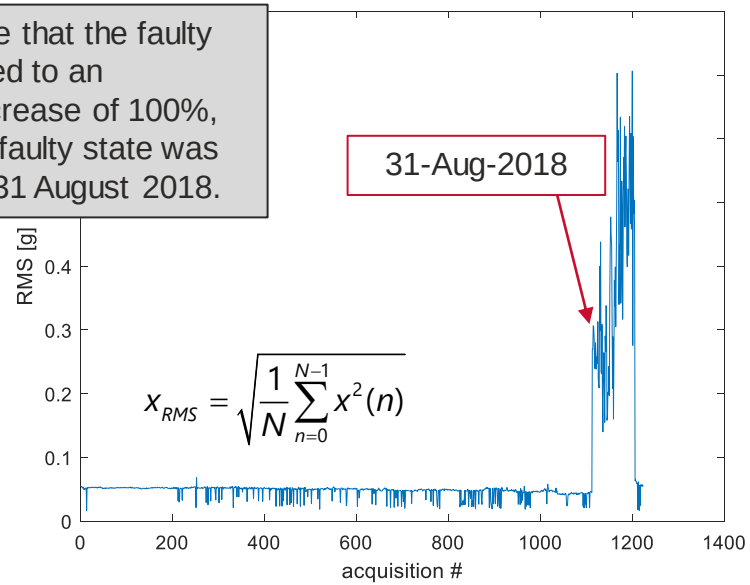


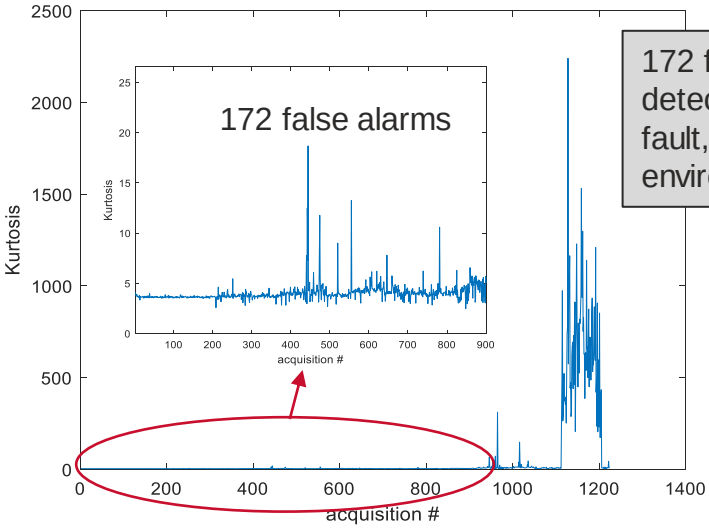
Signal by damaged or worn bearing

Fault signature



If we suppose that the faulty state is related to an amplitude increase of 100%, the machine faulty state was detected on 31 August 2018.



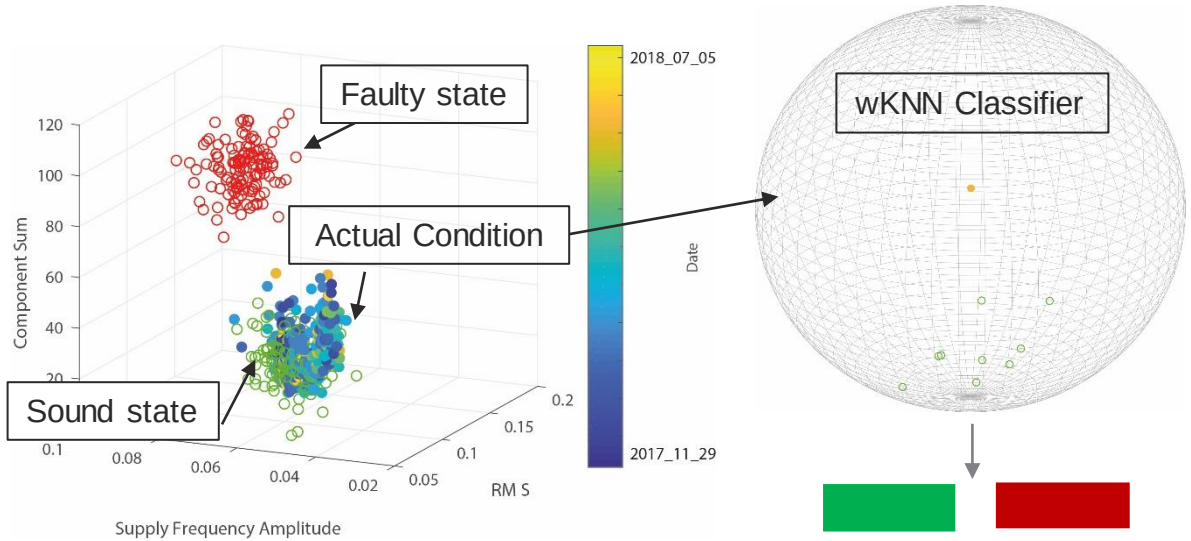


172 false alarms has been detected before the real machine fault, due to change in environmental conditions.

2nd Step: Machine Learning on sandblasting machine and conveyor

Engine diagnostics

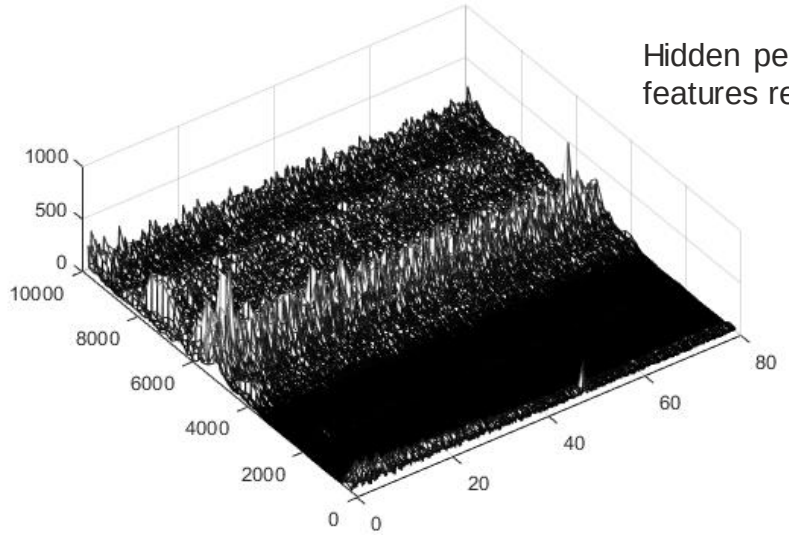
- The machine learning algorithm introduced in the second step was the weighted k-Nearest Neighbour (wKNN) feature related to the working condition and state of health of the electrical engine, are evaluated from the current signal and classified with a wKNN algorithm. Initial states are generated randomly, based on the sound data distribution.



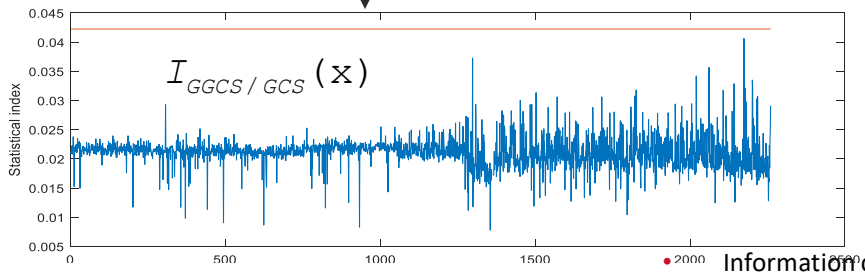
Bearing diagnostics

- Bearing diagnostics is based on evaluation of statistical indicators. The classification is based on hypotheses test involving two key vibration signal characteristics, i.e. cyclostationarity and gaussianity

Hidden periodicities are features related to the fault



Statistical index



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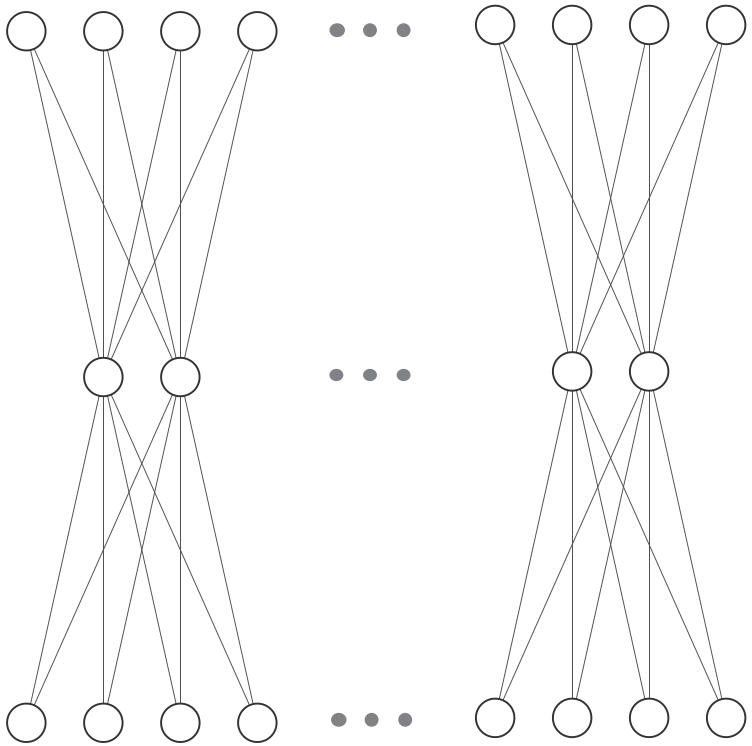
3rd Step: Machine learning upgrade in Painting Line

Targets where:

- Creation of an unified approach for plant monitoring (integration of painting and welding departments)
- Increasing of the effectiveness of the condition monitoring algorithm.
- More accurate subdivision of the current state of heath in three different classes, i.e. sound, anomaly and faulty.

Neural network functioning scheme



Input layer: 215 neurons (sigmoid function)

Hidden layer: 100 neurons (sigmoid function)

Output layer: 215 neurons (sigmoid function)

The ANN is trained with:

- 40000 sample for sound condition are adopted.
- 100 training iteration were performed

Classification error is evaluated and compared with two thresholds, in order to classify features in sound, anomaly and faulty states →

Output probability

1	0	0
0	1	0
0	0	1

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Predictive maintenance future steps in LTE

FY | 2022 | 2023 | 2024

MAST PAINTING LINE

- **Integration of new sensors** due to equipment upgrade
- Extraction of parameters related to **components operation** (energetic consumption, environment, etc.)

- **New sensors for conveyor bearings and rails** for the whole monitoring
- **Advanced training** for condition monitoring application
- Connect the extracted data to **automatically practical actions** of maintenance department

- Study the possible **monitoring of positioning stations** and intermittent mechanical components
- Creation of internal specialists and internal **know-how acquisition**;

OTHER DEPARTMENTS

- **New condition monitoring system** developed "ad hoc" for tack welding
- **Cylinder Painting Line diagnostics** based on process parameters extracted by PLC

- **New condition monitoring system** developed for **robot cells**

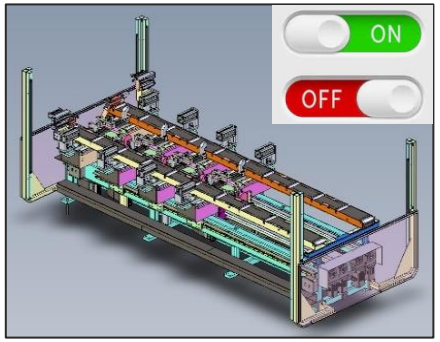
- Predictive maintenance extension to **compressors and aspirators.**
- **Consolidation** of condition monitoring system **in robot cells**

Predictive Maintenance in Welding Line highlights

Tack Welding condition based maintenance

After obtaining good results in painting line, it was decided to proceed with a subsequent advancement of predictive project in tack welding line, with a system similar to the first one. Machine condition are displayed on a dedicated dashboard near the welding station and accessible across over company computers, also in maintenance department.

Accelerometer



National Instruments Boards

Current sensor

WL1 choice reasons:

Flexibility needs

High production volumes

Background application on company server

Web Application

Main Sensors Dashboard

Legenda

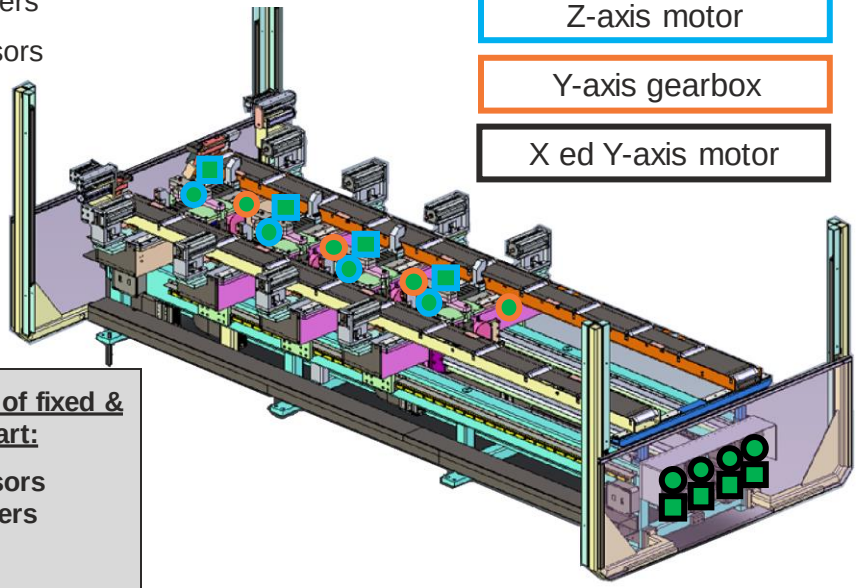
Accelerometers

Current sensors

Z-axis motor

Y-axis gearbox

X ed Y-axis motor



Electric motors of fixed & mobile cart:

- ❑ 8 current sensors
- ❑ 8 accelerometers

Gearbox:

- ❑ 4 accelerometers

Dashboard Output

Sound

Alert

Alarm

ご清聴ありがとうございました

THANK YOU FOR YOUR KIND ATTENTION