PROPHESY

Platform for rapid deployment of self-configuring and optimized predictive maintenance services

DELIVERABLE

D7.2 – Demonstrators Sites Preparation Report v2

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Executive Summary

This report specifies the current state of the two complex demonstrators and is related to the Deliverable 2.4 in M8. While the Deliverable 2.4 is more related to the WHAT and WHY, this document is more related the HOW it is involved in the two complex demonstrators, which prepare the execution of the PROPHESY solutions at two different locations and industries:

- Jaguar Land Rover, Wolverhampton, UK, representing Automotive Industry
- Philips, Drachten, Netherlands, representing Health care

This deliverable concludes the work and results of Task 7.1, which ensures the proper planning of the complex demonstrators, including the readiness of the factories and pilot sites where the solutions will be deployed and operated. The work includes the mobilization of all stakeholders involved in the demonstrator, the preparation of the pilot production lines in terms of the required technical infrastructure (e.g., industrial PCs, smart glasses/gloves, networking), as well as the timely deployment of the PROPHESY-CPS platform for the purpose of testing and validating it on the field. Moreover, this task plans changes to production processes in order to transition from a preventive maintenance to a predictive maintenance approach, which is a common goal of the two demonstrators. A significant part of the task is devoted to the customization of the PROPHESY-CPS platform to the needs of each demonstrator, as well as its pre-deployment in each production line for testing and validation prior to the commencement of the pilot operation of the demonstrators.

Based on the first version of Deliverable 7.1 (M9), this second version (D7.2, M16) provides an updated state of each demonstrator and thus a big part of the demonstrator descriptions is repeated from D7.1 for your convenience. The focus of this Deliverable is the preparation and integration of the PROPHESY-CPS platform, unvealing the practical barriers that are faced during the integration of new systems within legacy environments.

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1.3	07.01.19	MMS	Public Version

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Definitions, Acronyms and Abbreviations

Acronym/ Abbreviation	Title
12NC	Philips specific product and asset numbering system
ANSI	American National Standards Institute
API	Application Programming Interface
AR	Augmented Reality
B2MML	Business to Machine Mark-up Language
CAE	Computer-Assisted Engineering
CAEX	Computer Aided Engineering Exchange
CBM	Condition Based Monitoring
CI	Continuous Integration
CMMN	Case Management Model and Notation
CNC	Computer Numerical Control
COTS	Commercial Off-The-Shelf
CPPS	Cyber-Physical Production System
CPS	Cyber-Physical System
CPSoS	Cyber-Physical System of Systems
CRISP-DM	Cross-Industry Standard Process for Data Mining
CTQ	Critical to Quality
DCS	Distributed Control System
DMC QR	Data Matrix Code – Quick Response
DPWS	Device Profile for Web Services
DSS	Decision Support System
EOL	End of Life
ERP	Enterprise Resource Planning
FIPA	Foundation for Intelligent Physical Agents
GUI	Graphical User Interface
HFML	High Frequency Machine Learning
HMI	Human Machine Interface
IACS	Industrial Automation and Control Systems
ICS	Industrial Control System
IEC	International Electrotechnical Commission
IIC	Industrial Internet Consortium
IIRA	Industrial Internet Reference Architecture
IIoT	Industrial Internet-of-Things
IoT	Internet-of-Things
ISA	International Society of Automation
IT	Information Technology
KPI	Key Performance Indicator

LFML	Low Frequency Machine Learning
Local DSS	It is a DSS local to the PRPOPHESY-CPS
JADE	Java Agent Development Framework
JLR	Jaguar Land Rover, Wolverhampton
KPI	Key Performance Indicator
M2M	Machine to Machine
MES	Manufacturing Execution System
ML	Machine Learning
MMS	Marposs Monitoring Solutions
NIST	National Institute of Standards and Technology
OEE	Overall Equipment Effectiveness
OEM	Original Equipment Manufacturer
OPC	OLE for Process Control
OPC-UA	OPC Unified Architecture
OT	Operation Technology
P&P	Plug and Produce
PdM	Predictive Maintenance
PHI	Philips Consumer Lifestyle, Drachten
PLC	Programmable Logic Controller
PLM	Product Lifecycle Management
PROPHESY-AR	PROPHESY-Augmented Reality
PROPHESY-CPS	PROPHESY-Cyber Physical System
PROPHESY-ML	PROPHESY-Machine Learning
PROPHESY-PdM	PROPHESY-Predictive Maintenance
PROPHESY-PdM Platform	The hardware and necessary software connected to several PROPHESY-CPSs and to the PROPHESY-AR. The platform is responsible to calculate KPIs from the data and using the PROPHESY-ML algorithms.
PROPHESY System	It is the combination of the PROPHESY-CPS and PROPHESY-PdM platform
PROPHESY-SOE	PROPHESY-Service Optimization Engine
QM	Quality Management
QMS	Quality Management System
RAModel	Reference Architectural Model
RCA	Root Cause Analysis
REST	Representational State Transfer
ROI	Return on Investment
RTD	Research and Technology Development
RUL	Remaining Useful Life
SCADA	Supervisory Control and Data Acquisition
SOA	Service Oriented Architecture
SoS	System-of-Systems
SotA	State-of-the-Art
SSN	Semantic Sensor Network
WP	Work Package
WS	Web Service

1 Introduction

1.1 The PROPHESY Concept

The PROPHESY project aims at designing, delivering and validating a PdM services platform while acting as a catalyst for the wider deployment and uptake of next generation, optimal, adaptive and self-configurable PdM services and solutions (see Figure 1).

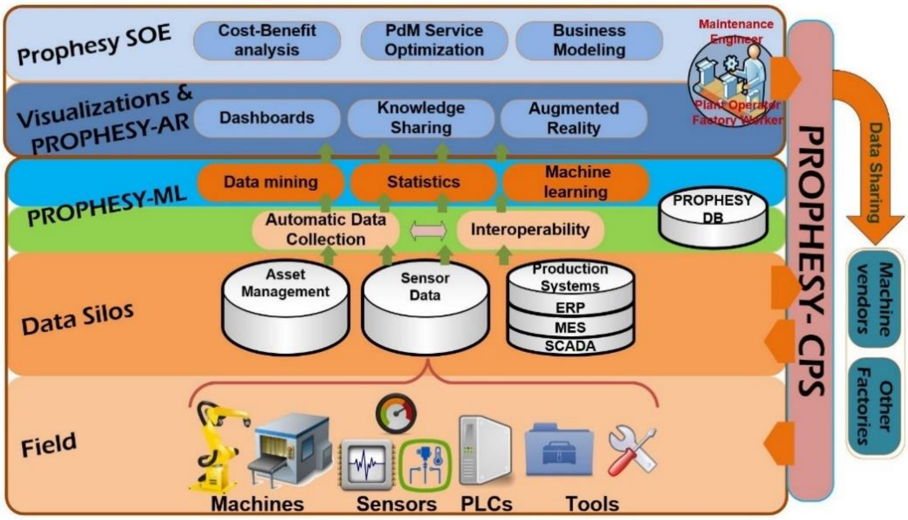

Figure 1: High Level Overview of the PROPHESY-PdM Platform

Despite the proclaimed benefits of predictive maintenance, the majority of manufacturers are still disposing with preventive and condition-based maintenance approaches which result in suboptimal OEE (Overall Equipment Effectiveness). This is mainly due to the challenges of predictive maintenance deployments, including the fragmentation of the various maintenance related datasets (i.e. data “silos”), the lack of solutions that combine multiple sensing modalities for maintenance based on advanced predictive analytics, the fact that early predictive maintenance solutions do not close the loop to the production as part of an integrated approach, the limited exploitation of advanced training and visualization modalities for predictive maintenance (such as the use of Augmented Reality (AR) technologies), as well as the lack of validated business models for the deployment of predictive maintenance solutions to the benefit of all stakeholders. The main goal of PROPHESY is to lower the deployment barriers for advanced and intelligent predictive maintenance solutions, through developing and validating (in factories) novel technologies that address the above-listed challenges.

In order to alleviate the fragmentation of datasets and to close the loop to the field, PROPHESY will specify a novel CPS (Cyber Physical System) platform for predictive maintenance, which shall provide the means for **diverse data collection, consolidation and interoperability**, while at the same time supporting digital automation functions that will **close the loop to the field** and will **enable “autonomous” maintenance functionalities**. The project's CPS platform is conveniently called PROPHESY-CPS and is developed in the scope of WP3 of the project.

In order to exploit multiple sensing modalities for timely and accurate predictions of maintenance parameters (e.g., RUL (Remaining Useful Life)), PROPHESY will employ advanced predictive analytics which shall operate over data collected from multiple sensors, machines, devices, enterprise systems and maintenance-related databases (e.g., asset management databases). Moreover, PROPHESY will provide tools that will facilitate the development and deployment of its library of advanced analytics algorithms. The analytics tools and techniques of the project will be bundled together in a toolbox that is named **PROPHESY-ML** and is developed in WP4 of the project.

In order to leverage the benefits of advanced training and visualization for maintenance, including **increased efficiency and safety of human-in-the-loop processes** the project will take advantage of an Augmented Reality (AR) platform. The AR platform will be customized for use in maintenance scenarios with particular emphasis on remote maintenance. It will be also combined with a number of visualization technologies such as ergonomic dashboards, as a means of enhancing worker's support and safety. The project's AR platform is conveniently called **PROPHESY-AR**.

In order to develop and validate viable business models for predictive maintenance deployments, the project will explore optimal deployment of configurations of turn-key solutions, notably solutions that comprise multiple components and technologies of the PROHPESY project (e.g., data collection, data analytics, data visualization and AR components in an integrated solution). The project will **provide the means for evaluating such configurations against various business and maintenance criteria**, based on corresponding, relevant KPIs (Key Performance Indicators). PROPHESY's tools for developing and evaluating alternative deployment configurations form the project service optimization engine, which we call **PROPHESY-SOE**.

Figure 2 shows where the PROPHESY-PdM core elements support the three reasoning phases and feedback processes. It is important to consider that the PROPHESY-PdM system will be especially focused on the work unit (PROPHESY-CPS) and area levels (PROPHESY-PdM platform), however, it will also provide some support to the enterprise level thanks to a set of applications that will be designed and implemented during the project and will run on the top of the PROPHESY-PdM platform.

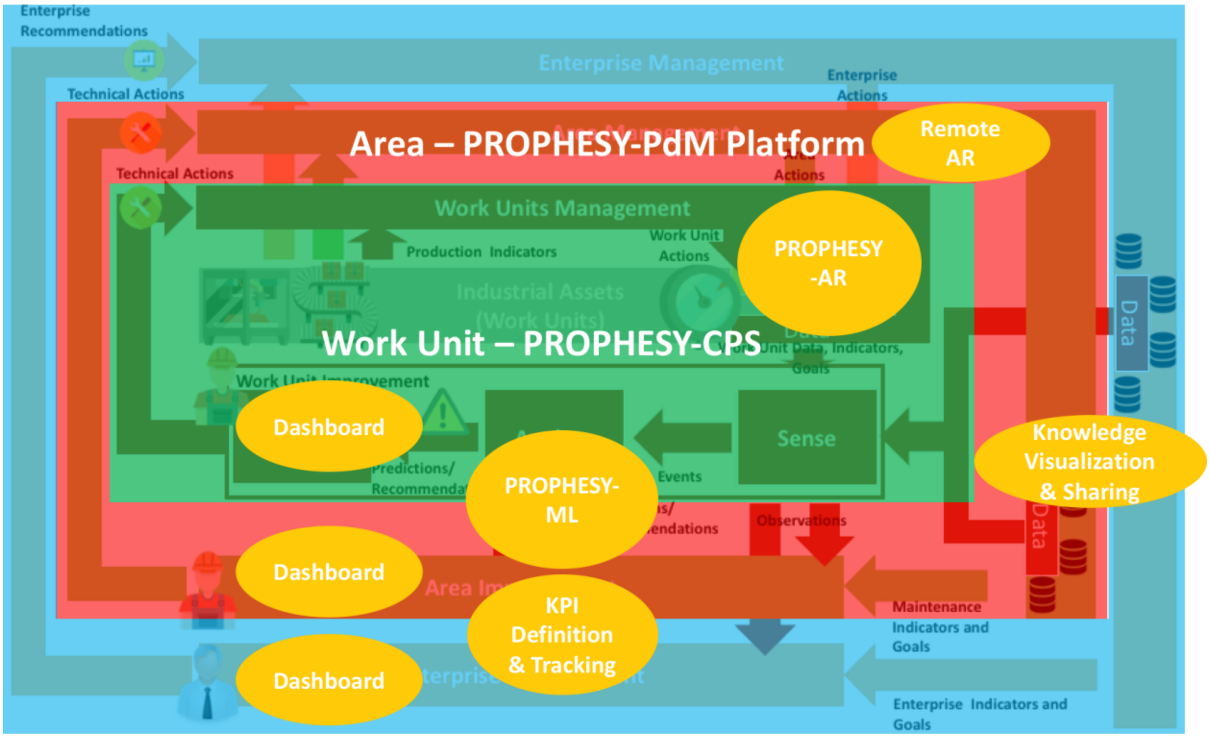

Figure 2: Instantiation of the main elements of the PRPOHESY PdM system to support the identified reasoning phases and related feedback processes

More information of the PROPHESY overall strategy is presented in Deliverable 2.1.

1.2 Strategy of WP7 and Task 7.1

The work package 7 (WP7) will be devoted to the integration, validation and evaluation of the two complex demonstrators of the project, which will take place in real-life production lines of PHILIPS and JLR. The main objectives of WP7 are:

- To prepare the two pilot sites for the PROPHESY platform deployment and use in the scope of the real-life predictive maintenance scenarios that will be demonstrated.
- To integrate, operate and demonstrate a PROPHESY-based solution for predictive maintenance of production tooling at PHILIPS factory.
- To integrate, operate and demonstrate a PROPHESY-based solution for predictive maintenance of cylinder head machining at JLR factory.
- To perform a thorough technical and business validation of each one of the solutions, including their techno-economic evaluation on the basis of tangible indicators such as OEE, EOL, RCA, RUL, productivity improvement, quality improvements and more.
- To evaluate the complex demonstrators based on feedback from stakeholders, including manufacturers, solution integrators and machine vendors, while at the same time taking into account this feedback in order to fine-tune the demonstrators and enhance their sustainability and exploitation potential.

Task 7.1 will ensure the proper planning of the complex demonstrators, including the readiness of the factories and pilot sites where the solutions will be deployed and operated. The work includes the mobilization of all stakeholders involved in the demonstrator, the preparation of the demonstrator production lines in terms of the required technical infrastructure (e.g., industrial PCs, smart glasses/gloves, networking), as well as the timely deployment of the PROPHESY-CPS platform for the purpose of testing and validating it on the field. Moreover, this task will plan changes to production processes in order to transition from a preventive maintenance to a predictive maintenance approach, which is a common goal of the two demonstrators. A significant part of the task will be devoted to the customization of the PROPHESY-CPS platform to the needs of each demonstrator, as well as its pre-deployment in each production line for testing and validation prior to the commencement of the pilot operation of the demonstrators.

1.3 Document scope and structure

Task 7.1, together with the remaining tasks from work package 7 and work package 2.4, sets the context for the PROPHESY integration and validation in industrial use-cases. To this purpose, the document at hand contributes the ongoing PROPHESY implementation into the complex industrial demonstrator, and gives a detailed overview about the machining hardware, monitoring hard- and software as well as the interfaces used. Finally, the document presents the implementation plan and next steps for the use-cases of the industrial demonstrators.

The current document is structured as follow:

- Section 1. **Introduction**: details the document context, purpose and intended audience, as well as, the overall strategy applied in the WP7 while underlining the role played by this document with respect to the whole project;
- Section 2. **Demonstrator at Philips:** details the hard- and software for machining and monitoring as well as the interfaces at PHI demonstrator to the PROPHESY objectives. Focus is lead to the use-case description and the integration of the PROPHESY-CPS.
- Section 3. **Demonstrator at JLR**: details the hard- and software for machining and monitoring as well as the interfaces at JLR demonstrator to the PROPHESY objectives. Focus is lead to the use-case description and the integration of the PROPHESY-CPS.
- Section 4. **Conclusions**: provides the conclusion of this document and points out the next steps.

The functional description of the industrial use-cases is presented in Deliverable 2.1 and Deliverable 2.2. For the more generic description of the PROPHESY use cases refer to Deliverable 2.4. A more detailed view to the Prophesy Sensor Data Collection is provided in Deliverable 3.5.

2 Demonstrator at Philips

2.1 Introduction

Philips Consumer Lifestyle in Drachten develops a wide range of innovative products like rotary shavers, beard trimmers, hairdryers, epilators, vacuum cleaners, SENSEO® coffeemakers and Wake-up Lights. Philips Drachten employs 2000 people, amongst which 600 developers with 35 different nationalities. Philips Drachten is also world leader in mass production of rotary shaving devices, occupying over 50% market-share of a € 1 billion market. For more than 60 years Philips has been manufacturing shaving systems in the Drachten factory.

For cold forming metal parts, there are multiple production lines. Each production line creates a product mix. On these production lines over 50 individual metal products are created. In total, there are over 300 individual dies. As part of the project's work plan, PROPHESY will be implemented on one production line and one die set. When PROPHESY is functional for this production line it will be expanded to more production lines and more dies. Ultimately, the whole factory can be equipped with a PdM solution, but implementation needs to be done merit based. It will be highly profitable to implement PdM on high quantity / fast running products, but less interesting on small quantity, specialised products.

Because of IT and hardware infrastructure, the expansion of PROPHESY will be done first on the production line where the demonstrator is implemented. This will affect a limited product mix of three (3) products. After this, other lines can also be equipped with IT and hardware. It is estimated that at least 4 cold forming production lines are interesting to implement PROPHESY on. These lines are the high volume production lines. This will affect approximately 55 metal products and 280 dies.

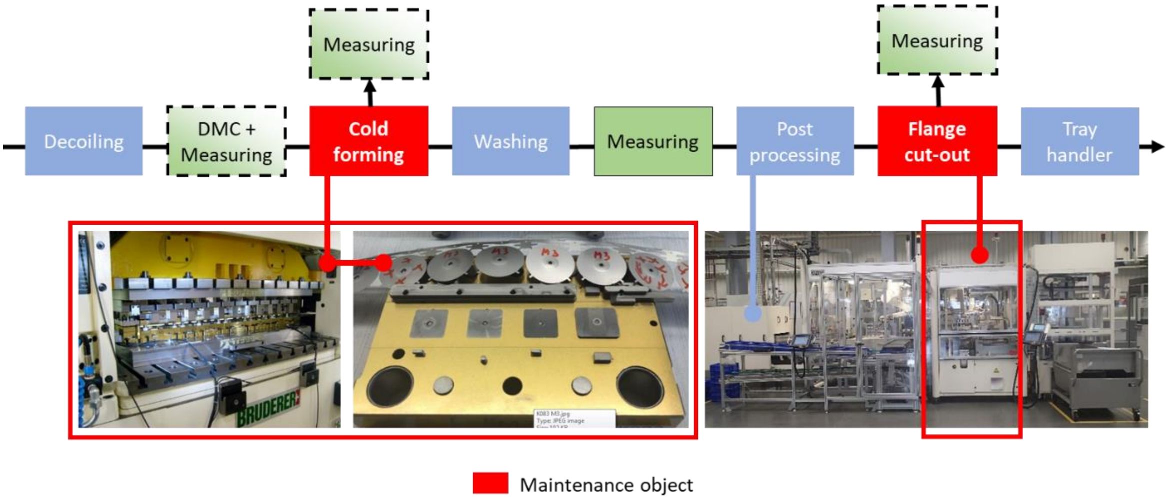

Figure 3: Overview PHI demonstrator

The considered Phillips production line contains 6 steps (1: cold-forming, 2: Washing, 3: Measuring, 4: Post-processing, 5: Flange cut-out, 6: Tray handler).

The ERP system is built on SAP, providing work-streams, production plans and BOM data.

The majority of the manufacturing data is funnelled through the self-developed MES system, called Factory Information System (FIS).

Within FIS, several modules for tooling management (GIS), quality control (QSP), process parameter management (PPS) are fully integrated in the daily operational procedures. At present, a commercial MES solution is being implemented; Hydra.

The Prophesy use-case 1 focuses on the cold-forming machine (MP12) and the use-case 2 focuses on Flange cut-out machine (UK02).

In Deliverable 2.4 a detailed description of the state-of-the-art of the demonstrator as well as a description of all existing components at PHI demonstrator is provided.

2.2 Stakeholders of PHI use-cases

In PROPHESY a lot of adaption and reconfiguration of the PHI demonstrator is planned, to integrate and validate the PROPHESY objectives. To make sure, that this process will not negatively affect the overall production, all stakeholders of the demonstrator must be identified and informed. That is why he first step towards a complex demonstrator description is the identification of all stakeholder at the demonstrator.

Table 1 shows a list of all stakeholder of PHI demonstrator.

Table 1: Identification of PHI stakeholder, on role-level.

Role	Interest Area
SW engineer	MES, SCADA
Maintenance manager	Maint. Mgt Info
Maintenance engineer	Tooling maint. Data
Production engineer	Process knowledge & Uptime
Maintenance manager die-workshop	Maint. Performance & Stock levels
Group lead technical support group	Planning & uptime
Assistant production manager	Planning & uptime
Reviewer	Project performance
Manager manufacturing IT department	Data security, IT-architecture
Spare parts stock management	Stock levels, lead-time
Coldforming engineer	Process knowledge
Process engineer	Data mining & Adv. Process control
Production manager	Uptime

Business planning specialist	ERP, SAP-interface
PL-internal & Production engineer	Planning & uptime
Manager maintenance & production support	Maint. Mgt Info
Coldforming engineer	Augmented reality for maintenance
Support	Man Machine Interfaces
Maintenance technician	Tooling maint. Data

The list of PHI stakeholder is not static and will be updated continuously. Before any intervention or update/adaption of the demonstrator, all involved persons will be informed. For this public version, the names of each responsible person were removed.

2.3 Philips Use-cases

The considered Philips production line contains 6 steps (1: cold-forming, 2: Washing, 3: Measuring, 4: Post-processing, 5: flange cut-out, 6: Tray handler).

A description of the software used in the Philips Use-case is provided in section 2.4.4.

The Prophesy use-case 1 focuses on the cold-forming machine (MP12) and the use-case 2 focuses on Flange cut-out machine (UK02).

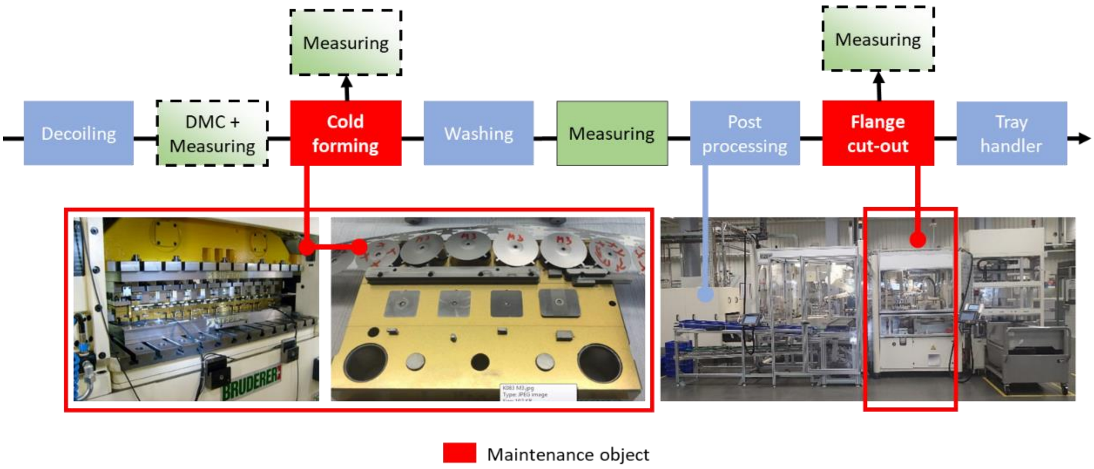

Figure 4: PHI use-cases production line

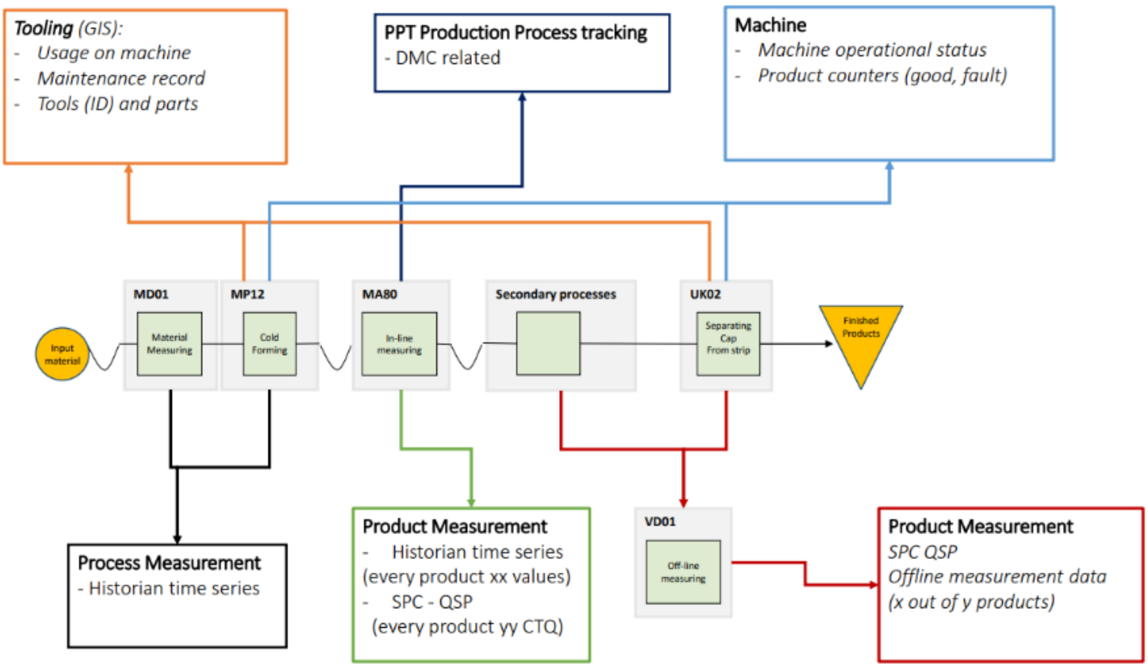

Figure 5: PHI use-cases production line

2.3.1 Use-case 1: short description

The use-case 1 relates to machine MP12 (cold forming press). The main purpose is to predict the RUL (remaining useful life) of specific wear parts within a tool assembly. Two wear parts are considered: a punch (on the top part of the tool assembly) and a cutting bush (on the bottom part).

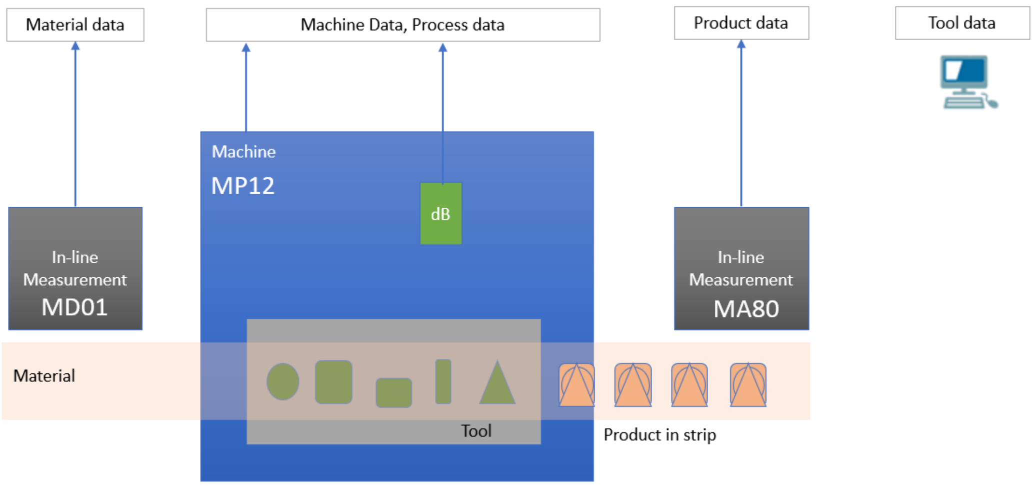

Figure 6: PHI use-case 1 - machines

Figure 7: PHI use-case 1 - cold forming press MP12

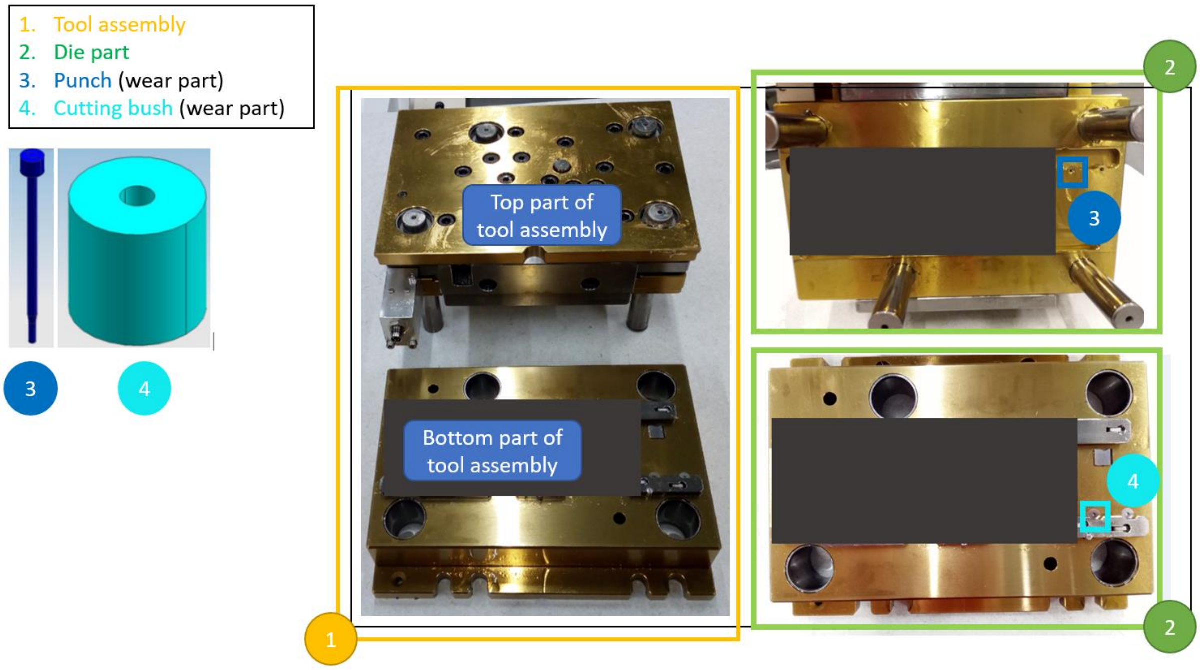

Figure 8: PHI use-case 1 - tool assembly

2.3.1.1 Process description

Before entering in the cold-forming machine MP12, some measurements are taken on the raw material (metal coil): temperature (1 value), thickness (1 value) and magnetic properties (48 values). The measuring machine name is “MD01”.

Measurements are taken on every product (based on current cycle time approx. 100 per minute) but utilization of the line can differ. The measurements are linked with the product id (DMC: Data Matrix Code).

The cold-forming machine MP12 shapes the product in a few steps of cutting, bending and calibrating.

The machine has also a Brankamp X5 installed on which an acoustic measurement is already active (one profile per minute).

The in-line measuring machine MA80 measures the quality of the products coming from machine MP12. The machine measures some characteristics such as diameter, roundness and shape accuracy. In case of non-quality, it stops the MP12.

2.3.1.2 Tools management description

The operator specifies in the tooling system which tool is on which machine (start of the die run). If a failure occurs, the operator ends the die run in the tooling system and generates a new work order by picking a work order reason from a picklist and enters extra free text as additional info for the maintenance mechanic.

Before starting the maintenance, the mechanic logs on to the die for maintenance (currently they log on and off when the entire maintenance loop for a die is finished).

Reset counters for the die and wear parts are also done after the maintenance work (basically a new start for the threshold monitoring).

After changing the wear part(s) (can be regarded as a wear part usage, currently no identification of the wear part), the mechanic logs off from the die for maintenance. Doing so, he must choose that the die maintenance is finished (and ready again for production) or interrupted (currently not used). A free text field can be entered as information for later usage. The time between logging on to and off from a die equals the time to repair (TTR) from which a mean time to repair (MTTR) can be calculated for a specific maintenance job.

These actions are managed and registered inside GIS (part of the MES legacy system).

2.3.2 Use-case 2: short description

The use-case 2 relates to machine UK02 (cutting out machine). The main purpose is to predict the RUL (remaining useful life) of specific wear parts within a tool assembly. Ten wear parts are considered: 5 identical punches (on the lower die half) and 5 identical cutting plates (on the upper die half).

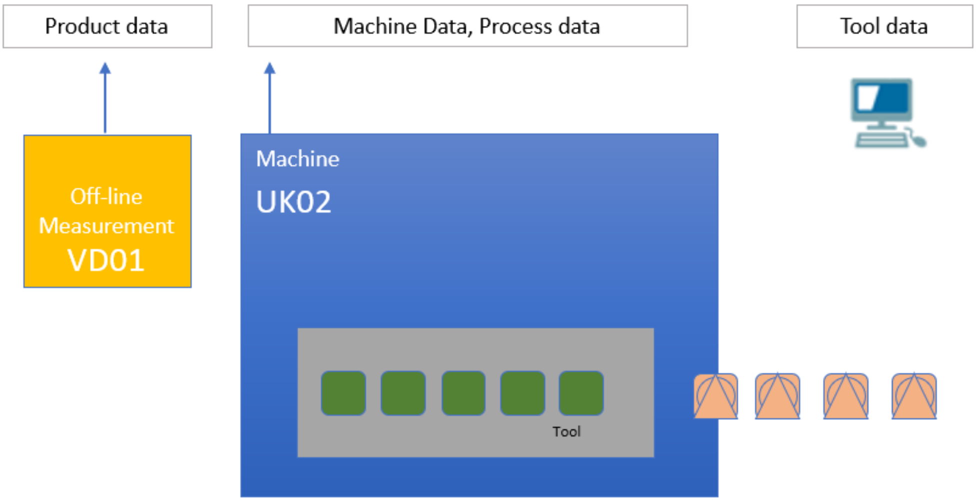

Figure 9: PHI use-case 2 - machine and systems

Figure 10: PHI use-case 2 - cutting out machine UK02

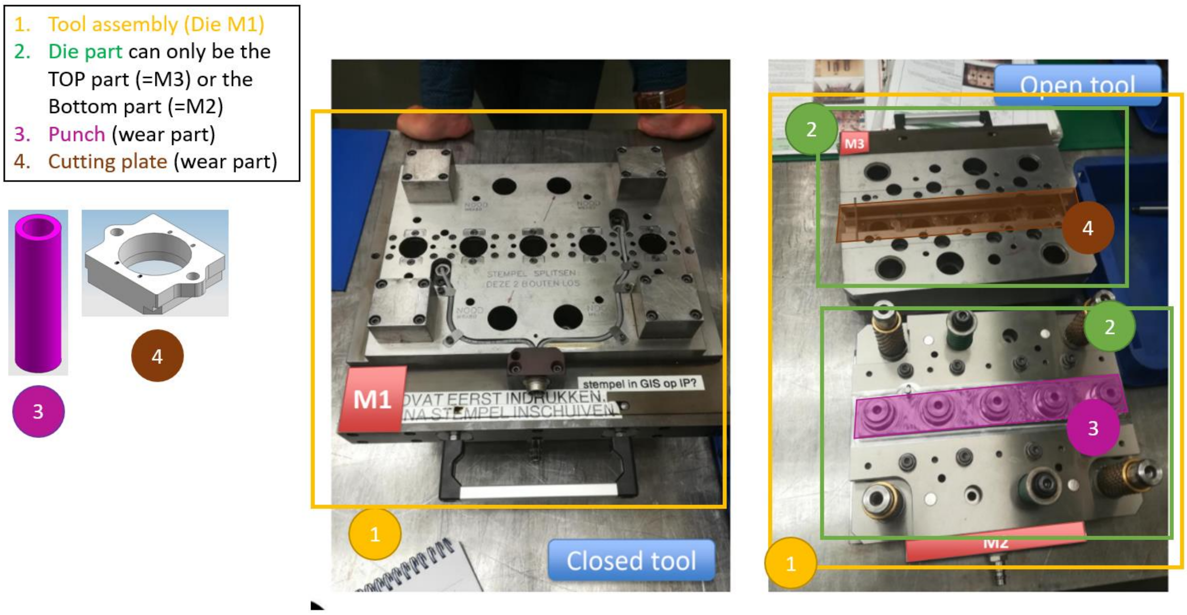

Figure 11: PHI use-case 2 - tool assembly

2.3.2.1 Process description

Before entering in the cutting machine UK02, quality measurements are taken on samples of products (machine VD01). These quality measurements allow to ensure that the product entering the UK02 process meets the basic requirements before being processed any further.

In UK02, products are being cut-out from their outer contour. Five products are being picked by a robotic arm and placed in a 5-fold product carrier. The product carrier is fed into the cut-out tool by a pneumatic indexing system. A linear motor drives the tool to cut the contour out. The contour is discarded as waste and the remaining product is collected for the next stage.

2.3.2.2 Tools management description

The tool management process (utilization & maintenance) is similar as described above (see section 2.3.1.2).

2.4 Preparation of the production line

In this section, the preparation of the PHI production line is described. The preparation and integrations follow the Prophesy Integration Plan provided in D2.4, section 2.4.

2.4.1 Machining part

The complex demonstrator ‘Production tooling in a cold-forming manufacturing process’ comprises of 2 main processes that are under investigation:

a. The cold-forming of a flat steel strip to a deep-drawn cup-shaped cap of the famous rotary Philips shaving-heads;
b. The cutting-out of the final cap from the base-material.

Ad a.) The cold-forming process is executed in a step-by-step manner to prevent the material from tearing. The tooling for this process is fully product-specific and, as a result, the product quality depends on the quality/health of the tooling. The design, commissioning and maintenance of these specific tooling sets requires a high level of experience.

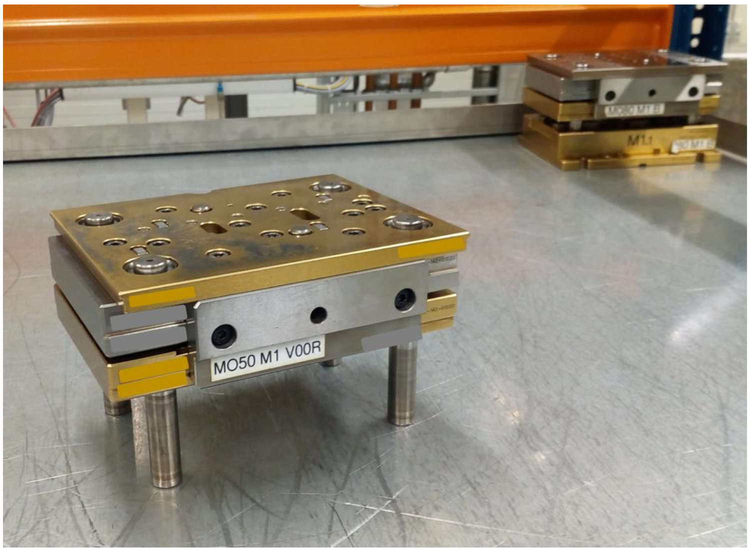

Figure 12: Upper part of a cold-forming tool-module (foreground) and a complete tool-module (background)

In Figure 7 and Figure 12 a picture of the Cold-forming press (MP12) with the current Brankamp X5 system on top of the control panel and the upper part of a cold-forming tool-module (foreground) and a complete tool-module (background) are presented.

Tiny deviations in the geometry of the forming parts of the tool will result in product quality deviations. By monitoring deformational, vibrational and acoustic behaviour and trends, the health of the tooling is constantly evaluated. Combining this data with material-data, product measurements, machine data and historical events, it is expected to accurately predict the Rest of Useful Life (RUL) of the tooling-set, based on the RUL of the tool-components.

Ad b.) The cutting-out of the final product is a straight forward operation, however a lot of tooling breakdowns and therefore productivity-loss occurs (see Figure 10). The tooling is designed in a way that 5 products are being cut-out in one stroke of the servo-driven press (see Figure 13).

Figure 13: 5-fold cutting-out tool, ready for manufacturing

Due to the very tight product- specifications, the tooling is designed and build with very narrow tolerances. Also, the cutting parts (punches and die-plates) are fragile due to the limited design space. By adding monitoring to this process, it is expected to find the correlation between the quality parameters of the incoming products (which are the output of the cold-forming process described before), the evaluated health of the cutting-out tooling and the occurrence of a tool breakage. The targeted situation is to avoid breakdown maintenance and be able to plan the condition-based maintenance right on time.

2.4.2 Measuring equipment

The product quality is assessed by both in-line and off-line measuring equipment. The equipment below will provide material and product data to the Prophesy PdM platform (see Figure 14, Figure 15 and Figure 16).

Figure 14: Experimental, in-line material measuring machine (MD01)

Figure 15: In-line product measuring machine (MA80)

Figure 16: Off-line product measuring machine (MA67)

2.4.3 Monitoring part

In the PHI demonstrator, basically three different sensor and monitoring concepts are followed: Brankamp Monitoring system, Machine integrated sensors and iCARE wireless sensors.

In deliverable 3.5 a list of all required physical measurements for the Philips Use-cases was presented (see Table 2). All of these signals must be monitored with the three proposed sensor and monitoring concepts.

Monitoring system X7

For the PROPHESY demonstrator the monitoring of process information is one of the main tasks. At Philips, a Brankamp branded MMS X5 system is already equipped at the UC1 machine. To allow an extended process monitoring by integration of further sensors and interfaces to PROPHESY, an upgrade to a Brankamp branded X7 system is necessary. For UC2, also a Brankamp X7 system will be implemented.

Figure 17: Brankamp X7 process monitoring system

Figure 17 shows a Brankamp X7 system as well as some possible process curves. The X7 system allows up to 24 channels for an extended process monitoring. The HMI part of the system runs on a Windows Operation System, so that an easy connection to other PROPHESY parts is possible. Furthermore, the X7 Cockpit provides a switchable mask design with flexible arrangement of the monitoring channels (according to the machine configuration). Binary input signals can be monitored with up to three monitoring windows to ensure the earliest possible fault detection. The failure distribution shows machine downtimes and the frequency of process failures for a quick and easy failure analysis.

The X7 system has different options to transmit the process data to the PROPHESY platform. For the Philips demonstrator, a standard PC (Edge-PC) will be used to gather all data from the X7 and provide the data in a secure way to PROPHESY (see Deliverable 7.1). The HFML as well as further data processing could be performed at this Edge-PC.

Machine integrated sensors:

Philips and MMS are working closely together to integrate force sensors and acoustic sensors in the tooling. Figure 18 presents a general sensor installation design to be applied on tool-modules for UC1.

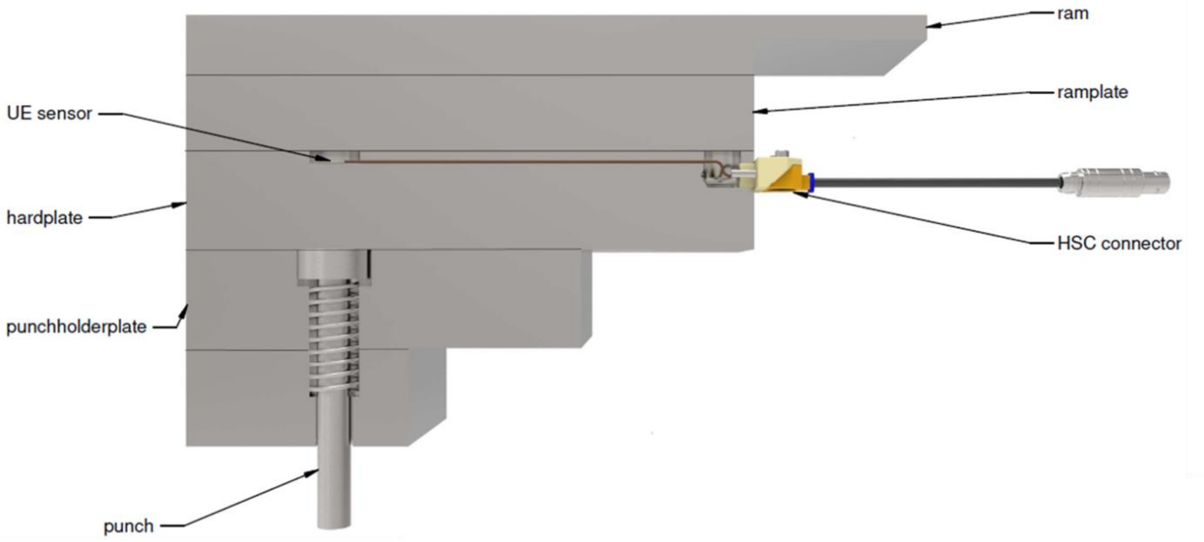

Figure 18: General sensor installation design to be applied on tool-modules for UC1.

For Use-case 1 the following sensor types will be equipped:

Sensor	System source	Sensor Description	Status
1	MMS Brankamp	Acoustic signal (sensor on guide plate)	Already existing
2	MMS Brankamp	Cutting force measurement (piezoelectric pressure sensor on top of punch head)	To be installed within Prophesy (in progress)

- Existing sensors (data will be fed to Prophesy)
  - 1x Acoustic sensor (die-housing)
  - 1x UE13 sensor in ram
  - 4x UE10 sensors for double material/slugs detection
- Existing, non-Prophesy sensors (data is not applicable to Prohesy-ML PdM)
  - 2x UE10 sensor in cold forming step 5 (module 5)
  - 2x UE10 sensor in cold forming step 6 (module 6)

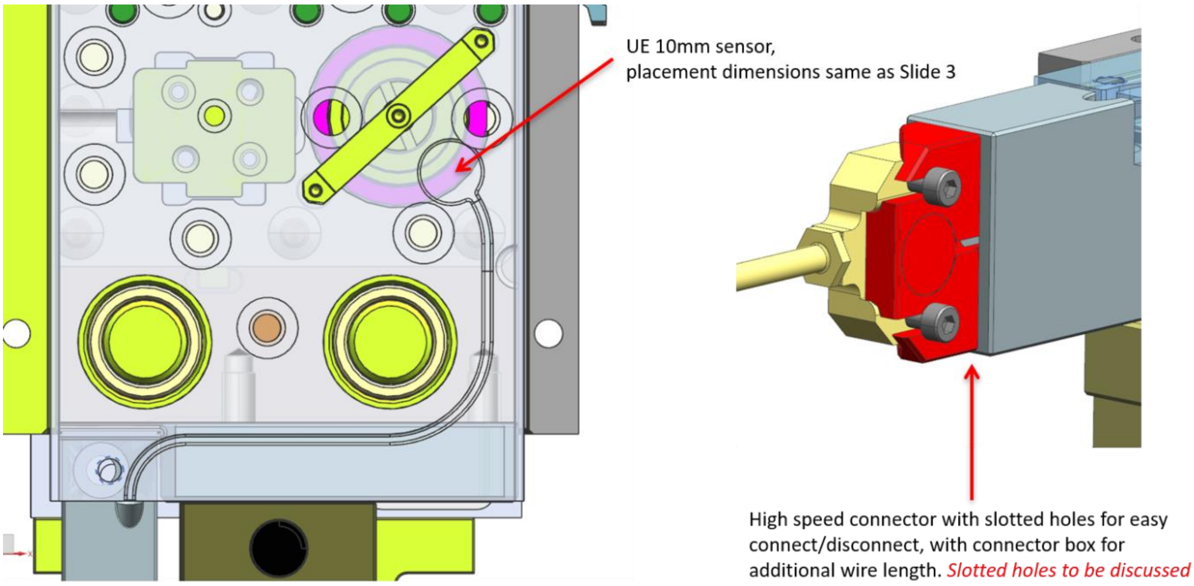

Figure 19: Use-case 1 description of sensor and connector

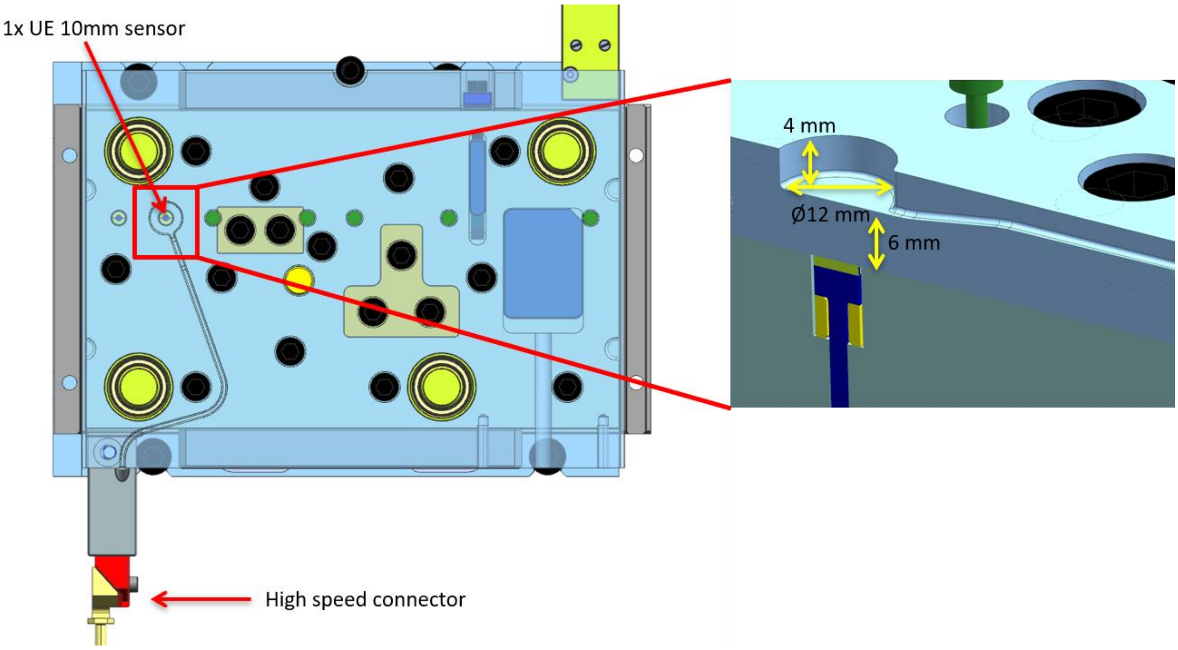

Figure 20: Use-case 1 description of sensor installation

For Use-case 2 the following sensor types and data collectors are required:

Sensor	System Source	Sensor Description	Status
1	MMS Brankamp	Acoustic signal (acoustic wave sensor on die)	To be installed within Prophesy (in progress)

2	MMS Brankamp	Cutting force measurement (piezoelectric pressure sensor under cutting bush)	To be installed within Prophesy (in progress)
3	Wi-care	Vibration sensors of servo drive	To be installed within Prophesy (done)

- Upper die half
  - 2x UE10 sensor in top plate
  - 1x Acoustic emission sensor under top plate
- Lower die half
  - 5x UE10 sensor in bottom plate
  - 1x Acoustic emission sensor under top plate
- Press frame
  - 3x UE10 sensor in holding strip right hand side
  - 3x UE10 sensor in holding strip left hand side
- Total amount of sensors: 15

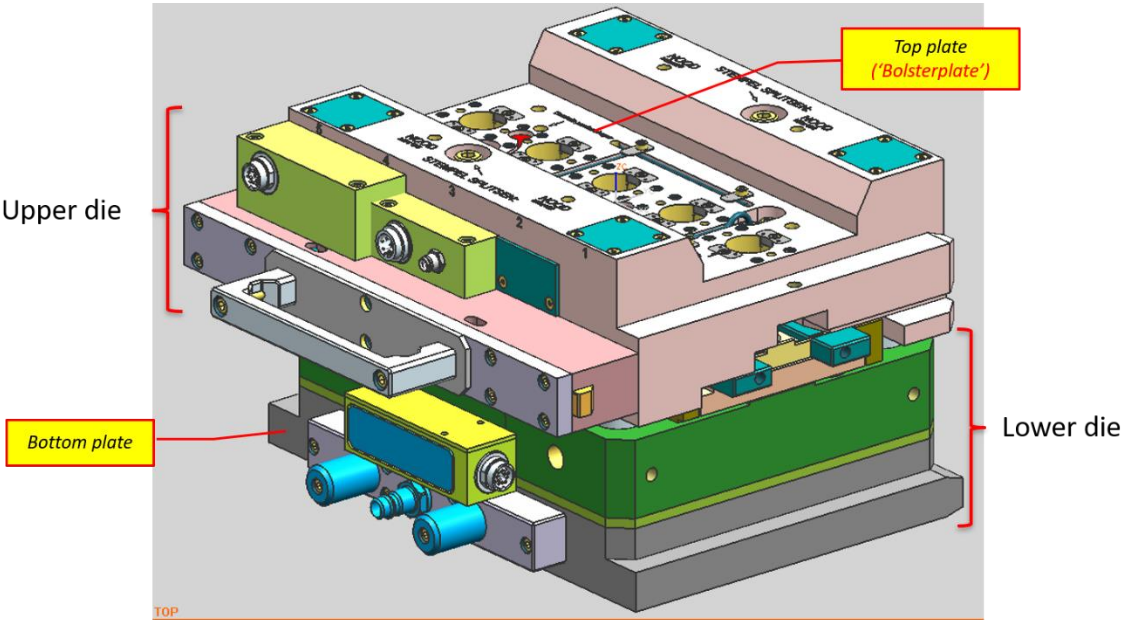

Figure 21: Use-case 2 description of top and bottom plate

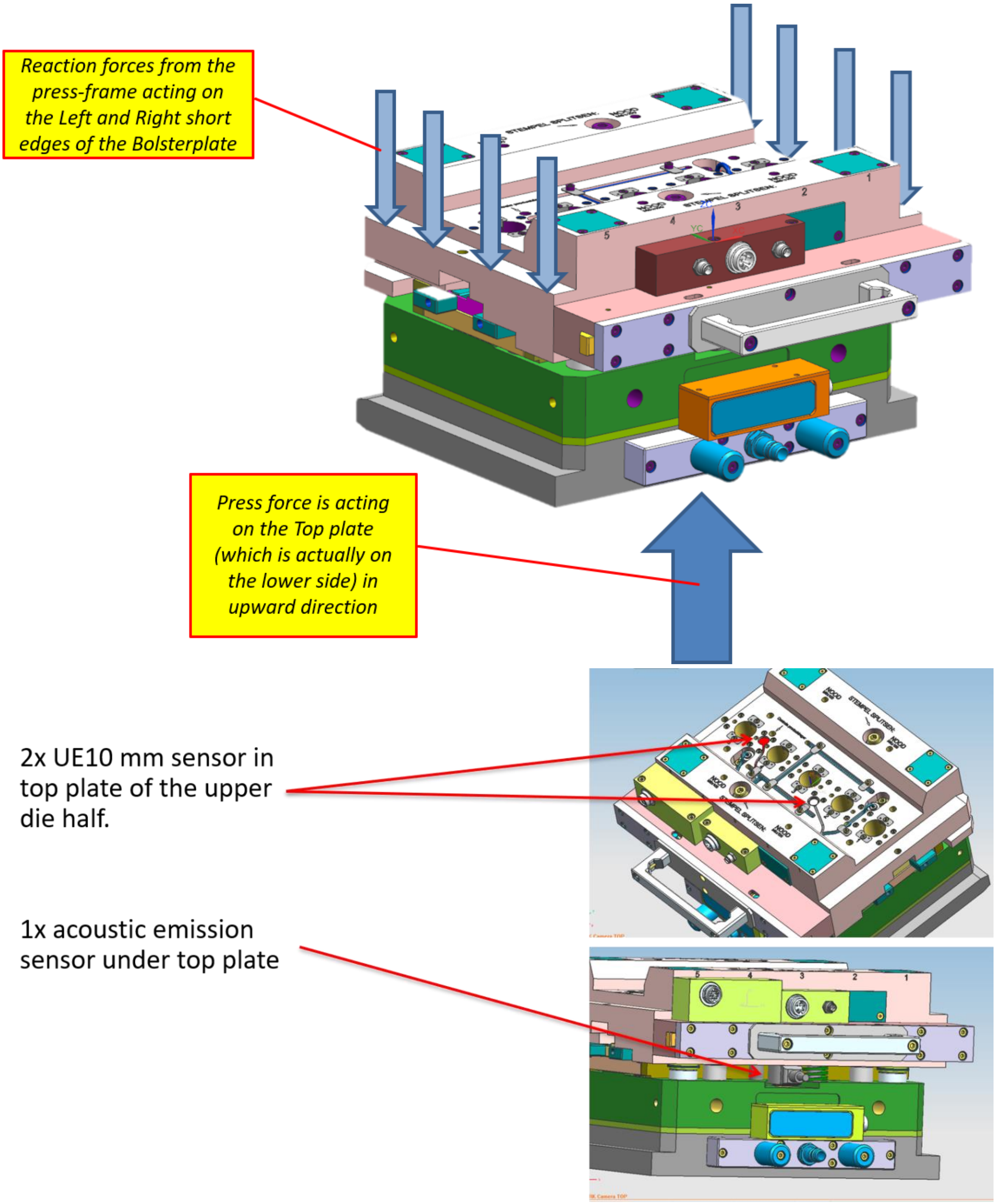

Figure 22: Use-case 2 sensor integration schematic

Wireless Sensor:

A Wi-care wireless vibration system has been installed on the cut-out unit at Philips on PHI_UC2. The Wi-care system is described with more details in Deliverables D3.5 & D3.6.

The Wi-care system is a wireless system capable of acquiring temporal and spectral vibration and temperature data on industrial equipment. The system provides an alternative to manual data collection and enables the use of cables to be avoided. In addition, the system is designed to last several years without the need for maintenance.

At Philips, two wireless sensors with single axis accelerometer are currently installed on the linear motor of the cut-out machine (Figure 23). These sensors are called MP1 and MP3 (Measuring Point #1 & Measuring Point #3).

- MP1: the wireless transmitter is wired to the accelerometer (because there is not enough place to use a directly-mounted transmitter). The sensor is pot
- MP3: the wireless transmitter is directly mounted on the accelerometer

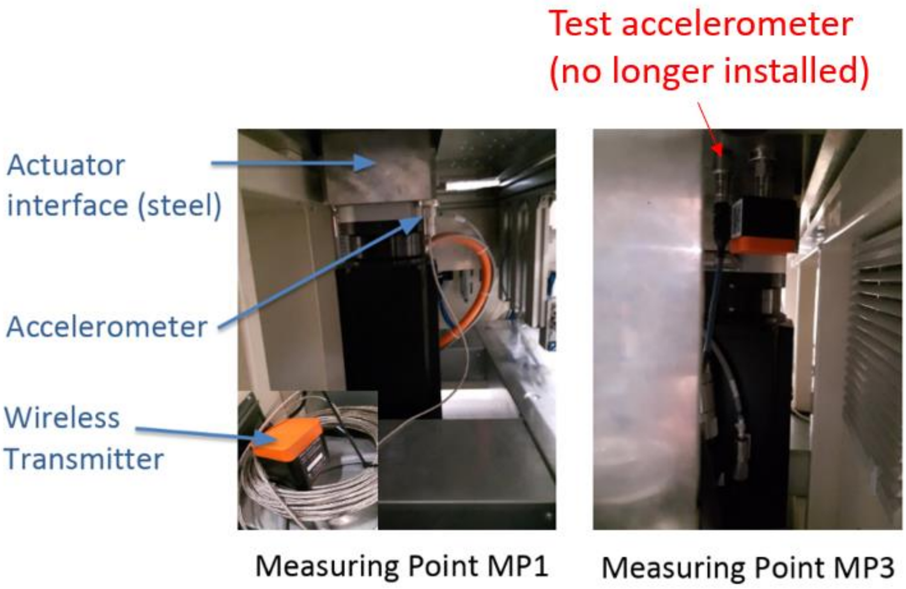

Figure 23 Wi-care measurement locations at Philips

The aim is to monitor and analyse the acceleration profile during the running cycles of the machine. The cutting tool cycles are different for different tool sets and it is expected that tool wear will produce different signals. The acceleration datasets of PHI_UC2 will be part of PROPHESY-ML inputs once the useful physical information will be extracted from the acceleration datasets of PHI_UC2. An example of acceleration recording is shown on Figure 24.

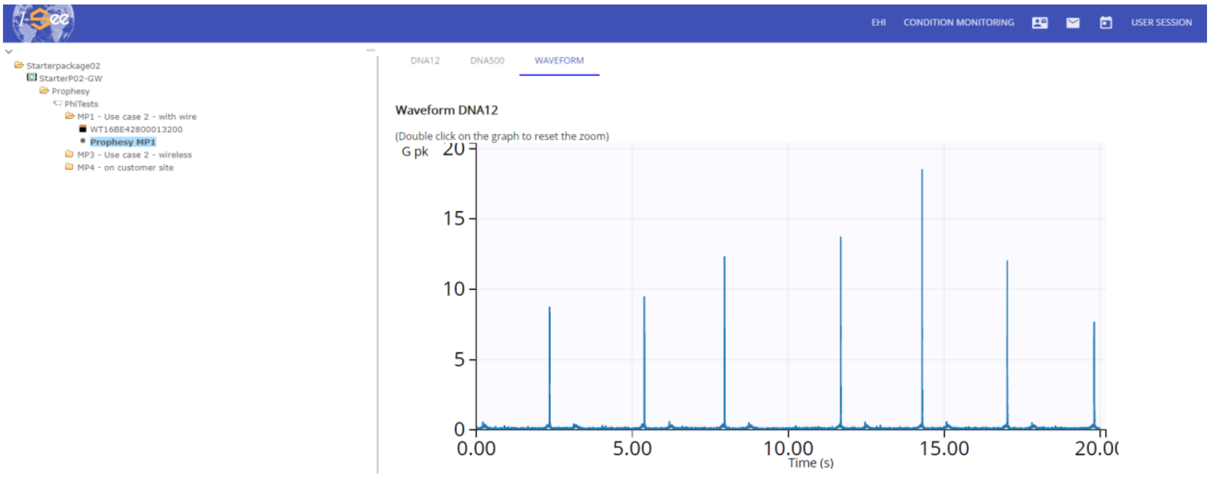

Figure 24 I-see web portal for acceleration data visualisation for PHI_UC2

To conclude, Table 2 lists all types of data to be acquired from the demonstrator equipment and the current status of the preparation.

Table 2: Overview data acquisition at the Philips and JLR demonstrator

	Machine	Part ID	Part Failure modes to consider	Number of historical events per each failure mode	Existing Measurements which are for sure representative of the failure mode detection	System (ex: MMS Genior modular, MMS Brankamp, Wi-care,...)	Existing Measurements which are probably representative of the failure mode detection	System	Non existing measurements which are maybe representative of the failure mode detection	System
PHI	MP12	USE CASE 1 Cold-forming tool	1.1 Broken punch	5x	Acoustic signal (sensor on guide plate)	MMS Brankamp	Magnetic properties of strip (Eddy current measurement)	MD01	Cutting force measurement (piezoelectric pressure sensor on top of punch head)	MMS Brankamp
					Diameter of punched hole (in-line CMM-IP measurement)	MA80	Thickness of strip (contact gauge)	MD01	Torque of servo feeding system (electric energy consumption of feeding stroke)	To be defined
					Roundness of punched hole (in-line CMM-IP measurement)	MA80	n.a. (not applicable)	n.a.	n.a.	n.a.
					Profile accuracy of punched hole (in-line CMM-IP measurement)	MA80	n.a.	n.a.	n.a.	n.a.
			1.2 Abrasive worn punch	14x	Diameter of punched hole (in-line CMM-IP measurement)	MA80	Acoustic signal (sensor on guide plate)	MMS Brankamp	Cutting force measurement (piezoelectric pressure sensor on top of punch head)	MMS Brankamp
					Roundness of punched hole (in-line CMM-IP measurement)	MA80	n.a.	n.a.	3D profile measurement of punch (offline optical 3D MM)	To be defined
					Profile accuracy of punched hole (in-line CMM-IP measurement)	MA80	n.a.	n.a.	n.a.	n.a.
			1.3 Broken die-plate	3x	Acoustic signal (sensor on guide plate)	MMS Brankamp	Magnetic properties of strip (Eddy current measurement)	MD01	Cutting force measurement (piezoelectric pressure sensor on top of punch head)	MMS Brankamp
					Diameter of punched hole (in-line CMM-IP measurement)	MA80	Thickness of strip (contact gauge)	MD01	n.a.	n.a.
					Roundness of punched hole (in-line CMM-IP measurement)	MA80	n.a.	n.a.	n.a.	n.a.
					Profile accuracy of punched hole (in-line CMM-IP measurement)	MA80	n.a.	n.a.	n.a.	n.a.
			1.4 Abrasive worn die-plate	5x	Diameter of punched hole (in-line CMM-IP measurement)	MA80	Acoustic signal (sensor on guide plate)	MMS Brankamp	Cutting force measurement (piezoelectric pressure sensor on top of punch head)	MMS Brankamp
					Roundness of punched hole (in-line CMM-IP measurement)	MA80	n.a.	n.a.	3D profile measurement of die-plate (offline optical 3D MM)	To be defined
					Profile accuracy of punched hole (in-line CMM-IP measurement)	MA80	n.a.	n.a.	n.a.	n.a.
PHI	UK02	USE CASE 2 5-fold cut-out tool	2.1 Broken punch	11x	n.a.	n.a.	Diameter of flange (off-line CMM-IP measurement)	VD01	Acoustic signal (acoustic wave sensor on die)	MMS Brankamp
					n.a.	n.a.	Roundness of flange (off-line CMM-IP measurement)	VD01	Cutting force measurement (piezoelectric pressure sensor under cutting bush)	MMS Brankamp
					n.a.	n.a.	Profile accuracy of flange(off-line CMM-IP measurement)	VD01	Torque of servo drive (electric energy consumption of stroke)	To be defined
					n.a.	n.a.	Hardness of product/flange (Vickers hardness measurement)	VD01	Acceleration on servo drive	Wi-care
			2.2 Abrasive worn punch	NA	n.a.	n.a.	Diameter of flange (off-line CMM-IP measurement)	VD01	Cutting force measurement (piezoelectric pressure sensor under cutting bush)	MMS Brankamp
					n.a.	n.a.	Roundness of flange (off-line CMM-IP measurement)	VD01	Torque of servo drive (electric energy consumption of stroke)	To be defined
					n.a.	n.a.	Profile accuracy of flange(off-line CMM-IP measurement)	VD01	3D profile measurement of punch (offline optical 3D MM)	To be defined
					n.a.	n.a.	n.a.	n.a.	Acceleration on servo drive	Wi-care
			2.3 Broken die-plate	40x	n.a.	n.a.	Diameter of flange (off-line CMM-IP measurement)	VD01	Acoustic signal (acoustic wave sensor on die)	MMS Brankamp
					n.a.	n.a.	Roundness of flange (off-line CMM-IP measurement)	VD01	Cutting force measurement (piezoelectric pressure sensor under cutting bush)	MMS Brankamp
					n.a.	n.a.	Profile accuracy of flange(off-line CMM-IP measurement)	VD01	Torque of servo drive (electric energy consumption of feeding stroke)	To be defined
					n.a.	n.a.	Hardness of product/flange (Vickers hardness measurement)	To be defined	Acceleration on servo drive	Wi-care
			2.4 Abrasive worn die-plate	NA	n.a.	n.a.	Diameter of flange (off-line CMM-IP measurement)	VD01	Cutting force measurement (piezoelectric pressure sensor under cutting bush)	MMS Brankamp
					n.a.	n.a.	Roundness of flange (off-line CMM-IP measurement)	VD01	Torque of servo drive (electric energy consumption of feeding stroke)	To be defined
					n.a.	n.a.	Profile accuracy of flange(off-line CMM-IP measurement)	VD01	3D profile measurement of die-plate (offline optical 3D MM)	To be defined
					n.a.	n.a.	Hardness of product/flange (Vickers hardness measurement)	To be defined	Acceleration on servo drive	Wi-care
JLR	OP90	USE CASE 4 Ball screw	Ballscrew and linear guide not parallel	2X	Increased electric current	PLC	Vibration Signals	MMS Artis	Sound signals	Microphone
					Contour deviation	PLC	Power consumption of machine tool	Energy Management System		
							Temperature on motor	?		
			Ballscrew bearing blocks not at the same level	2X	Increased electric current	PLC	Vibration Signals	MMS Artis	Sound signals	Microphone
							Power consumption of machine tool	Energy Management System		
			Motor and ballscrew not centric (gap created)	2X	Tracking error / Contour deviation		Vibration Signals	MMS Artis	Sound signals	Microphone
							Power consumption of machine tool	Energy Management System		
			Loss of preload, excessive backlash / worn	5X	Actual position S1 and S2 / Contour deviation	PLC	Temperature(in case of extra preload)	N/A	Sound signals	Microphone
							Power consumption of machine tool	Energy Management System	Vibration on the nut and consequently system	MMS Artis
			Poor lubrication in recirculation tube	1X	N/A	N/A	Excessive Temperature	N/A	Sound signals	Microphone
							Vibration Signals	MMS Artis		
			Excessive built up chips (machined) on ball nut tube	2X	N/A	N/A	Increased electric current	PLC	Temperature on screw and nut	N/A
							Vibration Signals	MMS Artis		
			Coolant ingress (electric box, motor)	1X	PLC warning	PLC	Abrupt slow down / rapid move	PLC	N/A	N/A
			Axial bend in ballscrew	1X	Vibration signals	Artis MMS	Increased noise from servo motor	N/A	Sound signals	Microphone
					Deviation from nominal value	Artis MMS	Power consumption of machine tool	Energy Management System		
			Faulty bearings	1X	Audible noise	N/A	Noticeable long rapid move	N/A	Sound signals	Microphone
					Contour deviation	N/A	Power consumption of machine tool	Energy Management System		
							Vibration	MMS Artis		
JLR	OP90	USE CASE 5 Cutting Tools (boring)	Valve guide diameter oversize	150 (tool life based on number of parts)	N/A	N/A (manual machine TPM checks)	Vibration Signals (damaged / worn / contaminated tools / spindle bearing deterioration)	MMS Artis	Sound signals	Microphone
						N/A(manual specified tool change frequency)	Digital Torque Analyser	MMS Artis		
							Surface roughness (material roughness ratio)	CMM (workpiece)		
							Power consumption of machine tool	Energy Management System		
			Valve guide diameter undersize	150 (tool life based on number of parts)	N/A	N/A (manual machine TPM checks)	Vibration Signals (damaged / worn / contaminated tools / spindle bearing deterioration)	MMS Artis	Sound signals	Microphone
						N/A(manual specified tool change frequency)	Digital Torque Analyser	MMS Artis		
							Surface roughness (material roughness ratio)	CMM (workpiece)		
							Power consumption of machine tool	Energy Management System		
			Valve guide bore out of position	150 (tool life based on number of parts)	CMM checks	CMM	Vibration Signals (damaged / worn / contaminated tools / spindle bearing deterioration / damaged machine axes)	MMS Artis	Sound signals	Microphone
						N/A (Manual Adaptor Plate Calibration Schedule | Adaptor Plate Wash Specification)	N/A (Adaptor plate datum features)	N/A (Adaptor plate datum features)		
						N/A(manual specified tool change frequency)	N/A (Damaged Machine Fixture Locations)	N/A (Damaged Machine Fixture Locations)		
							Power consumption of machine tool	Energy Management System		
			Valve guide bore surface finish out of spec	150 (tool life based on number of parts)	N/A	N/A (manual machine TPM checks)	Vibration Signals (damaged / worn / contaminated tools / spindle bearing deterioration / damaged machine axes)	MMS Artis	Sound signals	Microphone
						N/A (Manual Adaptor Plate Calibration Schedule | Adaptor Plate Wash Specification)	N/A (Adaptor plate datum features)	N/A (Adaptor plate datum features)		
						N/A(manual specified tool change frequency)	N/A (Damaged Machine Fixture Locations)	N/A (Damaged Machine Fixture Locations)		
							Power consumption of machine tool	Energy Management System		
			Valve seat angle incorrect	150 (tool life based on number of parts)	N/A	N/A(manual specified tool change frequency)	Vibration Signals (damaged / worn / contaminated tools)	MMS Artis		
			Valve seat angle depths too deep	150 (tool life based on number of parts)	N/A	N/A (manual machine TPM checks)	Vibration Signals (damaged / worn / contaminated tools / spindle bearing deterioration / damaged machine axes)	MMS Artis		
						N/A (Manual Adaptor Plate Calibration Schedule | Adaptor Plate Wash Specification)	N/A (Adaptor plate datum features)	N/A (Adaptor plate datum features)		
						N/A (manual machine TPM checks - coolant flush on fixture)	N/A (Damaged Machine Fixture Locations)	N/A (Damaged Machine Fixture Locations)		
							Power consumption of machine tool	Energy Management System		
			Valve seat angle depths too shallow	150 (tool life based on number of parts)	N/A	N/A (manual machine TPM checks)	Vibration Signals (damaged / worn / contaminated tools / spindle bearing deterioration / damaged machine axes)	MMS Artis		
						N/A (Manual Adaptor Plate Calibration Schedule | Adaptor Plate Wash Specification)	N/A (Adaptor plate datum features)	N/A (Adaptor plate datum features)		
						N/A (manual machine TPM checks - coolant flush on fixture)	N/A (Damaged Machine Fixture Locations)	N/A (Damaged Machine Fixture Locations)		
						N/A(manual specified tool change frequency)	Power consumption of machine tool	Energy Management System		
			Valve seat mask runout out of spec	150 (tool life based on number of parts)	N/A	N/A(manual specified tool change frequency)	Vibration Signals (damaged / worn / contaminated tools)	MMS Artis		
			Valve seat roundness out of spec	150 (tool life based on number of parts)	N/A	N/A(manual specified tool change frequency)	Vibration Signals (damaged / worn / contaminated tools)	MMS Artis		

2.4.4 Software environment

Tooling design information is stored and managed within PTC Windchill PDM. Work instructions for operations and tooling maintenance are stored and archived on Sharepoint. For data analytics, the main platform is Microsoft Azure IoT.

Below picture (Figure 25) shows the main interactions between Manufacturing IT (Production management) and Office IT (Advanced Analytics), which are fully separated networks.

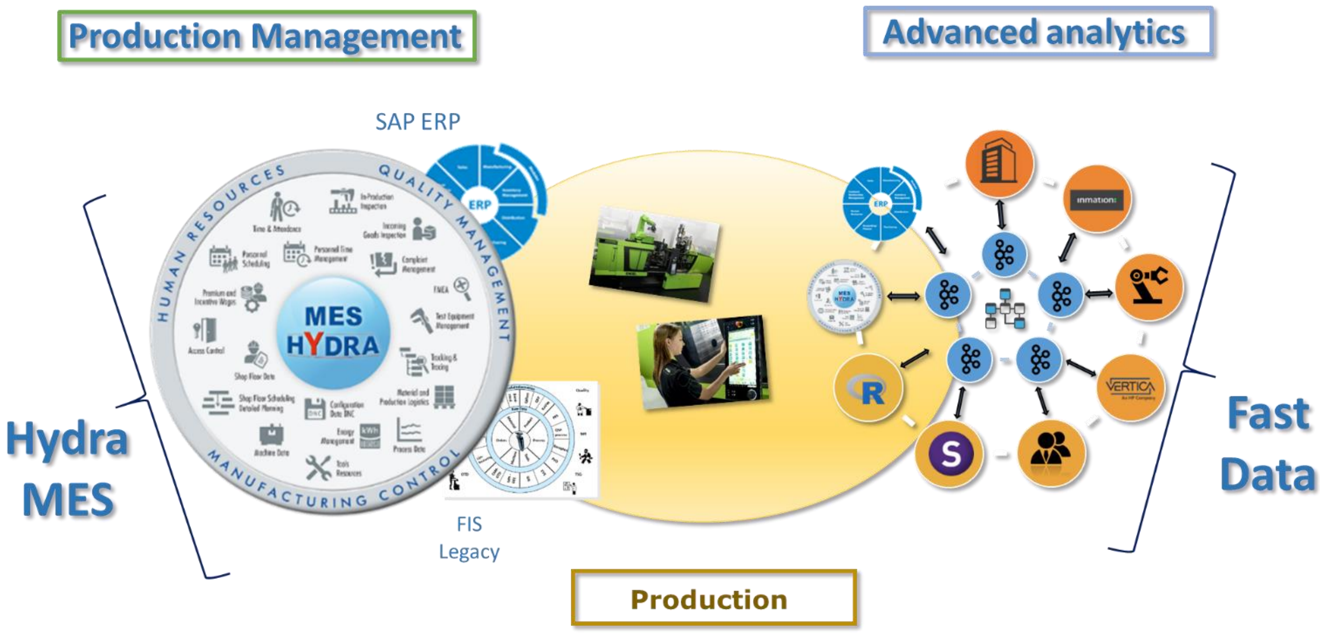

Figure 25: Software-environment for production at Philips

2.5 Integration of Prophesy-CPS

Each demonstrator is devoted to the implementation and delivery of the PROPHESY-CPS platform, which should be based on the MANTIS reference architecture and be optimized for Predictive Maintenance (PdM) services. The implementation is driven by the relevant specifications produced in WP2.

The top part of Figure 26 provides an overview on the respective subsystems of the Prophesy-CPS architecture that are described in deliverable D3.1. Bottom part of the figure provides a more detailed view of the bricks related to data sensing and external data collection. Starting from this view, it is easy to describe the connection between the demonstrator and the PROPHESY-CPS.

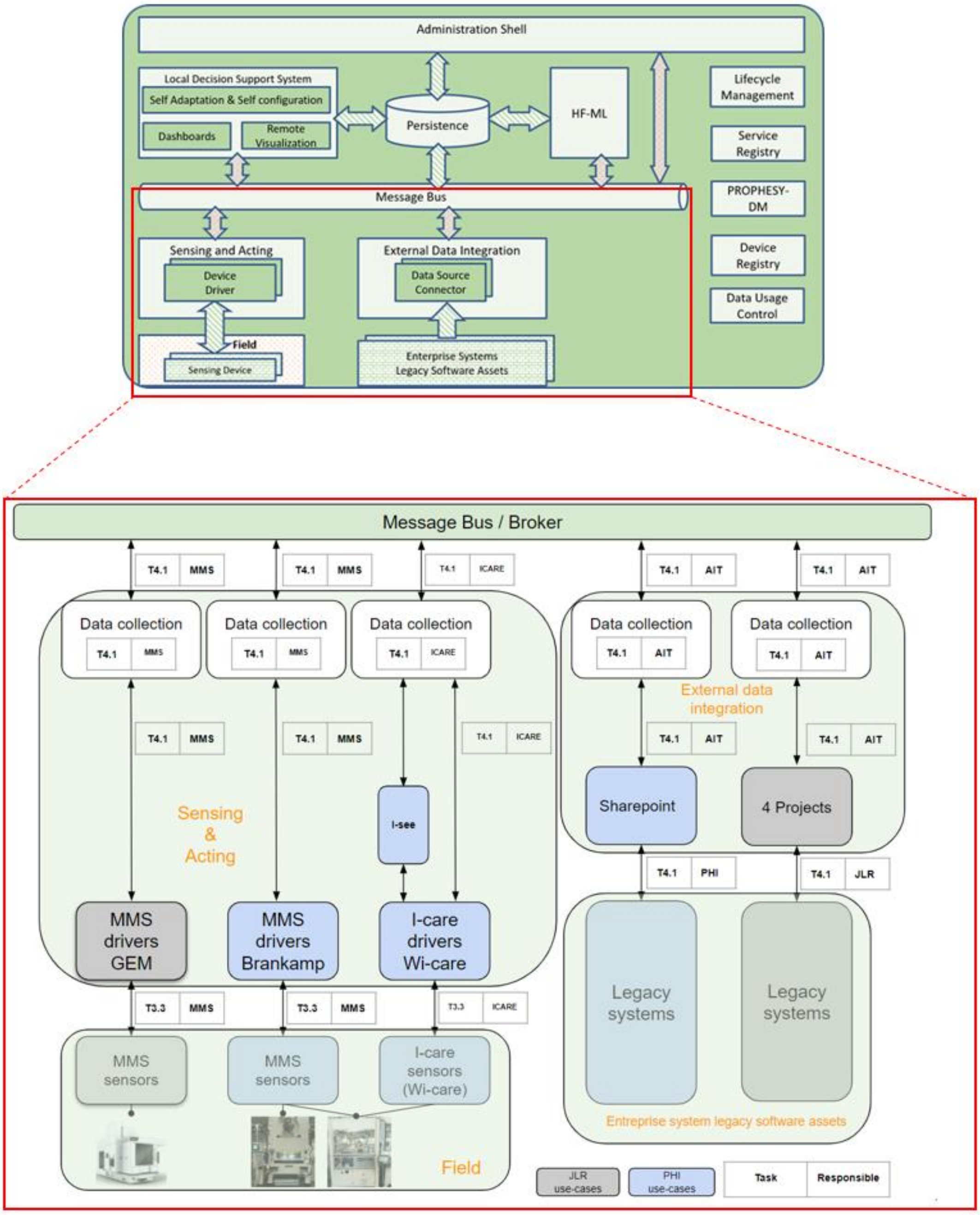

Figure 26: CPS overviews and schematic

Each component's functions are described below:

Components	**Function(s) within Prophesy**	**Related task**	**Responsible partners**
Field - Sensors	The sensors are used to collect physical measurements that will be	3.3	ICARE/MMS

	used to predict remaining useful life of machine wear parts.		
Sensing & Acting - Drivers	The drivers collect raw data from field sensors and convert them into a structured digital data format	3.3	ICARE/MMS
Sensing & Acting - Data collectors	The data collectors act as data producers for the message bus. They collect data automatically from the drivers at a given rate and convert the data according to the Prophesy data model (PROPHESY-DM)	4.1	ICARE/MMS
External data integration - Sharepoint & 4Projects	Collaborative platforms are used to collect and centralize data that comes from various legacy systems (ERP, CMMS, Process data, material data, product data...)	4.1	PHI/JLR
External data integration - Data collectors	Data collectors act as data producers for the message bus. They collect data automatically from the collaborative platforms at a certain rate and convert the data according to the Prophesy data model (PROPHESY-DM)	4.1	AIT
Message Bus	The message bus act as a message delivery tool that provide a mean to diffuse informations from the producers (data collectors) to the CPS consumers	3.2	AIT /FHG

For the Philips demonstrator, there is no direct connection between the Brankamp systems and the PROPHESY platform at the moment. From worker safety and data security perspective, this is not allowed. Following the proposed CPS structure, an external data integration by using a cloud based Sharepoint server is used. The Brankamp production data is first transmitted to the Philips Sharepoint from where a connection to the Prophesy platform could be established. This Sharepoint site is also used to feedback data to the Philips software environment. E.g. the RUL values calculated by PROPHESY-ML and PI's calculated by the PROPHESY-SOE will be fed to the Sharepoint site from which they can be used by Philips for maintenance planning optimization and PI dashboard.

The iCare sensor system allows a direct communication between the shopfloor and the PROPHESY platform, by using Wi-care. The Wi-care allows for remote diagnosis is a flexible solution enabling maintenance recommendations to be received on a periodic basis or "on demand". The Wi-care data flow is represented in Figure 27. The battery-powered sensors collect periodic data from the accelerometers. Acceleration data is wirelessly sent to a gateway that connects to a cloud server. Data is stored in a cloud server. A visualisation tool is provided to allow data visualisation: I-see web portal. For the purpose of the project, API and tools to connect to this API have been developed.

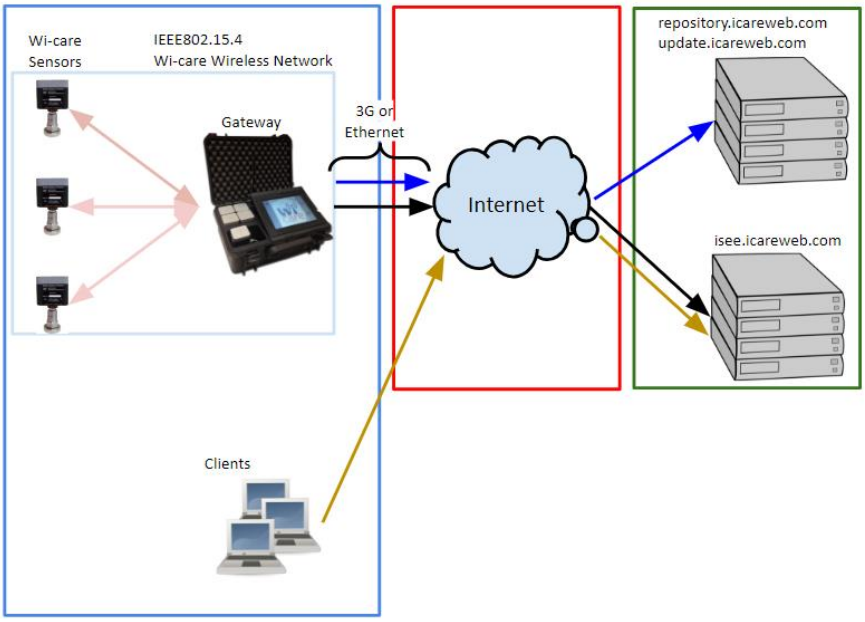

Figure 27 Wi-care dataflow

Machine learning will be used to analyze the data from all the separate sources (material data, process data, tooling data, product data and production planning data) and to calculate important parameters like RUL for maintenance scheduling and, in the end, OEE increase. The PROPHESY-ML algorithms will be run at the PROPHESY platform and PHILIPS manufacturing data will be provided to the PROPHESY platform via Sharepoint. Performance Indicators and PDM measures as calculated by PROPHESY-ML are fed back to the PHILIPS software environment via Sharepoint also.

PROPHESY-ML results will be used to provide machine operators, maintenance mechanics and production scheduling plus maintenance scheduling responsible persons with information to help them optimizing their work and operations PI's. This is the so-called local Decision Support System (DSS).

There will be no direct control loop from the PROPHESY-ML algorithms to the manufacturing processes at PHILIPS. This is not allowed from worker safety and machine safety perspective. Therefore, it is decided to work along the principle of 'human-in-the-loop' for all interactions with the actual running process.

It will be part of WP3 and WP7 to expand the current system, to allow and to improve the required CPS functionality (e.g. integration of ML-Algorithm, HMI).

2.6 Further integration plan

This document at hand contributes the ongoing PROPHESY implementation into the complex industrial demonstrator, and gives a detailed overview about the machining hardware, monitoring hard- and software as well as the interfaces used.

Sensor-integration in some tool-modules for UC1 and UC2 are on plan and should be finalised in the next months. It has to be mentioned that it is hard to reserve time for a time-consuming interruption of a running production.

A continuously adaption of the demonstrator is a normal process and will improve the overall performance. A first official demonstration for the Use-cases is planned in Q1 2019.

All in all, the demonstrator is quite ready for the validation of the PROPHESY concept.

3 Demonstrator at Jaguar Land Rover

3.1 Introduction

Jaguar Land Rover (JLR) is the leading premium automotive OEM in the UK. Built around two iconic British car brands, Jaguar Land Rover designs, engineers and manufactures in the UK and now the only high-volume manufacturer of luxury vehicles in the UK. Jaguar Land Rover's plans for growth and investment will include many products launches in the coming years, with many in new segments for the company. This positions Jaguar Land Rover at the centre of the UK automotive industry's drive to deliver technical innovation in all areas of vehicle development.

Over the last five years Jaguar Land Rover has invested heavily in new products, facilities, research and developments, making it the UK's largest investor in manufacturing research and development, and has invested £3.5billion in the fiscal year to March 2016. This scale of investment requires excellent partnerships with suppliers and research partners to enable the delivery of Jaguar Land Rover's technology innovation. With a world class team of over 9,000 engineers and designers, based at two state-of-the-art engineering and design facilities in the West Midlands, Jaguar Land Rover has extensive engineering resources, including engineering design development, CAE and testing facilities.

JLR manufactures automotive Powertrains within their Engine Manufacturing Centre in Wolverhampton, UK. JLR will use the machining of cubic metallic cylinder heads (similar applicable operations exist for cylinder blocks) within a multi-axis machining centre as a complex demonstrator. JLR currently use approximately 100 high-performance 5-axis CNC machines for both cylinder block and cylinder head machining. In excess of 20 types of machining activities and 20 different cutting tools are used within a single machine including probing, milling, boring, drilling, reaming, tapping and brushing.

There are in excess of 100 CNC machines currently in use within JLR's Engine Manufacturing Centre. As a part of the PROPHESY project, development will take place within one operation on one product production line (less than 12 machines). However, any products developed within PROPHESY will be immediately deployable and exploitable across these 100+ machines.

There are a significant number of machine and assembly operations across 3 component production lines (cylinder head, cylinder block and crankshaft) and multiple engine assembly lines that will heavily benefit from the impact of predictive maintenance solutions. Therefore, the second phase of exploitation will be to apply the PROPHESY product to all machines within the Engine Manufacturing Centre.

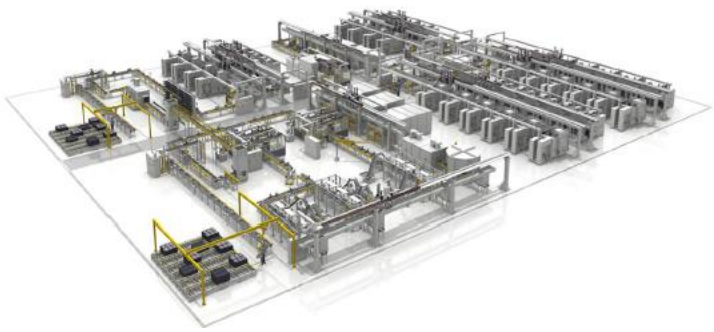

Figure 28: Overview JLR demonstrator

In Deliverable 2.4 a detailed description of the state-of-the-art of the demonstrator as well as a description of all existing components at JLR demonstrator is provided.

3.2 Stakeholder of JLR use-cases

In PROPHESY, a lot of adaption and reconfiguration of the JLR demonstrator is planned, to integrate and validate the PROPHESY objectives. To make sure that this process will not affect the overall production negatively, all stakeholders of the demonstrator must be identified and engaged. That is why the first step towards a complex demonstrator description is the identification of all stakeholders at the demonstrator.

Table 3 shows a list of all stakeholders in JLR's demonstrator.

Table 3: Identification of JLR stakeholder

Role	Interest Area
Head OP 90 Associate	Shopfloor alerts, AR
Asset Management / Reliability and Maintainability	Shopfloor alerts, machine parts RULs, AR
Tooling Engineers	Forward planning, cutting tools RULs (process/part specific)
Process Engineers	Process capability (process/part specific)
Controls Engineers	Shopfloor connectivity (machine network)
AMT Manager	Project benefit realisation, scope for further projects
Technology Managers	Forward planning, benefit realisation (process/part specific)
Machining Manager	Forward planning, overall benefits (machining)
Enterprise / Solutions Architects	IT processes, shopfloor connectivity
IT Product Managers	Shopfloor connectivity, business intelligence, machine learning
Digital Manufacturing Manager	Forward planning, overall benefits
Maintenance Managers	Forward planning, machines' overall benefits
Tooling & Gauging Manager	Forward planning, tooling / measurements' overall benefits
Collaborative R&D Managers	Lessons learnt, scope for further projects
Plant Director	Planning, plant overall benefits
PTME / PTO Directors	Confirm investment, planning, overall business benefits
Manufacturing Executive Director	Approve investment, planning, overall business benefits

The list of JLR stakeholder is not static and will be updated continuously. Before any intervention or update/adaption of the demonstrator, all involved persons will be informed. For this public version, the names of each responsible person were removed.

3.3 JLR Use-cases

The considered JLR production line contains 5 steps (OP30, OP40, OP50, OP70, OP80, OP90, OP100).

The ‘cubed’ (pre-machined parts at castings vendor to locate datum points) cylinder head castings enter the EMC machining process at OP30 for valve seat and guide rough machining, which are subsequently cleaned at OP40 and assembled with seats and guides at OP50. Various CNC machining processes including hole generation and milling begin at OP70 on the CNC machines through to OP90, followed by cleaning at OP100.

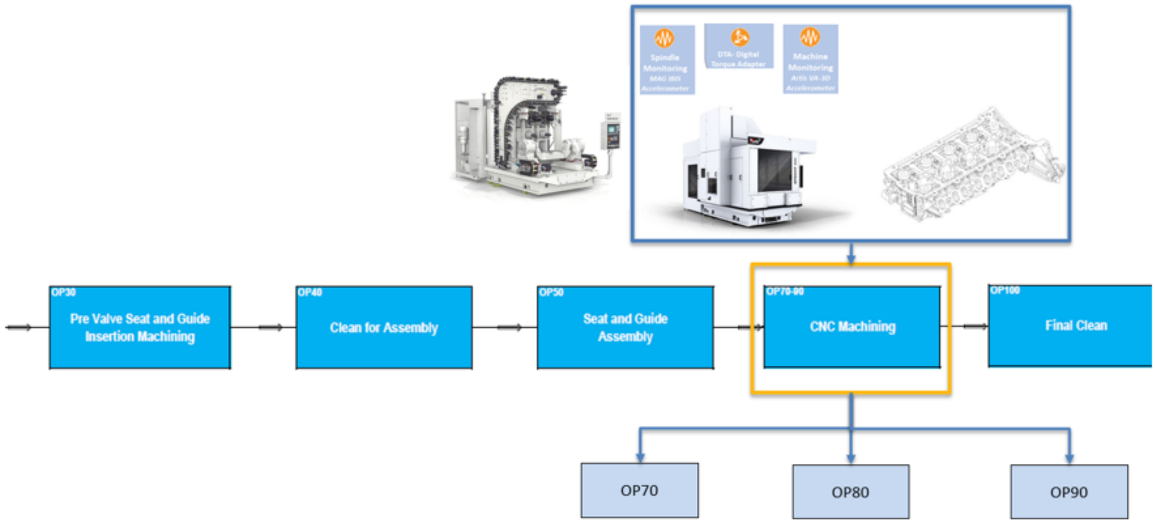

Figure 29: JLR use-cases production line

Both JLR use-cases relate to OP90.

The use-case 4 focuses on the ball screw RUL prediction while use-case 5 focuses on the tools RUL prediction.

Figure 30: Ball screw wear

Figure 31: Tools for Use-cases 4 and 5

The various systems linked to the OP90 are shown in the figure below.

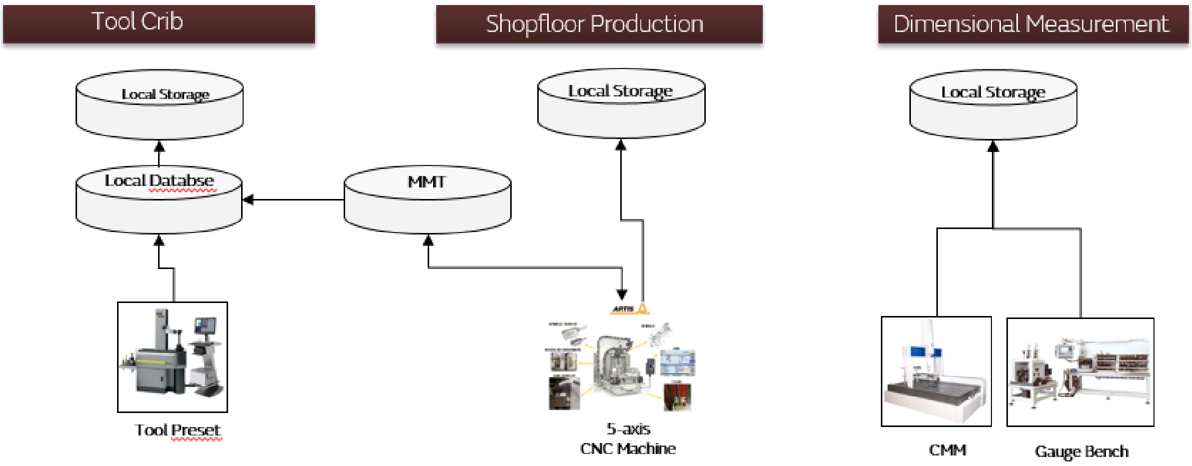

Figure 32: JLR use-cases 4 and 5 - machine and systems

In the first evaluation step for Use-case 4 and 5, the Genior Modular system is configured to monitor the following signals under real-time conditions with a sampling time of 10ms.

- Torque S1
- Torque Z1
- ACC of Ibis Vibration Sensor
- GEO of PCB Sensor

Furthermore, after a pre-defined number of processes, a fingerprint cycle is executed, in which the following data are monitored.

Signal/Sensor		OP90
DTA 1		Torque CS1
DTA 2		Torque X1
DTA 3		Torque X2
DTA 4		Torque Y1
DTA 5		Torque Z1
DTA 6		Torque Z2
DTA 7		Torque A1
DTA 8		Torque B1
Aux8		Sp- Speed S1
VM-Module A VA3D		ACC X
		VEL X
		ACC Y
		VEL Y
		ACC Z
		VEL Z
VM-Module B IBIS		ACC 1
		VEL 1
VM-Module C PCB		ACC 1
		ACC 2
		ACC 3
		GEO
		Vel 1
		Vel 2
		Vel 3

Beside on real-time data, the Genior Modular also provides pre-processed indicator data, which involves information about Min, Max, Average etc. values for each sub-process.

A result of the first evaluation step should be, if an improved data monitoring (more signals, higher sample rate, etc.) is mandatory for the predictive maintenance algorithm.

3.4 Preparation of the pilot production lines

In this section, the preparation of the JLR pilot product line is described. The preparation and integrations follow the PROPHESY Integration Plan provided in section 3.4 of Deliverable 2.4.

3.4.1 Machining part

Cylinder head machining is distributed into the following machining operations: OP30, OP70, OP80 and OP90.

The ‘cubed’ (pre-machined parts at castings vendor to locate datum points) cylinder head castings enter the EMC machining process at OP30 for valve seat and guide machining, various CNC machining processes then follows from OP70 through to OP90 as detailed in the table below:

Op	Description	Equipment	Process
30	CNC Cell 1 Inter-Bore Drillings, Parent Cylinder Bores, etc.	5-axis CNC	**Features Machined:** ➢ Machine parent metal valve guides and seats in preparation for valve guide and seat insertion. ➢ Machine other features as required to balance process and optimise CNC utilization.
70	CNC Cell 2	5-axis CNC	**Features Machined:** ➢ Machine various holes and features. ➢ Machine other features as required to balance process and optimise CNC utilization.
80	CNC Cell 3	5-axis CNC	**Features Machined:** ➢ Machine various holes and features. ➢ Machine other features as required to balance process and optimise CNC utilization.
90	CNC Cell 4	5-axis CNC	**Features Machined:** ➢ Machine fire face, finish valve guide and seat machining, finish swirl chamfer (diesel only), injector bore, spark plug (dependent on tolerances) ➢ Machine other features as required to balance process and optimise CNC utilization.

OP90 is quite complex so that this process is perfectly suited for the PROPHESY demonstration. Once the PROPHESY concept is validated at the OP90 it will be expanded to the other OPs in CNC machining.

3.4.2 Monitoring part

The process monitoring is a key feature of PROPHESY concept, due the real-time and non-real-time process signals are the base of the Machine-Learning and Predictive Maintenance approaches. Next, the CNC Machine Monitoring, the MMS Genior Modular real-time monitoring, the machine-integrated sensors as well as an overview about the overall signal configuration is presented.

CNC Machine Monitoring

The JLR CNC machines are able to provide machine component monitoring either in standard mode or optional mode. It is also possible to upgrade the machines with additional sensors in order to have a broader view of the machine status. The JLR CNC machines offer some condition monitoring systems in standard modes. Table 3 shows the components which can be monitored in standard modes considering their priorities.

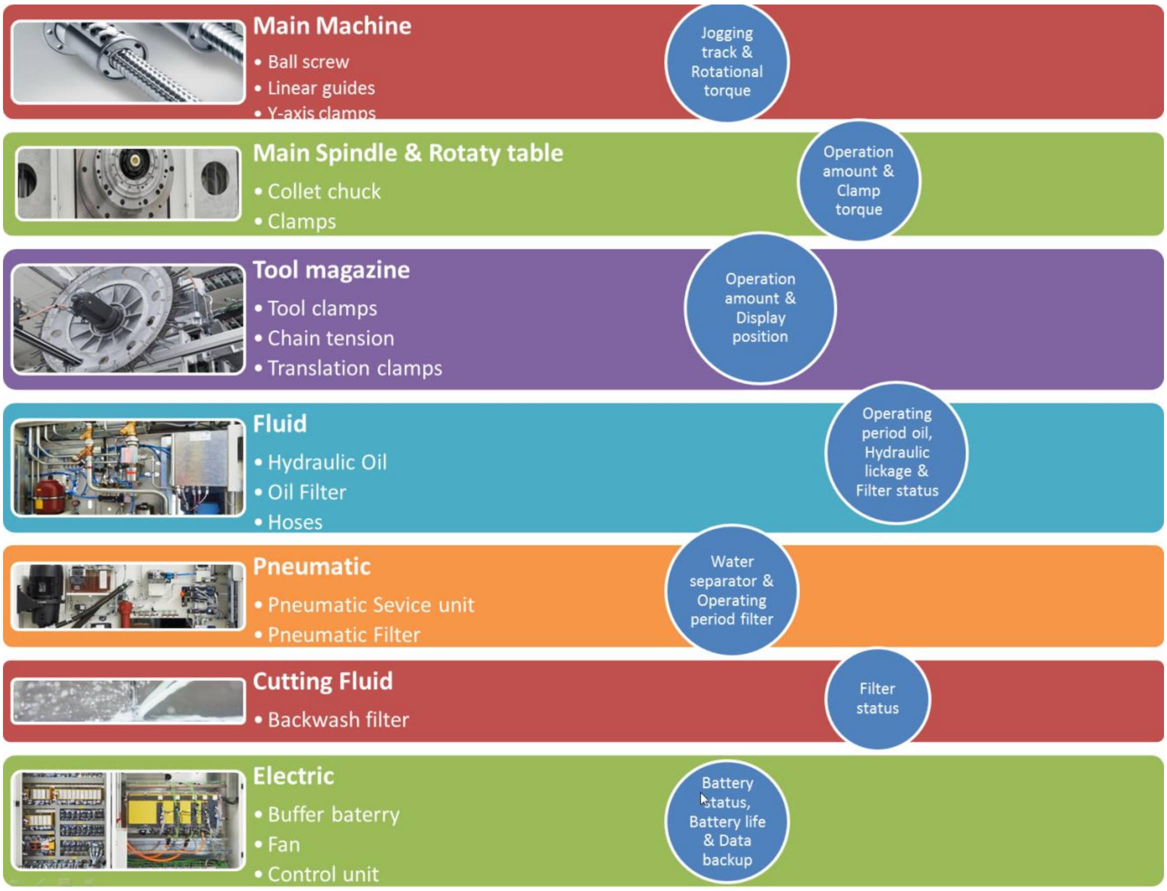

Table 4: The JLR CNC machine standard monitoring systems

As mentioned above, machine tools can be upgraded with sensors like vibration, ultrasonic, temperature, infrared and etc. in order to depict its condition with more precision and help build a better prediction. For instance, having vibration sensor installed, one can monitor the status of bearings in the ball screw drive or can tell if there were a bent on the threaded shaft. A structure-borne noise microphone can record the machine sound which can outline the health of the system or help to detect a fault during machine operation.

Genior Modular

Process monitoring is the key task to demonstrate the enabling capabilities from PROPHESY.

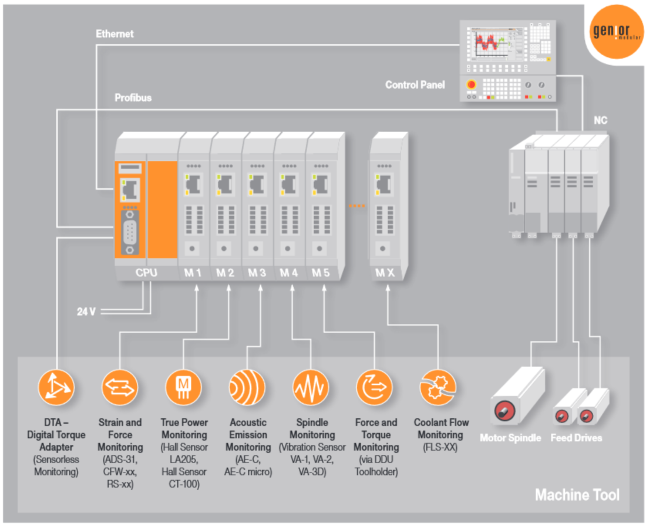

Figure 33: Artis Genior Modular CPU-02 process monitoring system

Figure 33 shows a Artis Genior Modular CPU-02 system as well as the modular system structure of the Genior systems. Genior Modular can simultaneously monitor and visualize up to 24 signals and 10 channels. The Multiview display is ideal for the simultaneous monitoring of multiple spindles, axles and other equipment values. It shows the entire machining situation at a glance. Genior Modular is easy to install and to integrate in machine controls. Depending on the area of application, visualization and operation can be done alternatively via the control or an external system (Windows or Linux). The central evaluation unit can be upgraded with various measuring transducers to operate the system with sensors and can be modularly expanded at any time. Thus, Genior Modular is prepared for a huge range of requirements.

Process monitoring using ARTIS hardware use special learning algorithm. Learning based process monitoring is a key feature of ARTIS process monitoring systems. The process monitoring is based on process signals of the machine control. Furthermore, the process monitoring could be based on additional sensor signals (e.g. vibration, force, etc). Genior Modular is the main module of ARTIS hardware. In this module the interface to the machine control as well to the HMI is provided. The process monitoring algorithm and the determination of the limits and parameters are calculated on the Genior Modular device, as well. For the user, the QNX based Genior Modular provide an intuitive HMI to configure the process monitoring task. The system determines all limits and parameters automatically. Additional input-keys provide the possibility of making certain adjustments. In detail view display mode, these input keys are immediately visible. In multi view display mode, it is necessary to first select one of the windows in order make the keys visible. The user has the possibility to manually adjust the limit, being less or more sensitive to process changes.

For the learning process, some reference processes must be executed in advance. The system calculates automatically how many learn steps must be performed. Apart from that, a manual adjustment of the learning process repetitions is possible.

Once the learning is complete, the process monitoring can be started.

Figure 34 shows a schematic description of ARTIS (MMS) monitoring hardware integration at JLR demonstrator. VA-3D, PCB, and IBIS are vibrations and acceleration sensors, which are located at different positions inside the machine.

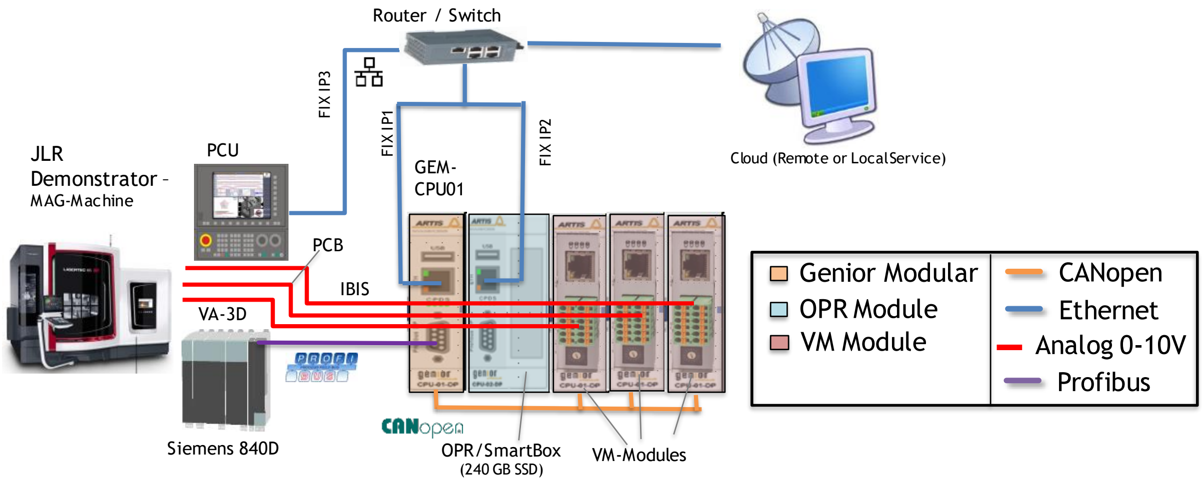

Figure 34: Schematic description of ARTIS (MMS) monitoring hardware integration

The Genior Modular monitors real-time data from the machine control and receive and process the real-time data from the additional devices. In the Genior Modular device alarm signals, process limits, machine instructions etc. could be configured.

- OPR: Offline Process Recorder, which is a prototype unit working as a local intelligent storage isle, providing the connection to the cloud platform and allowing local process analysis based on the statistical R program.
- VM-Module: Vibration Module, which provides acceleration and velocity signals of connected acceleration sensors in real-time.
- GEM-VISU: Visualization software, which could be installed at the machine control, PC or mobile devices. The GEM-VISU allows an intuitive overview about the ongoing and past processes and will serve as framework for the Twin-Control shopfloor HMI. Furthermore, through the Multiview function it is possible, to analyze more machines at the same time in one display.

Beside this standard configuration, further devices and applications could be installed to support the individual research tasks. So it is planned to replace the OPR by the new ARTIS Smart-Box Edge-Gateway. This Edge-Gateway based in Windows 10 IoT OS and is compatible to different Iot standards as KAFKA, OSGi, etc.

Two VM-01 measurement transducers are currently installed on the JLR CNC machining centres. This splits into a 3-dimensional accelerometer affixed permanently near the machine bed, as shown in Figure 35 below, and another accelerometer connects to the spindle, extracting measurements from pre-installed CNC machine sensor.

Figure 35: Position of the Artis GEM 3D accelerometer positioned on the casting next to the X-axis rai

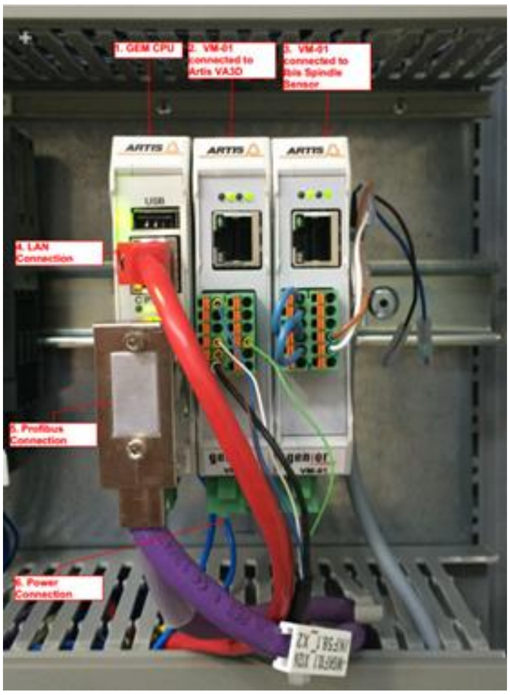

Figure 36: Artis GEM system with the CPU monitoring module, VM-01 module, profibus connection, LAN connection and power connection shown

The DTA (Digital Torque Analyser) signals can be generated from the spindle and axis data, which can subsequently be retrieved and monitored from the PLC (Programmable Logic Controller). Along with the Profibus communication, the DTA signals can be received, used and monitored from the inverter drives. Figure 37 above shows the Artis GEM system.

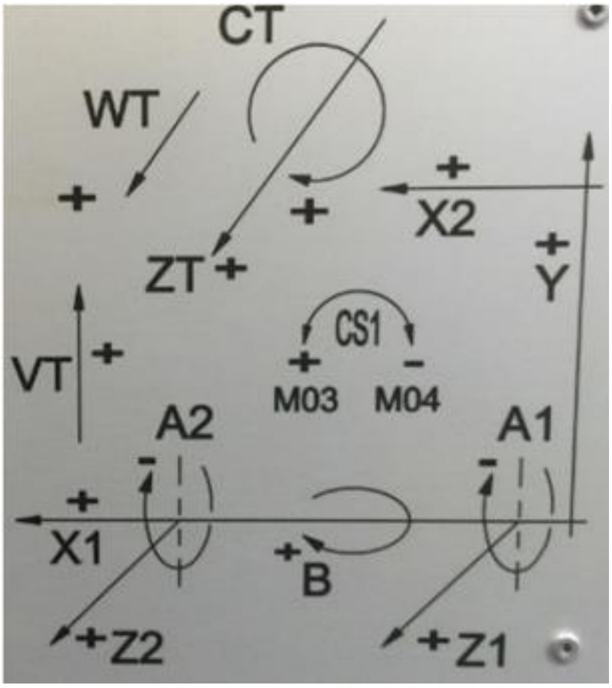

Figure 37: The CNC machine axes

Two sequences / cycles can be launched to monitor the signals measured by Artis GEM.

In the Preventive Maintenance (PM) cycle, the spindle and Z1 axis torque are monitored. In the Condition Based Monitoring (CBM) cycle, X1, X2, Y, Z2, A and B are monitored. Acceleration (Acc) and velocities (vel) are collected from each vibration sensor, with the PM cycle concentrating only on acceleration, whereas the CBM cycle monitors all the axes: VA-3D Acc and Vel, along with Acc and Vel from IBIS.

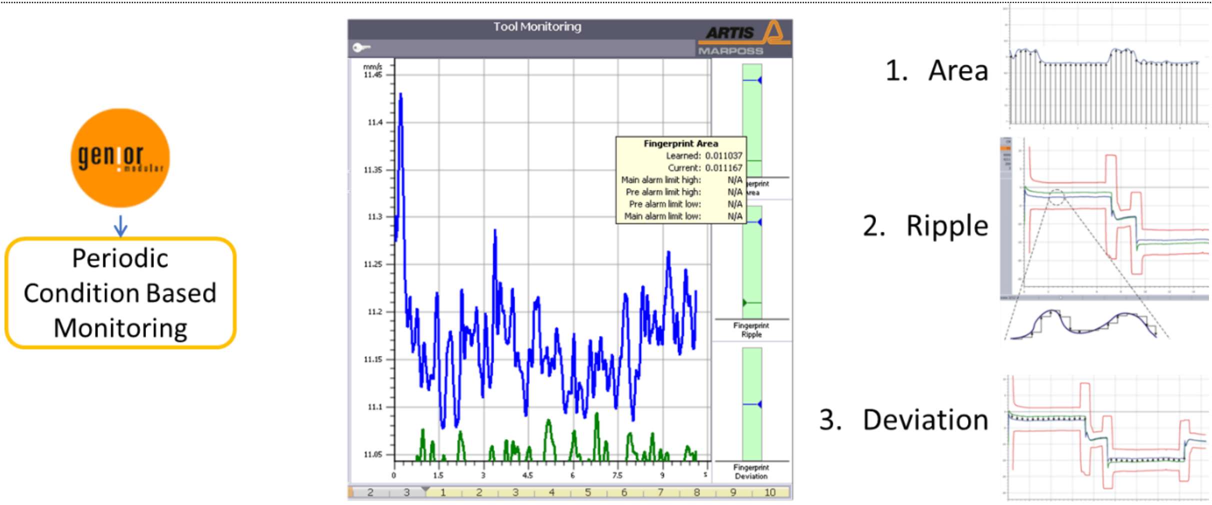

Figure 38: Screenshots of GEM – current, periodic Conditions Based Monitoring

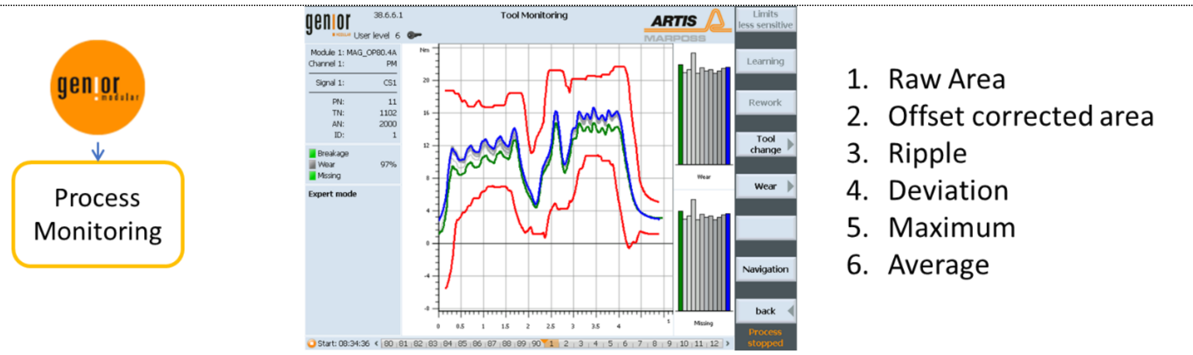

Figure 39: Screenshots of GEM – current, Process Monitoring

Figure 39 shows a visualization software GEM-Visu. Next, the most important indicators of this visualization are listed.

Line graphics:

- Green curve: learned signal curve
- Grey curve: signal curves of the last 10 processed are displayed
- Blue curve: current signal curve
- Red curve (1): lower Breakage limit
- Red curve (2): upper Breakage limit

Bar graphics:

- Green bar: area value of the learned process
- Grey bar: area value of the previous 10 processes
- Blue bar: area value of the current process

The alarm reaction could be configured by the user. So, the system could send just a warning or fully stop the machine.

Figure 38 shows, that the Genior Modular calculates some pre-processed information (e.g. Area, Ripple, Deviation) which allows the user an intuitive analysis of the fingerprint (periodic condition based monitoring) and process monitoring modes.

Similar to the X7 system, Genior Modular provide also some different options to transmit the process data to the PROPHESY platform. For the JLR demonstrator, an Smart-Box device will be used to gather and store all data from the Genior Modular and provide the data in a secure way to PROPHESY (see Deliverable 7.1). The LFML as well as further data processing could be performed at this Smart-Box device.

3.4.3 Software environment

The JLR demonstrator involve some different software components, which will be described in this section. Beside the Google Cloud Shopfloor Software, the GEM-Visu, C-Thur 4.0 database and the CNC machines' CM-Box are presented.

For Use-case 4 and 5 Figure 40 shows a schematic of the data exchange configuration.

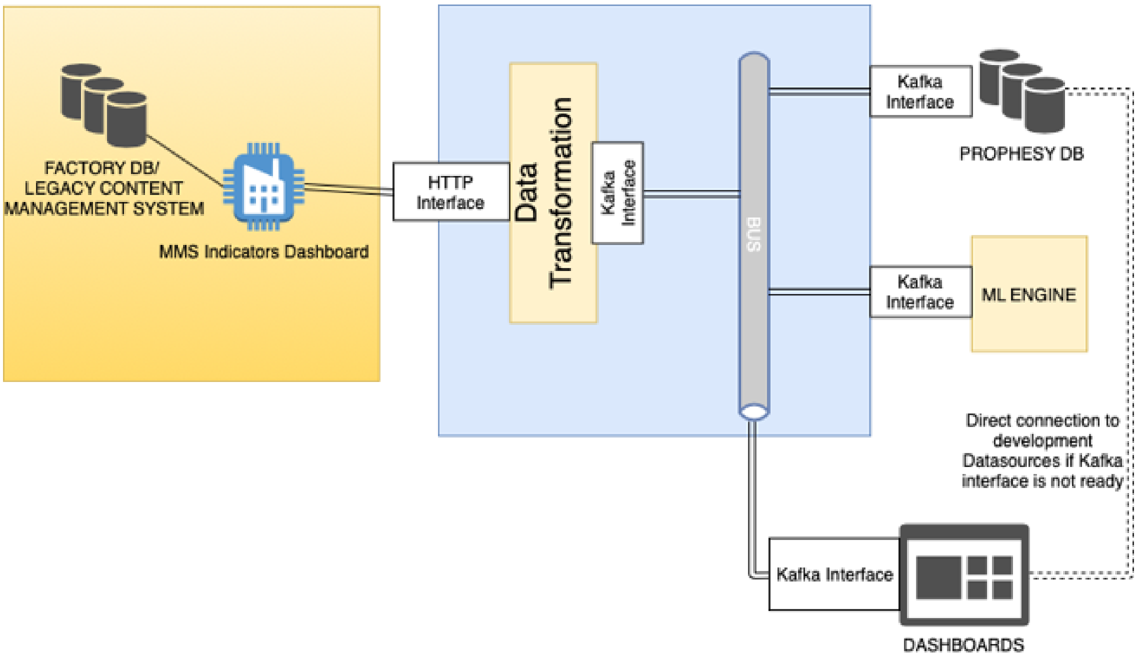

Figure 40: Data exchange for JLR use-case

Shopfloor Software

At JLR demonstrator, a Google cloud solution is used. Next, the Google cloud solution is described in more detail:

Google has had an aPaaS offering since 2008 but did not enter the cloud IaaS market until Google Compute Engine was launched in June 2012 (with general availability in December 2013).

Offerings: Google Cloud Platform (GCP) is integrated IaaS+PaaS. It combines an IaaS offering (Compute Engine), an aPaaS offering (App Engine) and a range of complementary IaaS and PaaS capabilities, including object storage, a Docker container service (Google Kubernetes Engine) and event-driven "serverless computing" (Google Cloud Functions, in beta). Compute Engine VMs are KVM-virtualised and metered by the second. Enterprise-grade support is extra. It has a multi-fault-domain SLA.

Co-location needs are met via partner exchanges (Google Cloud Interconnect).

Provider maturity: Tier 1. GCP benefits, to some extent, from Google's massive investments in infrastructure for Google as a whole.

Recommended mode: GCP primarily appeals to Mode 2 buyers (agile IT, emphasizing developer productivity and business agility)

Recommended uses: Big data and other analytics applications, machine learning projects, cloud-native applications, or other applications optimized for cloud-native operations.

Strengths

Google's strategy for GCP centers on commercialising the internal innovative technology capabilities that Google has developed to run its consumer business at scale and making them available as services that other companies can purchase. Google's roadmap of capabilities increasingly targets customers with traditional workloads and IT processes, as well as with cloud-native applications. Google has positioned itself as an "open" provider, with a portability emphasis that is centered on open-source ecosystems. Like its competitors, though, Google delivers value through operations automation at scale, and it does not open-source these proprietary advantages.

GCP has a well-implemented, reliable and performant core of fundamental IaaS and PaaS capabilities — including an increasing number of unique and innovative capabilities — even though its scope of services is not as broad as that of the other market leaders. Google has been most differentiated on the forward edge of IT, with deep investments in analytics and ML, and many customers who choose Google for strategic adoption have applications that are anchored by BigQuery.

Cautions

While Google has made significant progress in its efforts to build an ecosystem around its IaaS capabilities, it still only has a small number of experienced MSP (Managed Service Provider) and infrastructure-centric professional services partners. GCP's own professional services are treated as profit centers rather than loss-leaders to drive customer implementations. Some prospective customers find that these ecosystem limitations significantly heighten the challenges of adopting GCP and believe that this adds additional cost and risk.

Customers sometimes cite ISV (Independent Software Vendor) licensing and support challenges when adopting GCP, despite Google's 2016 acquisition of the Orbitera software marketplace. In particular, note that Oracle will not normally license or support its software on Google Compute Engine; customers should discuss this directly with Oracle. GCP is increasingly supported by an ecosystem of both commercial and open-source management tools, but the depth of this support varies.

Google BigQuery is a Massively Parallel Processing (MPP) columnar datastore suitable for analysing very high volumes of data at high speed. The platform significantly outperforms any existing RDBMS with equivalent high data volumes. The platform is evolving very quickly but at the time of writing (Oct 2017) the following strengths and weaknesses are observed that are relevant to data management:

Strengths:

- Outstanding performance for large data sets
- No table maintenance. Table are simple data sets without the need for maintaining keys and constraints
- Replicating data across BigQuery tables is very simple
- BigQuery can handle objects as data values
- BigQuery can effectively federate over existing BigQuery tables, files and Google Sheets
- BigQuery is fully compatible with standard 2011 SQL and accessibility via existing tools is improving all the time
- Storage and consumption costs are low

Cautions:

- Immutable data source. Fundamentally data can only be appended to existing data sets. In its current form it is suitable for DBA and support processes rather than ETL processes
- Relatively poor table join performance. Google generally advise that data sets are denormalised into a single table to avoid joins. The join capability is available, and the performance is improving all the time
- There is no concept of primary or secondary keys in BigQuery. Any data uniqueness needs to be managed completely by the process that loads the data
- There is no foreign key or check constraint capabilities. Any such constraint requirements need to be managed by the process that loads the data
- Relatively poor performance for very small data sets

Genior Modular HMI

The Genior Modular HMI Visu provide the visualization of fleet and cloud-data at machine level. PROPHESY shopfloor HMI is the basic human-machine interface for monitoring and control being fully integrated in all use case machine tool control screens. In fact, it is the MMS / ARTIS Genior Modular VISU (GEM-VISU), which allows a comfortable way to display all relevant process information.

For PROPHESY the GEM-VISU is expanded with the addition of several Plug-Ins. This way, the PROPHESY shopfloor HMI at the machine tool integrates different module results (see Figure 3):

- **Genior Modular**: Data acquisition, local monitoring and control
- **Cloud Connect Remote:** Fleet based knowledge
- **NC Simulation:** Integration of simulation tool
- **OPR:** Machine learning results as web pages, like basic RUL estimation
- **GEM-VISU:** Visualization software, which could be installed at the machine control, PC or mobile devices. The GEM-VISU allows an intuitive overview about the ongoing and past processes and will serve as framework for the PROPHESYl shopfloor HMI. Furthermore, through the Multiview function it is possible, to analyze more machines at the same time in one display.

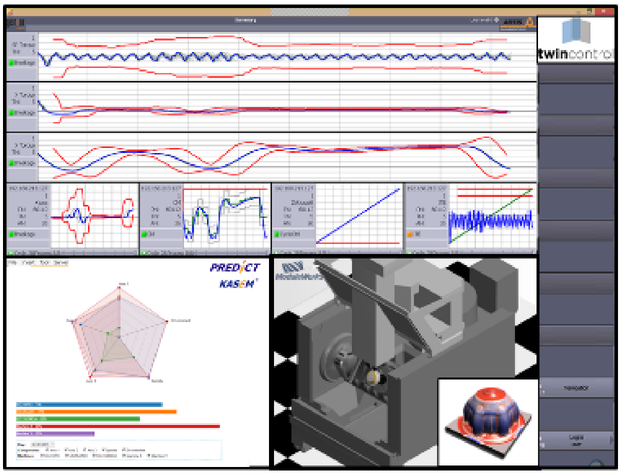

Figure 41: Design of the PROPHESY shopfloor HMI for the Monitoring and Control Operation mode

To provide the relevant information regardless of the location, a multiview-function is integrated. This function allows displaying the monitoring data of each connected machine-tool at one display. In terms of industry 4.0, smart devices come more and more in focus. Due to this fact, also a prototype GEM-VISU for Android OS will be developed (see Figure 42).

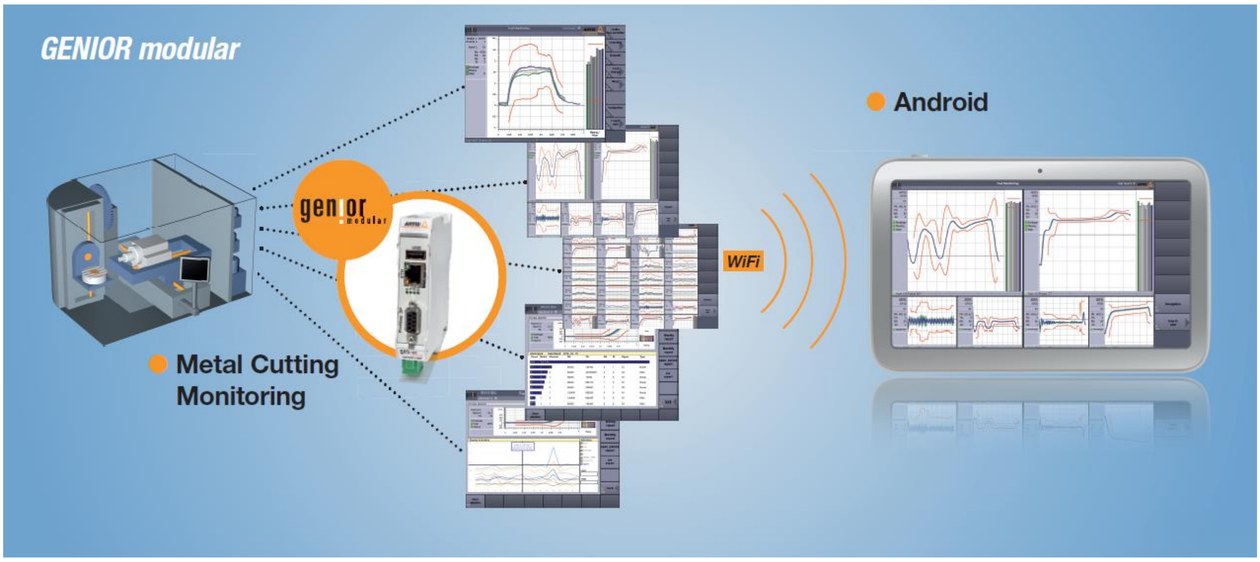

Figure 42: Smart devices for intuitive visualization of PROPHESY approach

With the successful monitoring of all use case machines the perfect initial situation is provided for starting the integration of the novel and innovative predictive maintenance strategies of PROPHESY.

C-Thru Database

For collecting data from different machines, MMS provide a C-Thru 4.0 approach. This approach includes software for collecting the data of different machines, pre-process these data and upload all data in a database. Furthermore, C-Thru 4.0 comes with different analysis and dashboard functions, which allows an intuitive way for analysing the data. The dashboard functions are also the base for the DDS (Decision Support System) which will be developed in WP3. Figure 43 presents a schematic of the C-Thru 4.0 approach.

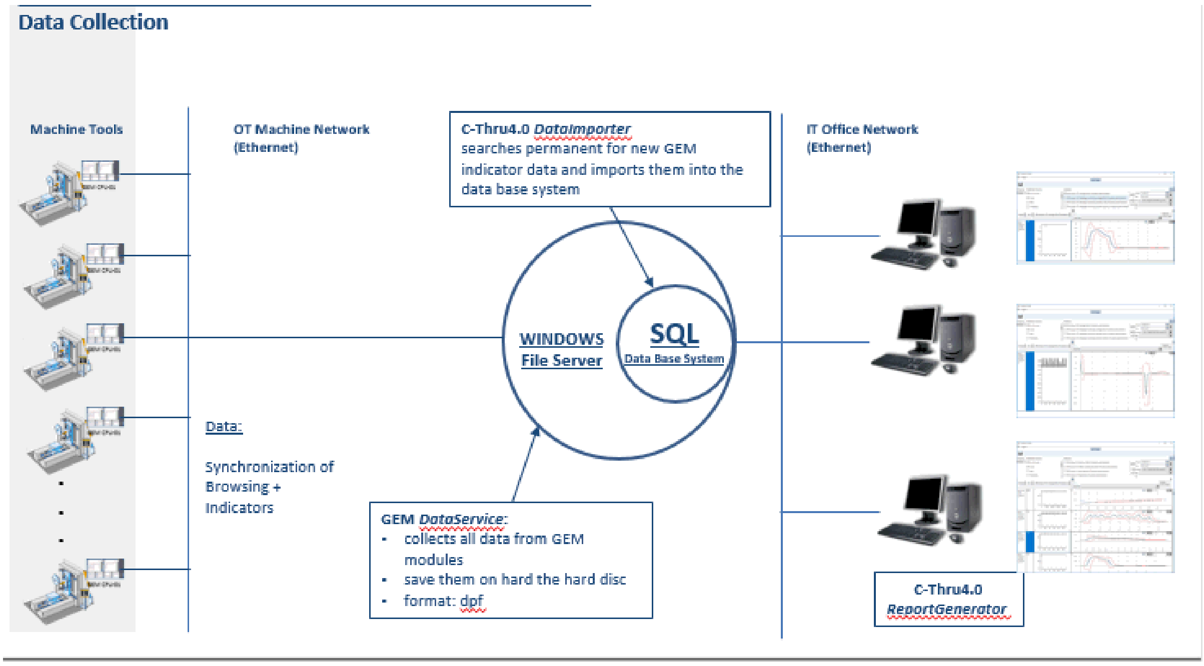

Figure 43: Schematic of C-Thru 4.0 data collection

3.5 Integration of Prophesy-CPS

Section 2.5 described the overall PROPHESY-CPS structure. For the Philips demonstrator this structure will be followed by developing and integrating the MMS-Smart Box as an Edge-Gateway.

At the moment, there I no direct connection between the Genior Modular and the Prophesy platform. The data are exchanged by using an external database. Figure 44 shows a schematic of the current implementation.

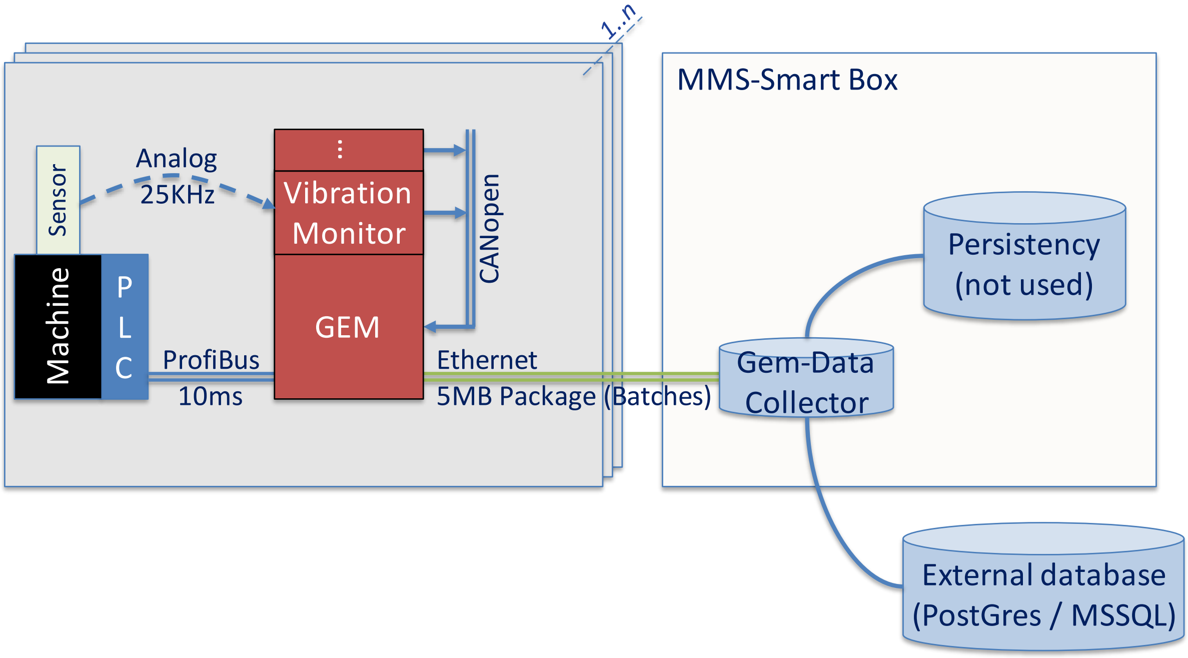

Figure 44: Current implementation of the data exchange

All process data are collected by the GEM-Data-Collector and automatically imported to a PostGres or MS-SQL database. This process could be done at the MMS-Smart Box or at any connected PC.

The development of the proposed Edge-Gateway is part of WP3. Figure 45 shows a schematic of the Edge-Gateway architecture.

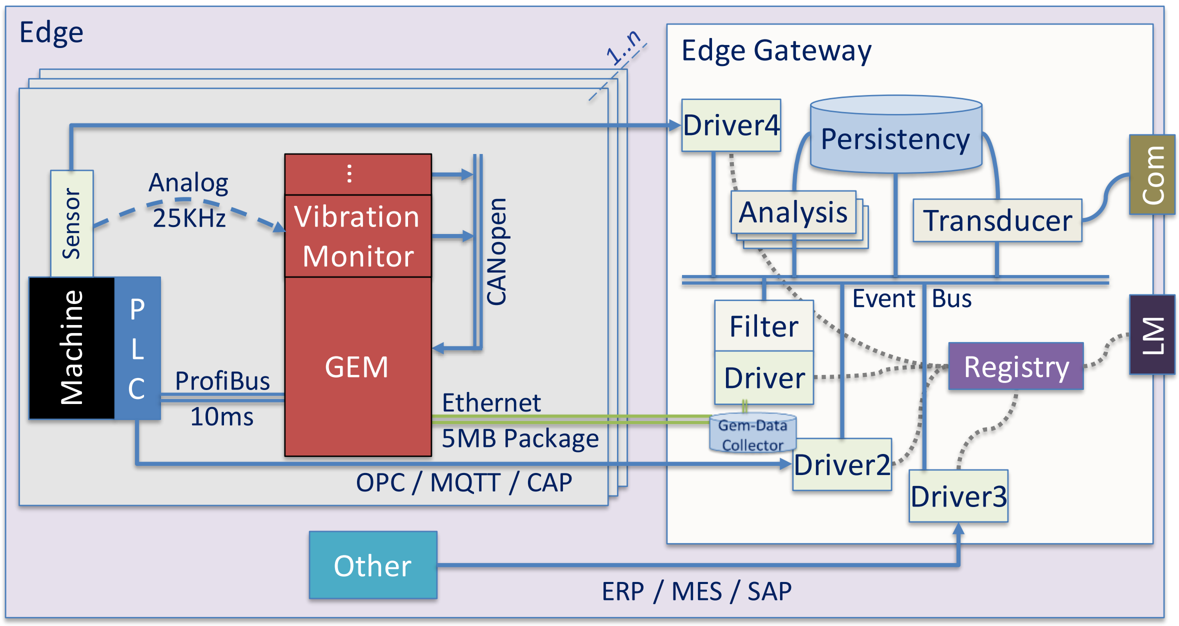

Figure 45: Schematic of Edge-Gateway

To this end the following technology stack is planned to be implemented with the demonstrator (Figure 46):

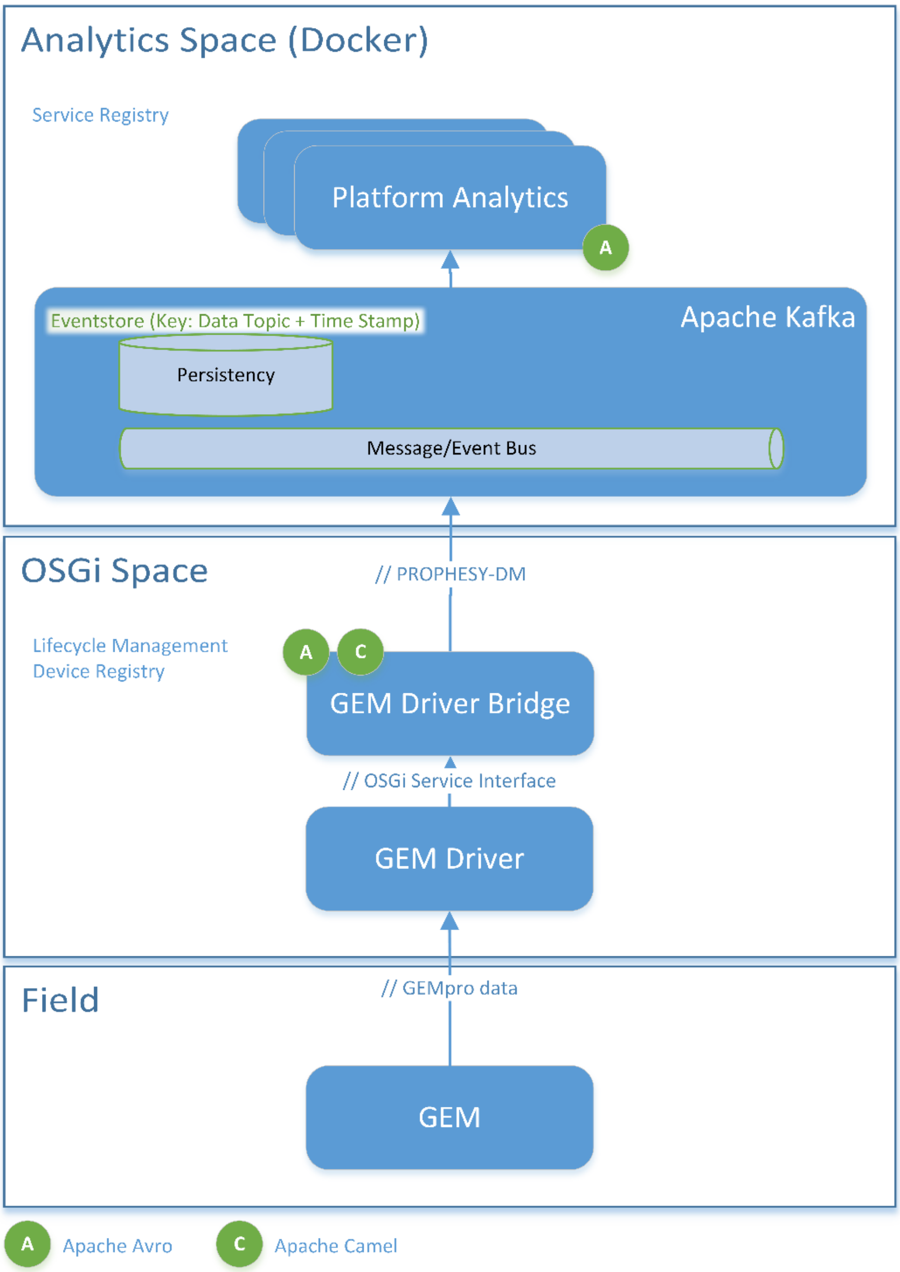

Figure 46: Technology stack for the proposed Edge-Gateway

Data from the field is transferred via the Genior Modular from MMS to the low-level part of an aligned driver in an OSGi environment, transferring the data to the OSGi service interface. The high-level part of the driver transduces the data to PROPHESY-DM and passes it to Apache Kafka using its message bus and event store capabilities. ML algorithms (i.e. platform analytics) will connect to Apache Kafka as well for data access. Apache Kafka as well as ML-algorithms are deployed in a Docker environment. In the technology stack Apache Avro is used for data serialization, and Apache Camel is deployed for routing and data mediation tasks.

It will be part of WP3 and WP7 to expand the current system, to allow and to improve the required CPS functionality (e.g. integration of ML-Algorithm, HMI).

3.6 Further integration plan

This document at hand contributes the ongoing PROPHESY implementation into the complex industrial demonstrator, and gives a detailed overview about the machining hardware, monitoring hard- and software as well as the interfaces used at JLR demonstrator.

Sensor-integration in some tool-modules for UC4 and UC5 are on plan and should be finalised in the next months. It has to be mentioned that it is hard to reserve time for a time-consuming interruption of a running production.

A continuously adaption of the demonstrator is a normal process and will improve the overall performance. A first official demonstration for the Use-cases is planned in Q1 2019.

All in all, the demonstrator is quite ready for the validation of the PROPHESY concept.

4 Conclusions

Work package 7 is devoted to the integration, validation and evaluation of the two complex demonstrators of the project, which will take place in pilot production lines of PHILIPS and JLR.

This document renders the objectives to be achieved in the complex demonstrators at Jaguar Land Rover and PHILIPS. Therefore, the current situation of each demonstrator is described, following by a list of all involved stakeholders. Due to the provided photos of the demonstrator machines and sensor devices, the reader should have a clear understanding of the demonstrator. The main part of this deliverable is the description of the hard- and software, which is needed for the final demonstrators. Also, the process monitoring hardware for each demonstrator is introduced.

The document also details the software environment of each demonstrator, which will be the interface to the PROPHESY main objectives – PROPHESY-ML, PROPHESY-SOE, PROPHESY-CPS and PROPHESY-AR. Further explanations to each objective are presented in the Deliverables of WP 2 and WP 3.

Also, a more detailed description of the implementation of the PROPHESY-CPS in the both demonstrators are provided.