PROPHESY

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

DELIVERABLE

D2.6 – Platform Architectures and Ecosystem Specifications v2

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D2.6 – Platform Architectures and Ecosystem Specifications v2

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Executive Summary

The purpose of the deliverable D2.6 – Platform Architectures and Ecosystem Specifications is to provide the technical architecture and detailed specifications for the PROPHESY-PdM platform as well as the PROPHESY ecosystem that will be built around the project's results. Therefore, it defines and describes all the main/core functional components of the PROPHESY-PdM platform, their internal structure and organization as well as the relations between them, together with all the mechanisms and elements necessary to build up and maintain an ecosystem around the platform. The document presents – at the beginning – the scope of the project together with the structure of architectural framework that has been created for specifying the PROPHESY-PdM platform. A State-of-the-Art analysis has also been included within the document to create the necessary foundations for the specifications. The functional specifications of the PROPHESY-PdM platform are then presented by using a conventional well-defined and known view-based approach based on the Kruchten 4+1 model. As for the PROPHESY ecosystem, a different approach is used that is more focused on businesses, actors and stakeholders and their interrelationships in a common software product and/or service. Therefore, in PROPHESY ecosystem the light is on strategies, analysis of the impacts on business as well as technical design choices as well as models of the relationships between all the involved actors.

This is the 2nd version for the deliverable. The derived architecture (already presented in the 1st version of the document) has been further refined by taking into account all the necessary input made available by tasks 2.3 and 2.4 on the "Services Platform Specifications" and "Complex Demonstrators Specifications". Moreover, necessary inputs have also been gathered, extracted and used from WP3 – "PROPHESY-CPS Platform Integration", WP4 – "PdM Data Collection and Analytics" and WP6 – "Predictive Maintenance Solutions Composition", in particular from:

a) Tasks 3.1, 3.2, 3.3, 3.4 and 3.6 and related deliverables (e.g. D3.1 – "PROPHESY-CPS Detailed Architecture V1", D3.3 – "Digital Models and Interoperability V1", D3.5 – "PROPHESY Sensor Data Collection V1", D3.7 – "PROPHESY-CPS Middleware Infrastructure V1" and D3.11 – "Security, trustworthiness and Data Protection Framework V1") to refine the main components of the PROPHESY-PdM platform, their interactions as well as their functional description;
b) Tasks 4.1, 4.3, 4.4 and 4.5 to refine the role of the Machine Learning algorithms and components together with their location within the PROPHESY-PdM platform and/or PROPHESY-CPS; and
c) Tasks 6.1, 6.2 and 6.4 to refine the overall PROPHESY Ecosystem specifications.

Therefore, the PROPHESY-PdM platform specifications have been refined by taking into account necessary implementation details and partners' technical items planned to be included in the PROPHESY envisioned solution. In this way a complete closed loop approach has been used where initial specifications (in 1st version of the document) pushed and supported the implementation actions, and the results and feasibility assessment of these actions have been used to align the specifications while improving the overall quality of the solution. Finally, emphasis has been given to the PROPHESY ecosystem. As a matter of fact,

the document provides a new and more detailed specification of the concept behind the PROPHESY Ecosystem establishing – *de facto* – the foundation for its implementation.

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Definitions, Acronyms and Abbreviations

Acronym/ Abbreviation	Title
ANSI	American National Standards Institute
API	Application Programming Interface
B2MML	Business To Machine Mark-up Language
CAEX	Computer Aided Engineering Exchange
CBM	Condition Based Monitoring
CI	Continuous Integration
CMMN	Case Management Model and Notation
COTS	Commercial Off-The-Shelf
CPPS	Cyber-Physical Production System
CPS	Cyber-Physical System
CPSoS	Cyber-Physical System of Systems
DCS	Distributed Control System
DPWS	Device Profile for Web Serivces
DSS	Decision Support System
FIPA	Foundation for Intelligent Physical Agents
GUI	Graphical User 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
LA	Lambda Architecture
Local DSS	It is a DSS local to the PRPOPHESY-CPS
JADE	Java Agent Development Framework
M2M	Machine to Machine
NIST	National Institute of Standards and Technology
OPC	OLE for Process Control
OPC-UA	OPC Unified Architecture
OT	Operation Technology
P&P	Plug and Produce
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	Is the hardware and the necessary software connected to several

Platform	PROPHESY-CPSs and to the PROPHESY-AR and 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
RAModel	Reference Architectural Model
RTD	Research and Technology Development
SCADA	Supervisory Control and Data Aquisition
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 Background

Despite the proclaimed benefits of predictive maintenance approaches and strategies, the majority of manufacturers are still adopting and thus adhering to purely preventive and condition-based maintenance approaches which result in suboptimal OEE (Overall Equipment Efficiency). 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 intelligence 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.

So as 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 coined **PROPHESY-ML** and is developed in WP4 of the project.

For the purpose of leveraging 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**.

So that we can 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**.

1.2 PROPHESY Architecture Framework

The design and development of software architectures typically requires knowledge about the domain of application and the specific environment available. To facilitate the way this knowledge is captured, organized and structured a simplified RAModel [1] is used (Figure 1) which includes the following macro elements, namely: Domain, Application, Infrastructure and Crosscutting Elements.

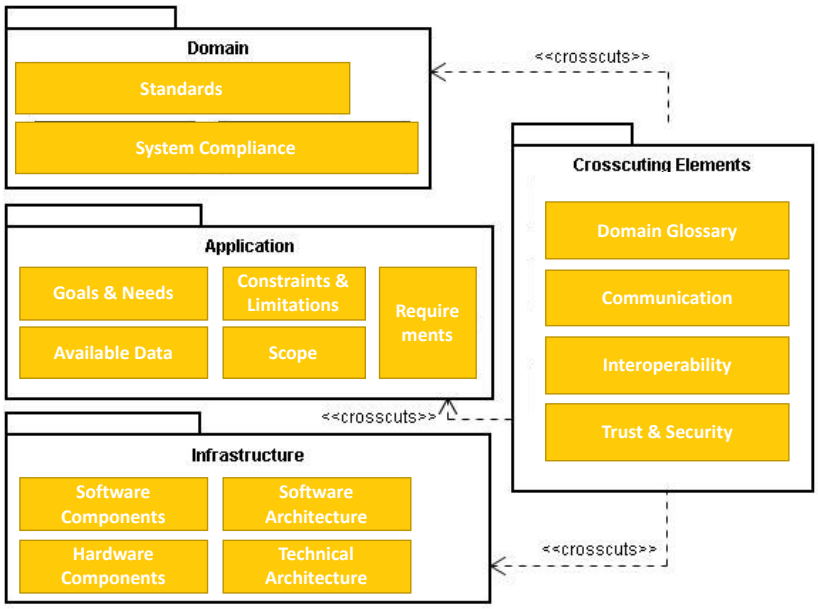

Figure 1: Adopted RAModel, adapted from [1]

Before starting with the definition and the specification of the Infrastructure, i.e. identification of the software and hardware components – as well as – the software and technical architectures a preliminary analysis has been performed that aimed to clearly define the domain (state-of-the-art analysis presented in section 2.3) and a common language (domain glossary). All these elements together provide the fundamental baseline for building up the overall infrastructure and/or PROPHESY system.

1.3 Specification Approach

Software architectures deals with several concepts spacing from abstraction to style and aesthetics passing through composition and decomposition. To facilitate and harmonize the way software architectures – and thus specifications – are defined, structured and documented the Kructhen's architectural framework (4+1 View model) [2] is used (see

Figure 2). The framework describes software architectures by using four views that reflects distinct phases of the architecture specification and software development, namely:

- *Logical View*: specifies the logical structure of the system and its functionalities in terms of generic components and/or concepts;
- *Development View*: specifies how concrete software artefacts are organized in the development environment. Therefore, this view provides – from one side – concrete implementations of the concepts and/or functionalities of the logical view and – from the other side – guideline to streamline the development and used tools and technologies;
- *Process View*: specifies the run-time behaviour of components and/or concepts in the logical view as well as how they dynamically collaborate and interact with each other; and
- *Physical View*: specifies and describes how the developed software is deployed, i.e. how it is mapped to the hardware.

The glue between the four views is represented by the use cases and related scenarios view that provide the reason why the four views exist by delivering significant requirements for the architecture.

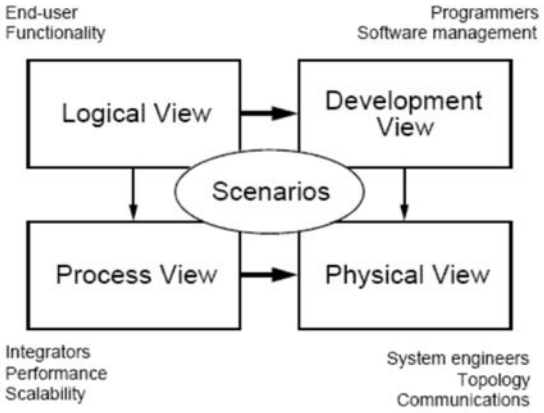

Figure 2: Kruchten 4+1 model [2]

In addition to the four views – proposed by the model – there is another one (data view) that needs to be considered especially in collaborative projects where developed software is deployed within already existing infrastructures. The data view describes how data are organized, structured and formatted.

Finally, the security & trust as well as the performance perspectives are also included within the specifications that are aimed to adapt and transform the proposed architecture in order to show a particular quality property. More in general, a perspective defines a collection of activities, tactics, and guidelines that are used to ensure that a system exhibits a particular set of related quality properties that require consideration across a number of the system's architectural views [3].

1.4 Document Purpose and Audience

The present document is aimed to provide an overview of the work realised by both industrial and Research and Technology Development (RTD) partners, in specifying the PROPHESY-PdM platform together with the related ecosystem. In particular, the work –

realised in the context of the task T2.5 PROPHESY-PdM Platform Architectures and Ecosystem Specifications – comprehends:

- the definition of the application domain and the identification of the main features of the PROPHESY-PdM, i.e. the clear understanding of the what the PROPHESY-PdM platform should achieve;
- the definition of the conceptual architecture as well as the description of the major functionalities associated to the envisioned components that are part of the PROPHESY-PdM platform. The conceptual architecture and the description of the components are organised according to the Kruchten 4+1 model. The focus in the PRPHESY-PdM description will be given to the definition of the main concepts that will drive the integration between the PROPHESY-PdM platform and the PROPHESY-CPS; and
- the definition of the PROPHESY ecosystem to enable the development of specific PROPHESY instantiations by composing core services.

1.5 Document Role/Scope

The high-level architecture of the PROPHESY-PdM system – the one initially included in the Description of Works (DoW) – has been further studied, described and detailed in the context of the WP2. The initial architecture was a layered architecture strongly oriented to the identification of the main elements of the PROPHESY-PdM system. A newer version of the PROPHESY-PdM system architecture (see Figure 3) has been designed in the first six months of the projects.

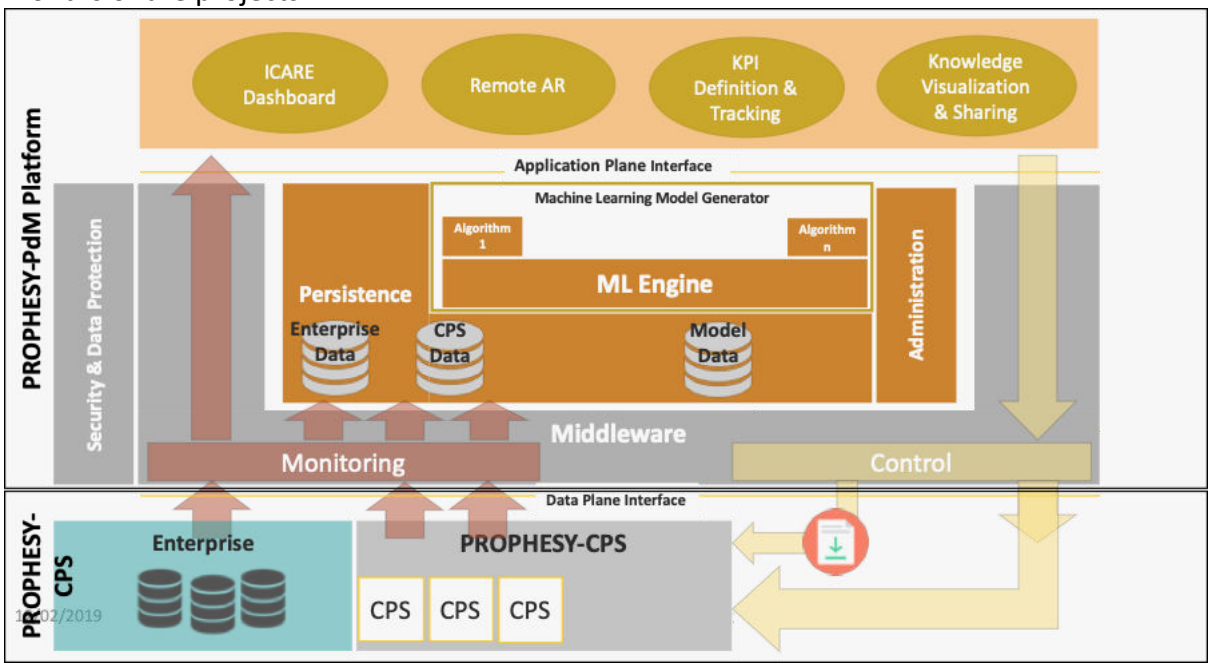

Figure 3: PROPHESY-PdM System overall architecture

The PROPHESY-PdM system is divided into two main computational levels, namely: a) the PROPHESY-CPS that is responsible for virtualizing physical assets located at the shop floor, processing shop floor data for "short-term" decisions; b) the PROPHESY-PdM platform that acts on the top of the PROPHESY-CPS and is responsible for processing more structured data

from several PROPHESY-CPSs for "medium/long-term" decision. With this in mind, several deliverables have planned for documenting the PROPHESY-PdM system. In particular **the current deliverable (D2.6 – Platform Architectures and Ecosystem Specifications V2) is primarily focused on the refinement PROPHESY-PdM platform level and details, PROPHESY-PdM platform main functional components, structure, relationship with the PROPHESY-CPS together with its physical instantiation by taking into account results and input, essentially, from the WP3 – PROPHESY-CPS platform integration. Secondly it puts the light on specifying the PROPHESY Ecosystem while highlighting that this PROPHESY is the first step towards the creation an entire ecosystem of PdM related knowledge and stakeholders the will perform supply and demand of content, knowledge, services and solutions.**

1.6 Updates over the previous version of the Deliverables

The document document differs from the previous version with respect to:

1. Refinement of the identified overall generic characteristics for PROPHESY-PdM platform (see section 2.3.3.2).
2. More detailed specifications of the architecture thanks to:
   2.1. Alignment with the systems implemented in the demonstrators (from Task 2.4).
   2.2. Alignment to technical developments in WP3 and WP4 and refinement based on these developments.
3. Detailed Specifications of the Ecosystem thanks:
   3.1. alignment with the specification of the PROPHESY-SOE platform (from Task 2.3).
   3.2. Alignment with the technical development in WP6 and refinement based on these developments.

1.7 Document Structure

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 WP2 while underlining the role played by this document with respect to the whole project;
- Section 2. **PROPHESY-PdM Foundations:** this section delivers a complete picture for framing the activities within the task 2.5. This section is intended to identify common issues and features for PdM platforms;
- Section 3. **PROPHESY-PdM Platform: Logical View**: describes the logical structure of the system and its functionalities (logical architecture);
- Section 4. **PROPHESY-PdM Platform: Process View:** specifies the run-time behavior of the components in the logical view as well as the inter-process communication style internally (within the PROPHESY-PdM platform) and externally (between the PROPHESY-CPS and the PdM platform).
- Section 5. **PROPHESY-PdM Platform: Data View**: describe the PROPHESY-PdM platform supported data models.
- Section 6. **PROPHESY-PdM Platform: Ecosystem**: delivers the explanation and specification of the ecosystem associated to the PROPHESY system.

- Appendix A: Provides an overview of the European Research initiatives that have been considered relevant for the specification of the PROPHESY-PdM platform.

2 PROPHESY-PdM Foundations

2.1 PdM Platform and Ecosystem Description within PROPHESY

The term PROPHESY-PdM platform refers to:

"*The hardware, the operating environment and the software components connected to several PROPHESY-CPSs and to the PROPHESY-AR that are necessary to execute PdM services and tasks and – thus – responsible to calculate defined KPIs from the data gathered by using the list of analytics provided by the PROPHESY-ML"*

The PROPHESY-PdM platform together with the PROPHESY-CPS represent the PROPHESY system that – in turn – can be defined as:

"*The combination of the PROPHESY-PdM platform and the necessary PROPHESY-CPSs*"

In particular, by using the definition in [4], the PROPHESY system provides:

"*A foundation technology and/or set of components used beyond a single firm and that brings multiple parties together for a common purpose or to solve a common problem*"

Directly connected to the above definition there is the concept/definition of PROPHESY Ecosystem. As a matter of fact, the PROPHEYS-PdM platform and more in general the PROPHESY system assumes a fundamental role if an ecosystem needs to be formed around it. Therefore, the definition of ecosystem considered in the context of PROPHESY and that is used throughout this document is the one extracted from [5], that defines the ecosystem as:

"*A set of actors functionating as a unit an interacting with a shared market for software as services, together with the relationships among them. These relationships are frequently underpinned by a common technological platform or market and operate through the exchange of information, resources and artefact*".

2.2 The Approach

The proposed approach for the PROPHESY specifications in general and for PROPHESY-PdM platform combine a top-down and a bottom-up approaches (see Figure 4). The former is aimed to describe the domain, define the context of application and identify the generic and core functionalities and features of a platform suitably designed for supporting PdM tasks and strategies, i.e. to characterize how a generic data exchange and sharing platform can be adapted and optimized to support PdM strategies. To do that, the SotA, the literature and the previous partner experience are explored. However, this approach alone is necessary but not sufficient for specifying the PROPHESY-PdM platform. As a matter of fact, the identification of features and the behavior of the system cannot be accurately established without any link to concrete architectures and IT/OT systems where PROPHESY should be applied. To guarantee and ensure the feasibility, reproducibility as well as the applicability of the PROPHESY-PdM platform specification in the industrial context a bottom-up approach is applied that is aimed to particularize the generic and core features – which have been previously identified – by taking into account the real and already installed and deployed shop floor solutions as well as implemented maintenance strategies. This is a fundamental validation *per se* since it ensures the industrial acceptance of the proposed solution and its implementation by all the involved stakeholders (e.g. system integrators, components/device providers and manufacturer).

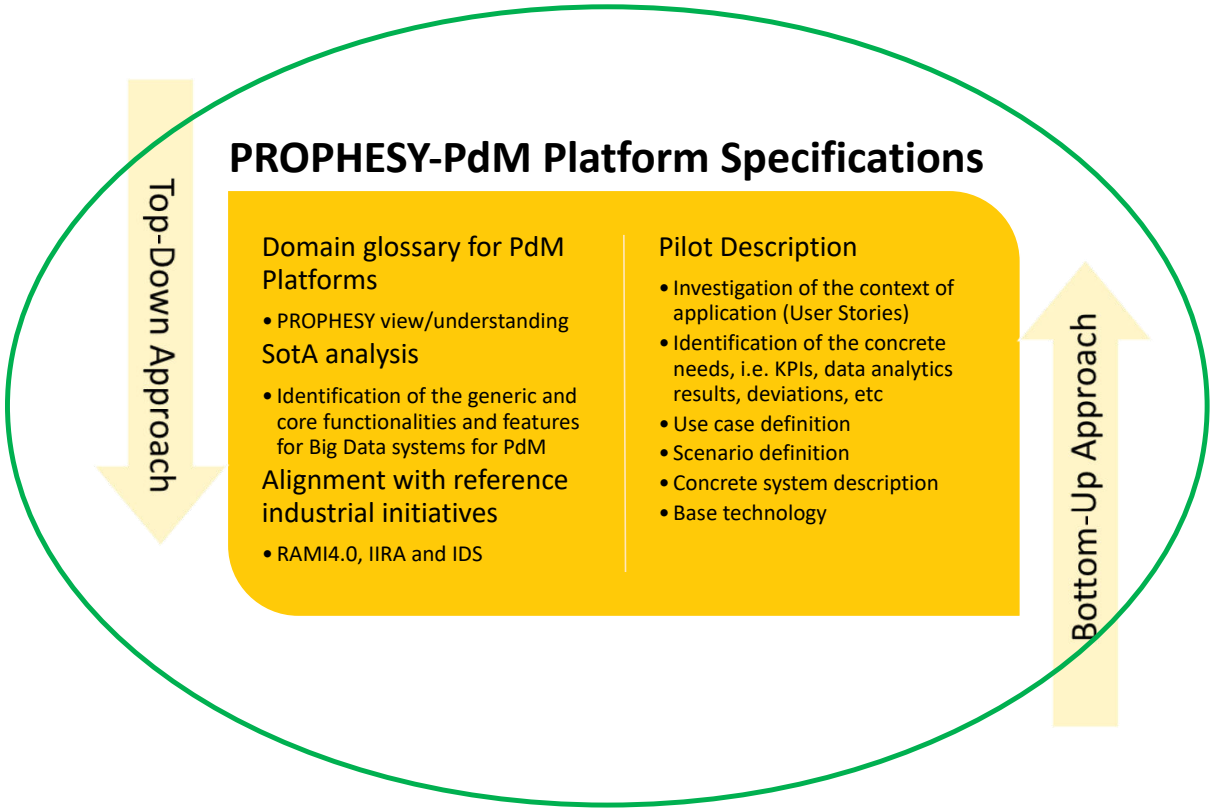

Figure 4:PROPHESY-PdM Specification Approach

2.3 Applying the Top-Down Approach

2.3.1 Rationale

The digitization of the industry is radically changing the nature of the manufacturing companies. The relation and – thus – the interface between provider/supplier and costumer is going to be completely reshaped around the concept of Servitization [6]. In this landscape, data are becoming more and more important thanks to the potential information and knowledge that encapsulates. Therefore, being able to manage data exchange and sharing effectively and efficiently to create the foundation for Servitization is a necessary condition for companies to be competitive on market sharing. The usage of the data and the design and implementation of platforms for facilitating the data exchange and sharing is a hot topic in both academic/research and industrial domains as confirmed by the numerous international research projects on topics like: big data, sensing enterprise, Servitization, product/service life cycle management, etc., as well as, by the numerous white papers (and related products) produced by leading automation companies like Rockwell and Siemens. Spanning over these all, there is the matter of identifying common features for data exchanging, sharing, and processing architectures and in particular for identifying patterns, reference architectural models, approaches and related technologies for building this kind of systems. Furthermore, critical architectural issues are also identified, the ones that are relevant for the specification of the PROPHESY-PdM platform and connected to the domain of application: PdM.

2.3.2 PROPHESY-PdM Platform Conceptual Aspects: CPS Taxonomy

The Figure 5, shows the main topics and principles that are interesting to the CPS domain. Since the PROPHESY-PdM platform is part of a CPS-populated system then it is useful to understand and identify which relevant topics and principles of the CPS main domain are considered as fundamental properties to guide the specification of the PROPHESY-PdM platform, i.e. to facilitate the definition of the internal structure and organization of the PROPHESY-PdM platform.

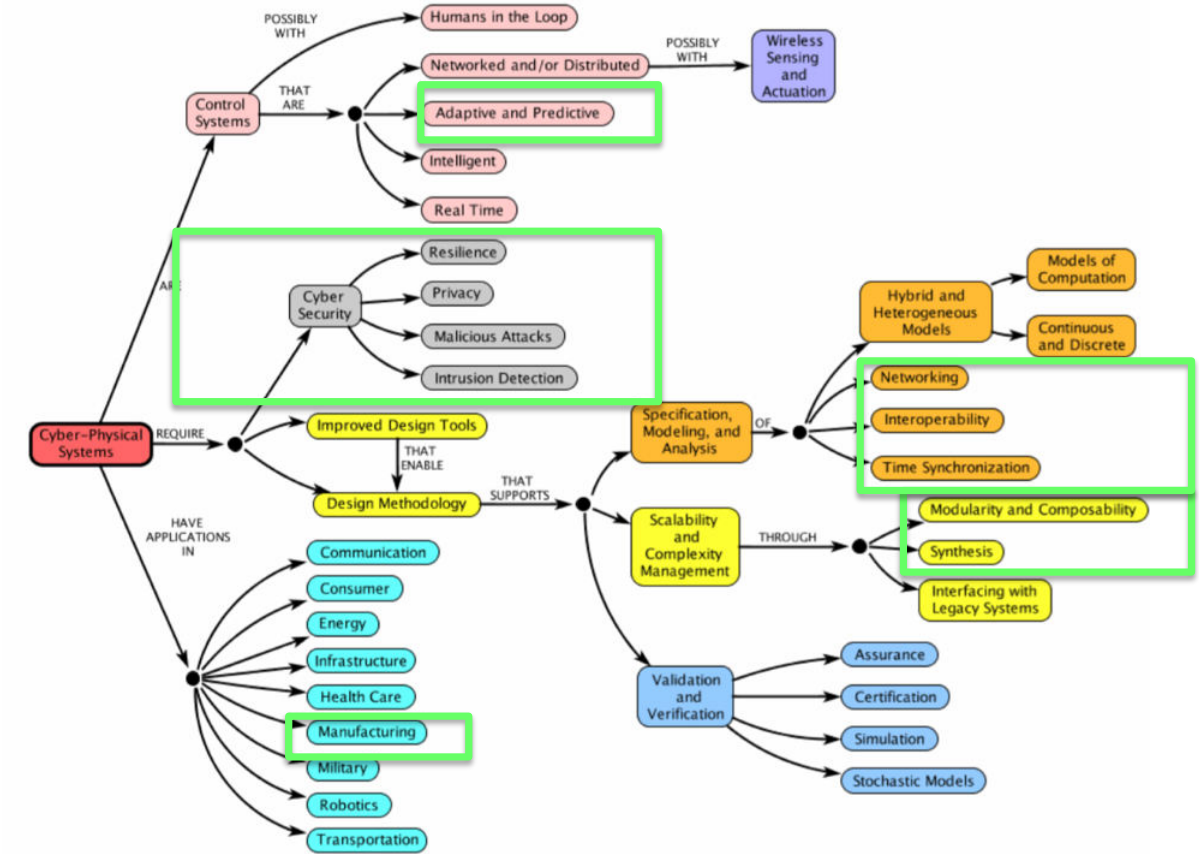

Figure 5: CPS Taxonomy [7]

2.3.2.1 European Research Projects

The Table 1 provides a list of EU founded projects that provided some input for the definition and the specification of the PROPHESY-PdM platform. The list of projects is the result of the SotA and is intended to identify generic features and characteristics of platform for smart manufacturing systems with special attention to maintenance strategies, policies, activities, etc.

The Appendix A provides a full description of the identified projects and highlight how these projects have impact on PROPHESY.

Table 1: Relevant European Research Projects for PROPHESY-PdM Platform

Project Name	Project Details	Involved Partner
PROASENSE	Project ID: 612329 Call for Proposal: FP7-ICT-2013-10 Duration: from 2013-11-01 to 2017-01-31	NOVA ID
MANTIS	Project ID: 662189 Call for Proposal: ECSEL-2014-1 Duration: from 2015-05-01 to 2018-04-30	MONDRAGON, FHG, NOVA ID, PHI, TUE
ARROWHEAD	Project ID: 332987 Call for Proposal: ARTEMIS-2012-1 Duration: from 2013-03-01 to 2017-02-28	MONDRAGON, NOVA ID
GOODMAN	Project ID: 723764 Call for Proposal: H2020-FOF-2016 Duration: from 2016-10-01 to 2019-09-30	NOVA ID
EPES	Project ID: 285093 Call for Proposal: FP7-2011-NMP-ICT-FoF Duration: from 2011-09-01 to 2015-02-28	None from PROPHESY
PROSECO	Project ID: 609143 Call for Proposal: FP7-2013-NMP-ICT-FoF Duration: from 2013-10-01 to 2017-09-30	NOVA ID
KAP	Project ID: 260111 Call for Proposal: FP7-2010-NMP-ICT-FoF Duration: from 2010-09-01 to 2013-12-31	None from PROPHESY
CREMA	Project ID: 637066 Call for Proposal: H2020-FoF-2014 Duration: from 2015-01-01 to 2017-12-31	None from PROPHESY
Self-Learning	Project ID: 228857 Call for Proposal: FP7-NMP-2008-SMALL-2 Duration: from 2009-11-01 to 2013-01-31	NOVA ID
POWER-OM	Project ID: 314548 Call for Proposal: FP7-NMP-ICT-FoF Duration: from 2012-08-01 to 2015-07-31	MMS
FAR-EDGE	Project ID: 723094 Call for Proposal: H2020-FOF-2016 Duration: from 2016-10-01 to 2019-09-30	AIT, UNPARALLEL

2.3.2.2 Industrial Initiatives

2.3.2.2.1 Reference Architectural Model for Industrie 4.0 (RAMI 4.0)

This section is aimed to show which elements of the RAMI 4.0 (see Figure 6) are relevant for the PROPHESY-PdM platform, a more exhaustive and generic description of the RAMI 4.0 has been included in the deliverable d2.1 – PROPHESY-CPS Specification.

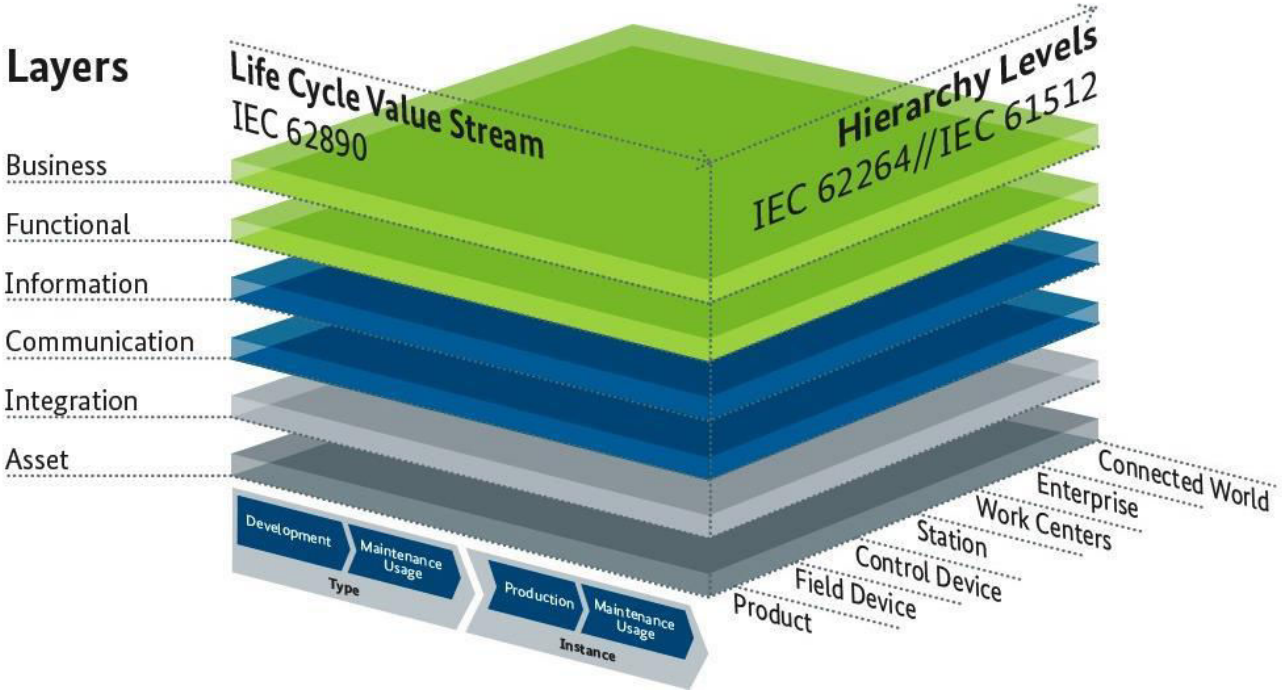

Figure 6: Reference Architecture Model for Industrie 4.0 (RAMI 4.0) [8]

The RAMI 4.0 is a global and unified model from product until connected world. Obviously, not all the elements of the RAMI 4.0 are necessary and/or are considered for specifying PROPHESY-PdM platform. If the PROPHESY-CPS – that has been specified in the deliverable d2.1 – is focused on the first tree IT layers and hierarchy levels, the PROPHESY-PdM platform is focused on the upper IT-layers and hierarchy levels. The core features and elements of the RAMI 4.0 that need to be considered in the domain of the PROPHESY-PdM platform are:

- from the IT layers point of view:
  1. Information: the I4.0 component layer where a standard and unique data representation is available and accessible by a harmonized communication (service based);
  2. Functional: is the layer of the functional representation and access to the physical assets. These functionalities and/or services can be uses, composed and included within business processes, i.e. they are the building blocks of business processes; and
  3. Business: realization of the business process and the usage of the data within business applications for facilitating the decision-making process at the business layer.
- From the functional Hierarchy Levels:
  1. Station;
  2. Work Centers (also called *Area* in the Isa-95 model); and
  3. Enterprise.

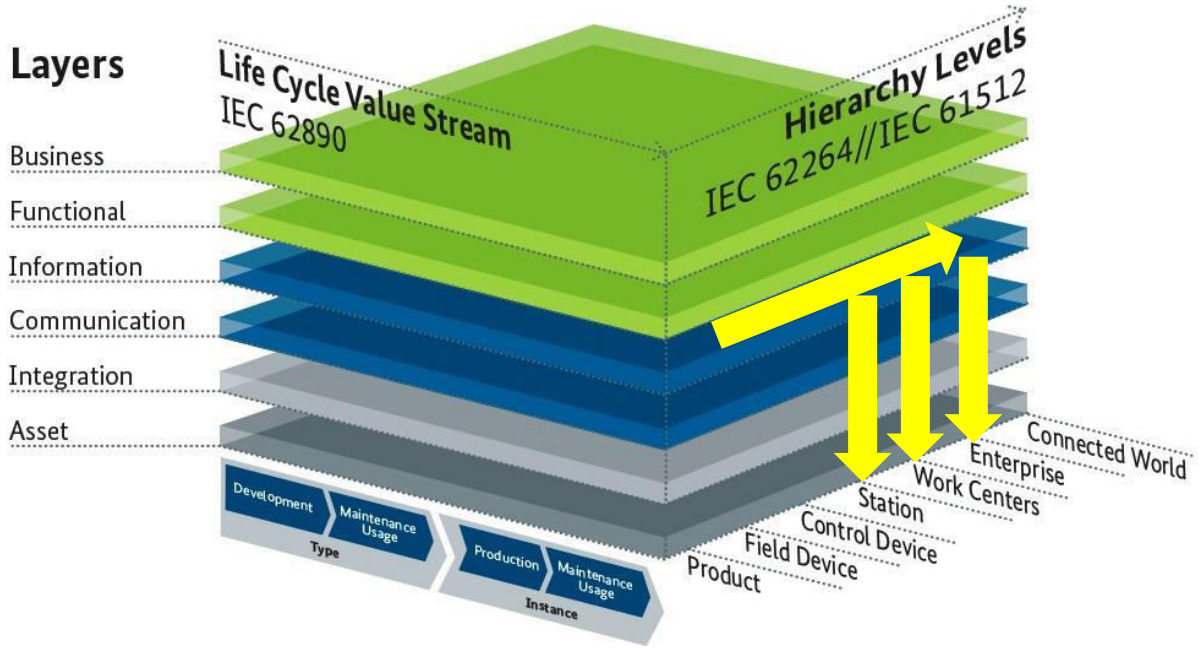

Figure 7: Considered aspects of RAMI4.0 in PROPHESY-PdM Platform

2.3.2.2.2 Industrial Internet Consortium Reference Architecture (IIRA)

As stated in [9], three architectural patterns have been considered and explained for designing and developing IIRA compliant software systems, namely: i) three-tier architecture pattern; ii) gateway-mediated edge connectivity and management architecture pattern; and the layered databus architecture pattern. The latter architecture pattern (see Figure 8) is considered as the reference one for PROPHESY. In the Figure 8, the higher-level systems use a dedicated databus for supervisory control and monitoring. Federating these systems into a System-of-Systems (SoS) enables complex, Internet-scale, potentially-cloud-based, control, monitoring and analytic applications where the physical assets at the bottom of the architecture are abstracted into functionalities and services to be used in business processes in the site and unit databus while the data representation is harmonized to facilitate the data sharing between the distinct levels.

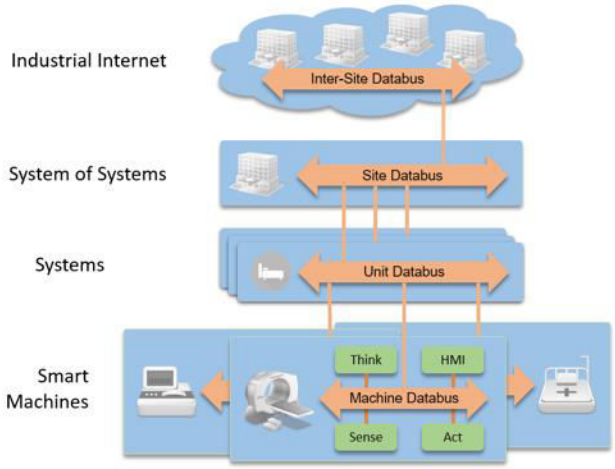

Figure 8: Layered Databus Architecture [9]

Each layer of the databus therefore implements a common data model, allowing interoperability between the layers. Adapters and translators can be implemented between the layers to match the distinct data models. In the case of the PROPHESY-PdM platform, the SoS and the Systems levels are considered as part of it. Therefore, the PROPHESY-PdM platform databus merges the Unit databus and the Site databus (see) in a single hardware and software infrastructure that uses a message-oriented middleware (MOM) for supporting the integration and the communication between distributed systems.

2.3.2.2.3 Industrial Data Space[1]

The Industrial Data Space (IDS) initiative was launched in Germany at the end of 2014 by representatives from business, politics, and research. The initiative is founded on the main assumption that data is the necessary link between the "Smart Service World" and the "Industrie 4.0"/ industrial manufacturing. Therefore, it provides an architectural model to support the new form of data management where the core features are: i) networking of humans and machines; ii) autonomation of processes and systems; iii) high information transparency; and iv) improved support to the decision-making activities. The IDS reference architectural model consists of four architectures, namely:

i. business architecture: comprises all the concepts to ensure the economic success and growth of the IDS;
ii. data and service architecture: describes the functional core of the IDS, i.e. the specification of the core services that are part of the IDS;
iii. software architecture: describes the implementation and deployment of the data and service architecture in the specific industrial application; and
iv. security architecture: comprises all the necessary security aspects to allow the integration of different levels of security within the IDS.

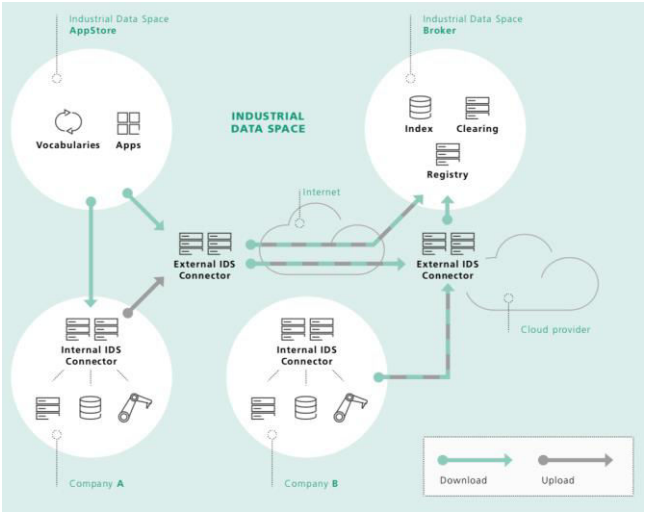

Figure 9: IDS Generic Functional Architecture [6]

[1] https://www.fraunhofer.de/en/research/lighthouse-projects-fraunhofer-initiatives/industrial-data-space.html

Since cloud-based platform landscape is characterized by a plurarity of architectural patterns and models it is necessary to have a reference architectural model for secure data exchange and trusted data sharing. The PROPHESY-PdM platform can take a significative advantage from the analysis and the inclusions of several of the concepts specified by the IDS and especially by the *AppStore* and the *Broker* that are part of the functional core of the IDS.

2.3.2.2.4 Lambda Architecture[2]

The lambda architecture (LA) is a data-processing architecture designed and defined by industry experts to handle and cope with the increasing quantities of data. It has been designed to respond to the increasing need to formalize and structure the way Big Data systems are designed. The main elements of the LA are presented in Figure 10, the descriptions of these elements have been included in the deliverable D2.1 – PROPHESY-CPS Specification and – thus – not repeated in this document.

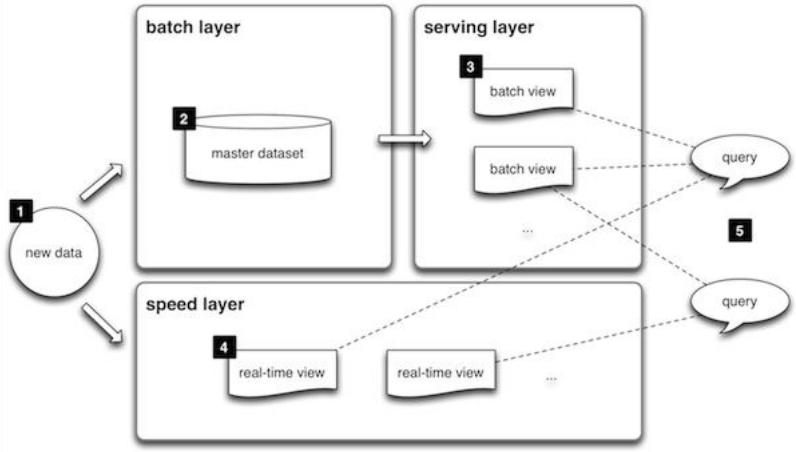

Figure 10: Lambda Architecture High Level Perspective [10]

The intrinsic nature of the PROPHEYS solution fits into the main stream of big data processing problems and platforms where multiple data from several data sources needs to be processed and correlated by using multiple kinds of data analytics technique. In particular all the layers of the LA can be part of both the PROPHESY-CPS and PROPHESY-PdM platform with a slightly differences and specific focus. As a matter of fact, the PROPHESY-PdM platform will be more and more focused on the batch layer and the serving layer (visualization of the results of the data analytics processes and tasks) while the PROPHESY-CPS will be essentially focused on the speed layer and the data extraction and collection mechanisms.

[2] http://lambda-architecture.net

2.3.3 Wrap-up

2.3.3.1 Generic Requirements from Current and Previous Relevant Projects and Initiatives

Industrial Requirements	PROPHESY generic objectives for PdM platform	Thoughts	Study
The system guarantees the early failure detection and – thus – the identification of predictive maintenance tasks based on the analysis of the data gathered at a system level (Area and Enterprise Levels)	Provide a mechanism for the evaluation of the system conditions based on the data available and predict problems and future failures (**Health Prognosis**)	Investigate methods, approaches and technologies for the early identification of process variables deviations	**PROASENSE, EPES, POWER-OM**
The system supports the decision-making process by providing suggestions about corrective actions (i.e. adaptations) to be executed as the result of the early/predictive failure detection	Provide a mechanism for identifying possible corrective actions and related adaptations to take.	Investigate methods, approaches and technologies for presenting proposed actions and adaptations (as the result of the computations of the data analytics tasks and processes)	**PROASENSE, EPES**
The system shall provide secure access to the data that are part of it	Provide appropriate security mechanisms to enable the secure access to the data and information	Investigate/explore methods, approaches and technologies to secure the access to data and information	**PROSECO, MANTIS, FAR-EDGE**
The system shall provide mechanisms for the easy configuration and deployment of data processing tasks	Provide appropriate engineering tools for facilitating the configuration and the management of the data processing tasks	Investigate/Explore the utilization of languages for defining and representing logic, workflows and rules to be used during the data processing tasks	**PROSECO, KAP**
The system shall be capable to calculate defined KPIs	Provide the necessary computational components to calculate predefined KPIs	Investigate/Explore architectures and framework for KPI determination	**CREMA, MANTIS, PROASENSE**
The shall provide a mechanism, a language and a reference model for defining new KPIs	Provide all the engineering tools necessary for describing all the details of the KPI, i.e. the information source, the way to calculate it and the set/target values	Investigate/Explore modelling languages from previous research projects for KPI definition and description	**PROASESE, KAP**
The system shall provide mechanisms for adding/removing/managing data sources	Provide core services to enable the management of the data sources (PROPHESY-CPS)	Investigate/Explore frameworks and technologies that provide such services (e.g. IDS, Arrowhead, etc)	**PROASENSE, PROSECO, MANTIS, POWER-OM**
The system shall provide the possibility to develop added value services in the top of it	Facilitate the development of new services and applications that can easily consume data from the PROPHESY-PdM platform	Investigate/Explore methods and approaches for designing and developing a PROPHESY-PdM ecosystem	**POWER-OM, MANTIS**

The system shall be capable to monitor and alert the user about any deviation of the relevant monitored variables	Provide mechanisms to notify the user about the need for an adaptation and/or a change in configuration	Investigate/Explore methods and approaches for integration of self-adaptation and self-configuration capabilities while assuring the presence of the human-in-the-loop	**PROASENSE, Self-Learning, CREMA**
The system should be highly responsive	The data analytics tasks should be designed according to parallel and distributed computing principles	Investigate/Explore methods, approaches and technologies for distributed and parallel computing (Haddop, Spark, Storm, Akka, etc)	**PROASENSE, MANTIS, FAR-EDGE**
The system should enable the analysis of distributed data by an open list of analyses.	Provide a list of algorithms and data analysis to be supported and applied on data, such as: - root cause of failure analysis - symptom analysis - automatic sensor data interpretation - remaining useful life estimation - calculation of optimized maintenance strategy	Investigate/Explore the analysis that make sense for PROPHESY, i.e. according to the type of the data and the objectives of the analysis	**MANTIS**
The system should enable real and non-real time data analysis	Provide a batch layer and a speed layer for non-real and real time data analytics respectively	Investigate/Explore methods and appropriate technologies for the implementation of a nor-real time data analytic layer and a real-time data analytic layer	**MANTIS**
The system should provide mechanisms for bi-directional communication from physical to virtual worlds and vice-versa	Provide a middleware for integrating the PROPHESY-CPS (edge level) and the PROPHESY-PdM platform	Investigate/Explore technologies to be used as the supporting infrastructure for the integration of all the relevant components of the solution	**MANTIS, FAR-EDGE**
The system shall support a cloud-based infrastructure	Provide a platform that comprises all the requirements for cloud-based systems	Investigate/Explore technologies and approaches for building a systemin accordance with cloud computing principles	**MANTIS, FAR-EDGE**

2.3.3.2 Identified Overall Generic Characteristics for PROPHESY-PdM

The analysis of the state-of-the-art allows to identify a set of generic and common requirements for the PROPHESY-PdM platform. A fundamental assumption in PROPHESY project is to design and develop a platform on the top of models, methodologies and technologies already developed within successful EU research projects. Keeping this in mind, from the previous analysis the following characteristics and features emerged for the PROPHESY-PdM platform:

- **Modularity and Composability;**
  - **Based on Service Oriented Architecture principles.**
  - **Support for system scalability and hierarchical system organization to enable the development of complex system designs;**
- **Decentralization and distribution of the functionalities provided;**
- **Data availability and pre-processing;**
  - **Extract manipulate and analyse and store the physical data in order to make it available for further analysis;**
    - **Support for data filtering, data aggregation, data cleansing and provisioning;**
- **Data Analysis;**
  - **Support for on-line and off-line data analytics**
    - **Condition Prediction and Prognostic reference models.**
- **Integration;**
  - **Use global available data and services (e.g. Enterprise Resource Planning, quality databases, etc);**
  - **Facilitate the connection and interaction with/between CPSs and other software assets (applications, components, etc) by using communication networks and implementing network accessible components;**
- **User Interfaces;**
  - **Provide a set of Human Machine Interfaces (HMI) to allow humans to interact with it i.e. to visualize the data analytics results and to decide about it;**
    - **Stakeholders to be involved strictly depend on the data analysed and the result of the analysis and could range from customers to manufacturers, equipment suppliers, manufacturing IT providers, technician, etc.;**
    - **Time constraints depend on the purpose of the decision as well as on the specific level of the manufacturing company hierarchy;**
- **Administration;**
  - **Support for control automation and platform monitoring;**
    - **System logs;**
    - **Performance parameters measurement;**
    - **Status of the physical and virtual levels.**
  - **Provide an environment and tools where available services can be used on-demand;**
  - **Dynamic environment that enable the smarter integration of new features, functionalities and services.**

- **Interoperability and Standardization;**
  - **To use appropriate data models and information structures that represent the manufacturing context;**
  - **Programming-by-interface and decouple the user interfaces from the main system logic;**
  - **Standard compliance as an interoperability necessary condition;**
- **Openness**
  - **Uniform access to platform;**
  - **Data services to third party apps.**
- **Security**
  - **IT security concepts, architecture, and standards to ensure the integrity and availability of the information;**
  - **Data protection and secure data access.**

The presented features and characteristics provide the fundamental capabilities that need to be part of the PROPHESY-PdM platform and must be considered in the specification stage.

2.3.3.3 Alignment with RAMI4.0 and IIRA expectations

The Table 2, presents the mapping between the PROPHESY-PdM platform identified characteristics and the necessary features established by both RAMI4.0 and IIRA for connected and smart factories of the future.

Table 2: Required features and mapping to relevant aspect of RAMI4.0 and IIRA

Industry 4.0/ RAMI 4.0 and IIC/ IIRA main characteristics	PROPHESY-PdM
Inclusion of new data sources via standardised interfaces using the plug&use approach	**Include the necessary mechanisms for managing the dynamicity of CPS-populated systems** • **Aligned with: PROPHESY-CPS Middleware Infrastructure (in Task 3.4)**
Production Planning & Performance Management/Monitoring through communication of autonomous systems (Optimized Decision Making)	**Extract, manipulate, analyse and store the physical data provided by a network of CPSs** • **Aligned with: PROPHESY-CPS Middleware Infrastructure (in Task 3.4)** • **Aligned with: PROPHESY-CPS Detailed Architecture (in Task 3.1)** **Exploit complex event processing technologies in real industrial scenarios;** **Compute condition prediction and prognostic reference models;** • **Aligned with: Data Analytics and Techniques for PdM V1 (in Task 4.3 and 4.4)**
Changes in production during the ongoing production process	**Access to physical data using sensors and affect physical processes by using actuators (CPS**

(Intelligent Control)	**compliant Design);** **Exploitation of event driven services and mechanisms for detecting any deviation from the predictive and prognostic models.** • **Aligned with: Maintenance-Driven COS System and Processes v1 (in Task 3.5)**
Data availability (vertical and horizontal integration)	**Use global available data and services (e.g. Enterprise Resource Planning, quality databases, etc);** **Facilitate the connection and interaction with/between CPSs and other software assets (applications, components, etc.) by using communication networks and implementing network accessible components;** **Openness.** • **Aligned with: PROPHESY-CPS Middleware Infrastructure (in Task 3.4)** • **Aligned with: PROPHESY-CPS Detailed Architecture (in Task 3.1)**
Human in the loop (human-centric design)	**Provide a set of Human Machine Interfaces (HMI) to allow humans to interact with it i.e. to visualize the data analytics results and to decide about it**
Service orientation	**Facilitate the connection and interaction between CPSs and other software assets (applications, components, etc) by using communication networks and implementing network accessible components** • **Aligned with: PROPHESY-CPS Middleware Infrastructure (in Task 3.4)** • **Aligned with: PROPHESY-CPS Detailed Architecture (in Task 3.1)**
Acceleration through exponential technologies	**Support for on-line and off-line data analytics;** • **Aligned with: Data Analytics and Techniques for PdM V1 (in Task 4.3 and 4.4)**
Standardization (Interoperability)	**Industrial Standard compliance** **Harmonization and simplification of existing standards for maintenance information exchange** **Programming-by-interface and decouple the user interfaces from the main system logic;** **Openness.** • **Aligned with: PROPHESY-CPS Middleware Infrastructure (in Task 3.4)** • **Aligned with: Digital Modelling and**

	Interoperability v1 (in Task 3.2)
Standardization and reference Architectures	**Standardization of the collaboration between software assets and components to facilitate the composability of the solution;** **Harmonization with already existing reference architectures (RAMI, IIRA, MANTIS)** • **Aligned with: PROPHESY-CPS Middleware Infrastructure (in Task 3.4)** • **Aligned with: PROPHESY-CPS Detailed Architecture (in Task 3.1)**
Migration strategies	**Support the integration of legacy systems and components;** • **Aligned with: PROPHESY-CPS Middleware Infrastructure (in Task 3.4)** • **Aligned with: PROPHESY Sensor Data Collection (in Task 3.3)**
Novel cloud/edge computing patterns	**Support for system scalability and hierarchical system organization to enable the development of complex system designs** • **Aligned with: PROPHESY-CPS Detailed Architecture (in Task 3.1)**
Modularity and Composability	**Decentralization and distribution of the functionalities provided;** **Openness.** • **Aligned with: PROPHESY-CPS Detailed Architecture (in Task 3.1)**
Security and Safety	**IT security concepts, architecture, and standards to ensure the integrity and availability of the information;** **Data protection, integration and secure data access.** • **Aligned with: Security, Trustworthiness and Data Protection Framework V1 (in Task 3.6)**

By looking at Table 2, the features and main requirements that drive the PROPHESY-PdM platform specification are clearly aligned with the key concepts extracted from RAMI4.0 and IIRA. Concretely, the PROPHESY-CPS – presented in deliverable D2.1 – PROPHESY-CPS Specifications – promotes the creation of a cyberspace and/or virtual environment where data from different physical assets is easily made available in order to be processed by machine learning algorithms and stream processors to analyse their behaviour. Therefore, it delivers a functional layer that enables the access to the physical assets. The PROPHESY-PdM platform makes use of this functional layer and base services for the creation of maintenance services, i.e. maintenance processes that are executed for implementing PdM

strategies. Thus, the PROPHESY-CPS and PROPHESY-PdM platform are complementary, the former is the enabler for the latter.

The complementarity of the PROPHESY-CPS and PROPHESY-PdM platform is shown in Figure 11, where the PROPHESY-CPS is aimed to *cyberize the physical* in terms of a set of functions (exposed through the *CPS Administration* Shell), while the PROPHESY-PdM platform is aimed to provide the whole machinery to enable the usage of these functions, i.e. link together CPSs into business processes.

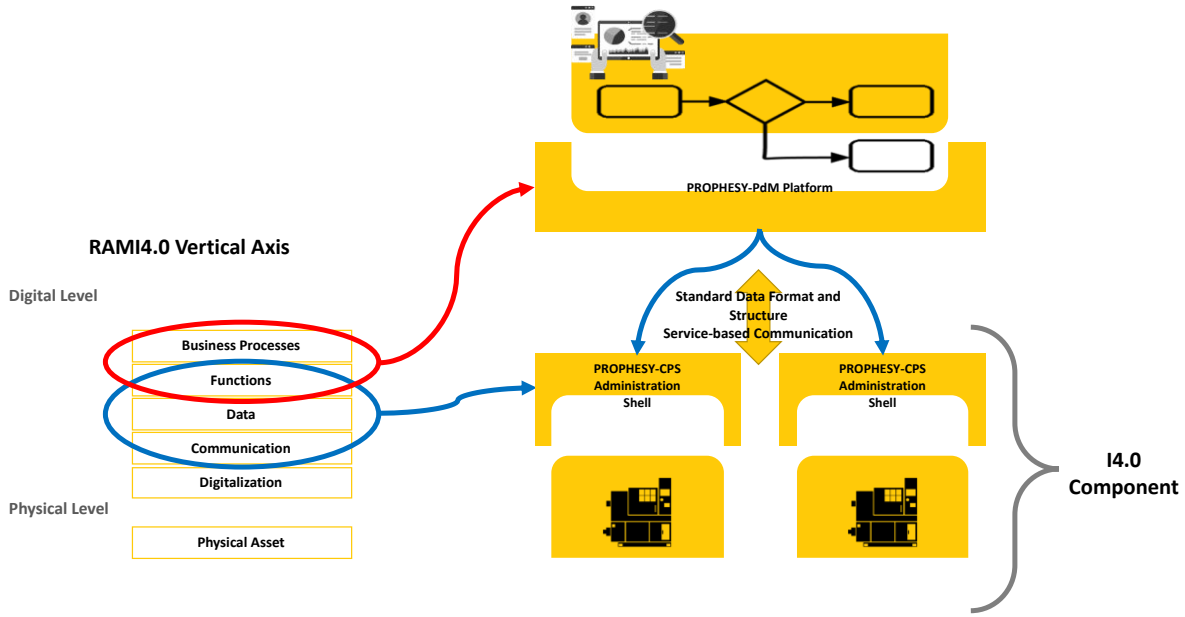

Figure 11: How RAMI4.0 is linked to PROPHESY-CPS and PdM platform

Finally, the rising complexity of a smart factory, where I4.0 Components are distributed within the factory space and capable to establish a transparent communication across the factory hierarchy levels, is growing more and more. To manage the rising complexity, PROPHESY decided to adopt specific architectural patterns. The adopted pattern – that is used as the foundation for the PROPHEYS-PdM platform specification – has been extracted from the IIRA that establishes several architectural patterns to facilitate the design and development of ioT-based solutions. In this landscape, a layered databus architecture is considered and the overall PROPHEYS-PdM databus is the higher level databus that provides the foundations for the analysis of the data flows from the PROPHESY-CPSs and the management flows for managing the provided assets and registered PROPHESY-CPSs (see Figure 12).

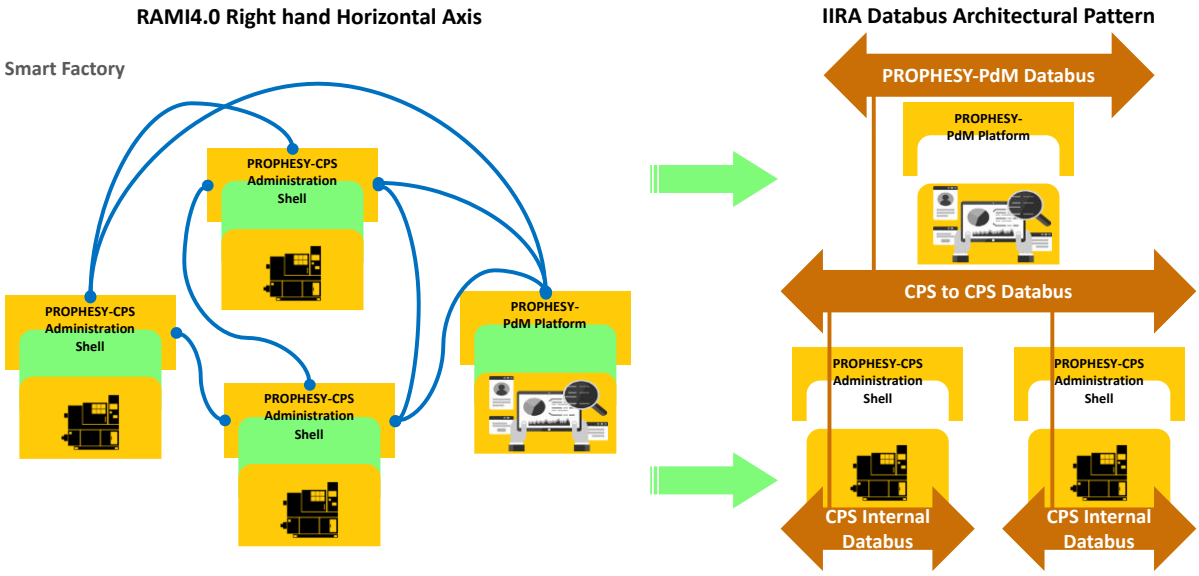

Figure 12: How RAMI4.0 and IIRA converge into PROPHESY-PdM platform

2.4 Applying the Bottom-Up Approach

2.4.1 Overall Proposed Approach

Scenario planning/analysis for system/software development is the technique adopted for discovering requirements. Scenarios (aka To-Be Scenarios) are imaginative representations of potential futures that provide the contextual basis for technology development and management. Scenarios provide a vehicle to actively include a number of different stakeholders for exploring a scene from distinct perspectives and – thus –discovering the requirements. Furthermore, they can be used as fundamental input for system/software specifications, or in other words, to help developers to make very technical decisions. As a matter of fact, the more one explores a given scenario, the more one learns about the subject matter and the inside the system/software you are planning to build.
The proposed approach for scenarios definition builds-up on the main assumption that the specifications of the PROPHESY PdM solution cannot be produced without:

- the description of the software/system needs – from the point of view of different stakeholders;
- the description of the concrete architectures of the considered pilots.

These descriptions together create the necessary baseline for the extraction of the system/software requirements while triggering the production of detailed specifications for the all the layers of the platform. The adopted scenarios building process is grounded on the approach presented in Figure 13. The approach is constituted by several steps organized in a "classical" V-Model. The main idea is to initially start from generic and high-level descriptions – user stories – from different system/software stakeholders and to go down with the abstraction level in order to build richly structured scenarios, to define associated use cases, to identify the company needs and finally to describe the concrete architecture, technologies, data format and communication links. The initial steps are providing directly and indirectly requirements that are then used for creating models, or in other words, for specifying all the necessary components of the PROPHESY platform.

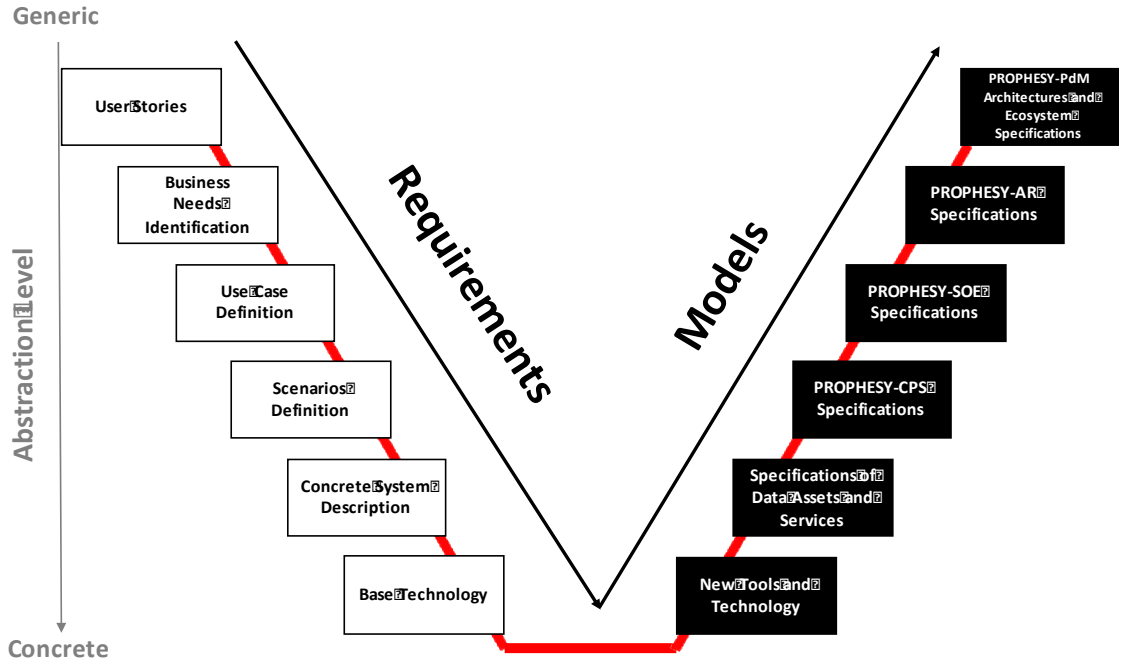

Figure 13: Applied Approach for Requirements identification

The main steps of the proposed approach are the following:

1. Investigation scope: concerns with the analysis of the domain of application to identify the business scope and/or boundaries of the system/software to develop as well as to lay the foundation for the identification of the business needs. A fundamental part in this step is represented by the user stories;
2. Identify business needs: concerns with the identification of the stakeholders as a source of knowledge for identifying relevant business events in the investigation scope;
3. Use Cases Definition: concerns with the identification of the business use cases that are triggered by the business events identified before;
4. Scenarios Definition: concerns with the creation of a scene around the business use case. These scenes can be detailed (concrete scenario) or not (conceptual scenario) and are necessary for identifying specific system/software features;
5. Concrete System Unique Description: unique description of the overall system, i.e. pilot concrete architecture plus PROPHESY components; and
6. Base technology: identification of the base technologies used within the pilot.

These steps together provide the baseline for the identification of the requirements for all the software components and assets to be developed and are used to create specification and technical architectures to respond to the main identified business events. The identified reference models are:

1. Tools and technology Identification: to identify tools and technologies that could potentially help/facilitate the integration of the PROPHESY components within the pilot ecosystem;
2. Specification of Data Assets and Services: to produce specifications for data collection, modelling, analysis and provisioning/sharing mechanisms within and between the PROPHESY components;
3. PROPHESY-CPS Specifications: to produce specifications for the CPS necessary components, i.e. connection to the pilot and integration of legacy systems within the platform, virtualization mechanisms for shop-floor assets to facilitate data collection, analysis and sharing as well as mechanisms to guarantee closed-loop control;
4. PROPHESY-SOE Specifications: to produce the specifications of the service bricks and/or core services (KPIs calculation, cost-benefit analysis, etc.) of the PROPHESY-SOE layer for the purpose of developing PdM solutions by composition;
5. PROPHESY-AR Specifications: to produce specifications for the Augmented Reality and visualization part of the PROPHESY-CPS and PROPHESY-PdM platforms;
6. PROPHESY-PdM Architecture and Ecosystem Specifications: to produce specifications of the PROPHESY-PdM platform and the associated ecosystem.

The PROPHESY-PdM platform is the main focus of the present document.

2.4.2 Specific Requirements for PROPHESY-PdM from the User Stories

As for the PROPHESY-CPS (see Deliverable 2.1), there are generic requirements and features and there are some further requirements – also called specific requirements – that take into account the deployment of the PROPHESY-PdM in a real and relevant industrial environment. In this landscape, the biggest challenge is, for sure, the integration of the PROPHESY-PdM system within the complex demonstrators since all the machines and production lines that are part of them are in daily and industrial use. These specific requirements are classified into IT-Requirements and Production-Requirements.

IT-Requirements:

Both complex demonstrators are integrated into an existing IT infrastructure. It must be ensured, that the ongoing production will not be affected, and that no IT-Security specification will be violated. Therefore, following points must be considered:

- **Integration of availability level, which separates the factory operations from all other IT activities.**
- **An accessibility level, which governs the access to the production data**
- **Firewall protection**
- **Different user administration level**
- **Handling sensitive company data**

Production-Requirements:

Beside the IT-Requirements, also for the production machines there are some necessary requirements, comparable to the PROPHES-CPS requirements. In this case, it is fundamental that

- **The integration, i.e. the deployment and the operation of the PROPHESY-PdM, must be a seamless and non-intrusive task meaning that the normal work and the production activities must continue with or without PROPHESY-PdM;**
- **The PROPHESY-PdM should be integrated within a smaller production unit and/or production environment to prove its reliability as well as feasibility.**

2.5 Progress beyond the State of the Art

The PROPHESY-PdM Platform Architecture and Ecosystem to be implemented as part of the PROPHESY system will go beyond the current state of the art by:

1. Promoting the usage and the integration of assets condition monitoring techniques and algorithms for fault and deterioration detection to support PdM decisions and activities at different granularity levels;
2. Extending and particularizing existing solutions by including new functionalities, principles and technologies – such as new architectural patterns, big data technologies for data extraction, transforming and loading, and real-time processing, etc. – that are necessary for the considered application domain;
3. Evolving the results reached in previous research projects by providing an integrated machine learning toolkit that delivers to the industrial practitioners the possibility to choose between several algorithms from different scientific communities and especially optimized for condition-based maintenance;
4. Providing a scaled-up framework of highly generic and evolvable CPS-populated shop floor to guarantee further deployment of them in different kinds of manufacturing systems (spacing from mass production to additive manufacturing), i.e. including all the necessary infrastructure to ensure the management of highly dynamic CPS-populated systems;
5. Providing a security framework that takes care of both Information Technology (IT) and Operational Technology (OT) subnetworks, i.e. provides particular security strategies when securing IT or OT networks;
6. Applying the concept for delivering the right information for the maintenance employee on the right mobile device and at the right time by natively supporting and promoting the integration of Augmented Reality (AR) techniques and technologies for PdM activities;
7. Delivering highly standard-based CPSs, that are optimized for maintenance activities (e.g algorithms, streaming processors, data persistence and standard connection for AR tools), ready-to-use and easily deployable in the case of both “brown” and “green” field investments.

3 PROPHESY-PdM Platform: Logical View

3.1 Mapping Requirements into the current PROPHESY-PdM Platform

The Table 3 summarizes the mapping between the requirements and or desired features – extracted from the SotA analysis. The proposed table is effort to summarize how the PROPHESY-PdM platform fulfils the generic requirements for PdM platforms. The main result is the logical architecture presented in Figure 14.

Table 3: Mapping Requirements into the PROPHESY-PdM Platform Conceptual Architecture

Features/ Requirements		Fulfilment
Data Availability and Pre-processing	Extract, manipulate, analyse and store data from PROPHESY-CPS	The PROPHESY-PdM platform will be designed around the Extract, Transform, and Load (ETL) process. It will provide all the necessary mechanisms to extract data, pre-process and transform the data and loading the data for further data analysis processing and storage.
Use global available data and services (e.g. Enterprise Resource Planning, quality databases, etc)		The PROPHESY-PdM platform will provide connectors and adapters to enable the extraction of the data from other relevant applications and data stores (legacy systems). The complete list of considered legacy systems and their characteristics have been presented in deliverable D2.4 – Complex Demonstrator Specifications.
Administration	Support for (re-)configuration, P&P and dynamicity of assets (devices/equipment). Management of CPS-populated systems	The PROPHESY-PdM platform will provide the necessary mechanisms to guarantee and facilitate the management of a network of PROPHESY-CPSs. A dedicated management messages/events flow will be implemented for allowing the platform to manage the PROPHESY-CPSs.
	Facilitate the connection and interaction internally and with PROPHESY-CPSs	
	Provide a set of Human Machine Interfaces (HMI) to allow user to manage and monitor the system	Graphical interfaces for PROPHESY system configuration and monitoring
Data Analysis	Support for on-line and off-line data analytics	The PROPHESY-PdM platform will ensure the data processing. It will provide a

	Use the results of the data analytics processes for actively and reactively adapting its behavior at runtime (self-configuration and self-adaptation)	Machine Learning toolkit for data analysis at the platform level. The goal of the low frequency machine learning compared to the one made in the CPS level is to gain knowledge on the fleet level and extract global conclusions of predictive maintenance actions. At the platform level more complex and structured data will be processed and the nature of the decision-making process will be focused on the overall system behavior. Moreover, the PROPHESY-PdM platform will also be responsible for building condition prediction and prognostic reference models (computed from data) that can be used within the PROPHESY-CPSs.
	Condition Prediction and Prognostic reference models	
Modularity and Composability	Service Orientation	The PROPHEYS-PdM platform will be built by following SOA-based patterns and principles. Moreover, it will be designed on the top of the IIC-IIRA data-bus architectural pattern to handle the rising complexity of networked and ubiquitous service-based systems.
	Support for system scalability and hierarchical system organization to enable the development of complex system designs	
Decentralization and distribution of the functionalities provided		The PROPHESY-PdM platform will be designed and developed by following a SOA approach and principles while preferring distribution rather than centralization of functionalities and logic.
Interoperability and Standardization	To use appropriate data models and information structures that represent the manufacturing context	The PROPHESY-PdM platform will built on the top of a well-defined and standardized data model and context representation to facilitate the data exchange and information sharing between all the components of the platform as well as to with the PROPHESY-CPSs. In particular, the PROPHESY-PdM platform will rely on standards (as also presented in deliverable d2.2 – Specification of Data Assets and Services) as the foundation for interoperability between all the components as well as stakeholders of the PROPHESY system.
	Standard compliance	

Security	IT security concepts, architecture, and standards to ensure the integrity and availability of the information	The PROPHESY-PdM platform will provide a secure infrastructure (that is available for both PROPHESY-PdM platform and PROPHESY-CPS) for assuring data protection and integrity, controlled access to the platform, secure communication channels, among others. In this landscape the adoption of standards will play a fundamental role by enabling the PROPHESY-PdM platform to meet the identified requirements.
	Data protection and secure data access	

3.2 PROPHESY-PdM platform Building Blocks: Core Components and Functionalities

3.2.1 PROPHESY-PdM Platform Logical Architecture

The primary capabilities of the PROPHESY-PdM platform are to provide a secure environment in which data are extracted and gathered from distributed PROPHESY-CPSs and properly processed to implement PdM strategies. The principal idea is to determine the current condition of the physical assets in order to predict when maintenance tasks should be performed and/or when production parameters should be adapted to enhance behaviour of the physical assets during their life-cycle. To do that, several software modules and components have been envisioned to allow the extraction/gathering of the data from the physical world, the processing/analysis of the acquired data for maintenance activities improvement and the provisioning of the results of the computation tasks to the user for supporting the decision-making process. These software modules and components represent the PROPHESY-PdM platform and are intended to be strictly integrated with the PROPHESY-CPS to deliver increased processing power and storage capabilities for running advanced machine learning algorithms to implement PdM maintenance strategies. In this landscape the PROPHESY-CPSs provide the foundations for the PROPHESY-PdM platform (as shown in Figure 14).

Focusing on the PROPHESY-PdM platform, the building blocks and/or software modules/components that are part of it are:

- **Machine Learning Model Generator:** provides a set of algorithms, data analysis processes and their execution engine for processing data gathered from the PROPHESY-CPSs and other Enterprise data sources in order to generate maintenance-related machine learning models to be applied/used by the PROPHESY-CPS;
- **Persistence:** provides the necessary repositories and data stores together with the communication API to enable each the other components and applications to securely store/retrieve data in the required format, enterprise, cps and model data repositories are part of the persistence layer;
- **Administration:** combines all the necessary elements that are needed to run and govern a CPS-populated system;

- **Middleware:** provides the basic integration mechanism between the PROPESY-PdM platform and PROPHESY-CPSs – from one side – and – from the other side – between all the components/modules within the PROPEHSY-PdM platform. Due to the presence of the PROPEHSY-CPSs a more generic solution can be provided;
- **Security & Data Protection:** is responsible of ensuring the confidentiality, integrity and the availability of the information in the platform. It is, thus, in charge of overseeing the access control of the platform contents, as well as monitoring interactions that occur between authorized peers.

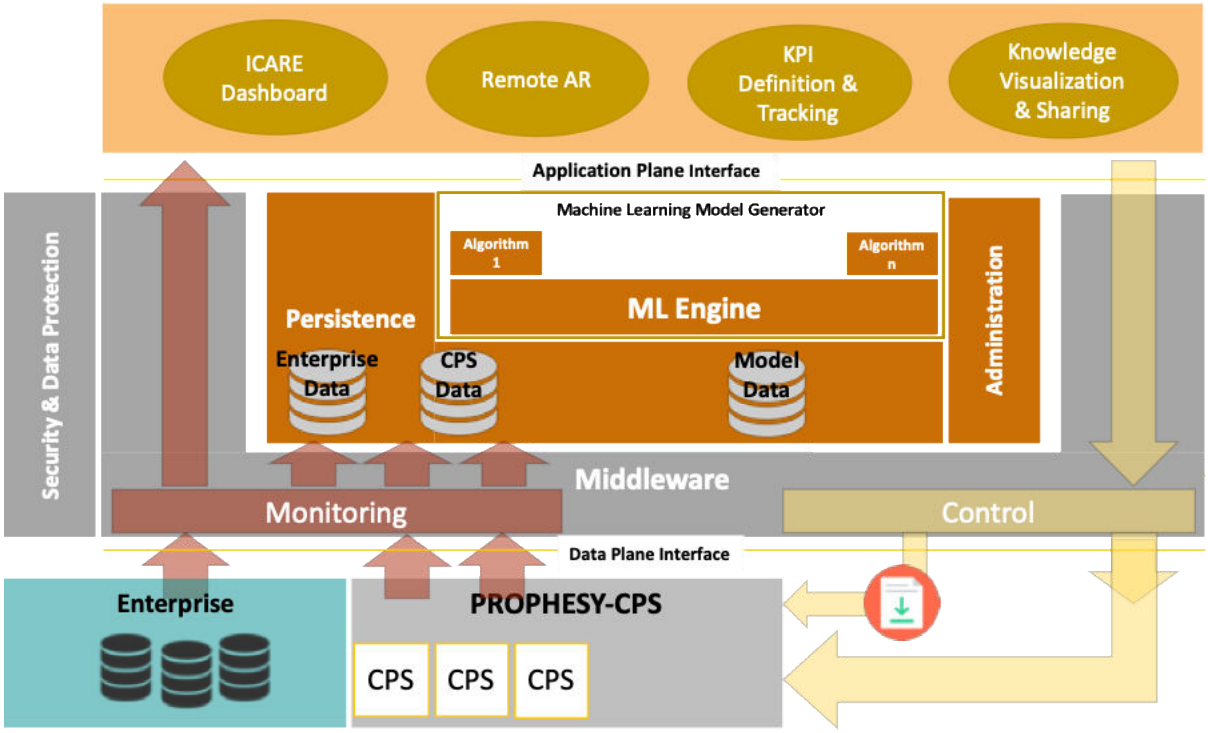

Figure 14: Global PROPHESY Envisioned Architecture – PROPHESY-CPS and PROPHESY-PdM platform

3.2.1.1 Machine Learning Model Generator Overview and Features

Name of component	**Machine Learning Model Generator (aligned with the outcomes of WP4 and in particular of the Tasks 4.3 and Task 4.4 and technical description included in D4.5 – "Data Analytics Techniques for PdM V1")**
Description	The Machine Learning Model Generator component delivers data analytics capabilities to the PROPHESY-PdM platform by delivering a complete ML toolkit that enables the proper design, configuration and deployment of data mining tasks. Therefore, it provides all the necessary mechanisms for processing data provides by the PROPHESY-CPSs (events) as well as extracted by enterprises legacy systems (data stores) in order to generate maintenance-related machine learning models to be applied at

	the PROPHESY-CPS and that may require the use of significant computing resources and computational power.
Features	**Functional Properties**: • Publish/Subscribe interfaces and technologies • Application of Analytics Algorithms on Streaming Data, including machine learning algorithms. • Interfacing to a message bus structure towards writing the results of its processing as new data streams. • Processing structured data organized according to the PROPHESY data model (PROPHESY-DM). • High level decision-making process support.
Need for semantics	The data model presented in deliverable D3.3 – Digital Modelling and Interoperability and deliverable D2.1 – PROPHESY-CPS Specifications.
Online or offline mode	The component is specified to support online mode
Expected input	Data (provided by PROPHESY-CPSs as well as other enterprise data sources) from the Persistence layer.
Interaction	The following interaction • Publish-Subscribe pattern • Request-reply pattern to acquire selected datasets in some scenarios.
Interfaces	The component needs to be interfaced with: • Data Stores; • PROPHESY-CPS
Foreseen constraints	N/A
Software requirements	N/A

3.2.1.2 Persistence Overview and Features

Name of component	**Persistence (aligned with the outcomes of WP3 and in particular of the Tasks 3.1 and technical description included in D3.1 – "PROPHESY-CPS Detailed Architecture V1")**
Description	The Persistence component delivers the facilities for storing/persisting all the information needed and/or generated during the platform operational phase. Relevant information such as the data collected from PROPHESY-CPSs and/or the results of the data processing tasks can be stored and retrieved by using such component. It assures that all the data is stored and accessed by using the underlining protocols of the repository along with the necessary security mechanisms.
Features	The Persistence component has the following features: • Store all the necessary configuration data for the

	PROPHESY-PdM platform and its own internal components; • Store all the necessary management data to allow the proper functioning of the PROPHESY-CPS level; • Store all the data collected/extracted from the PROPHESY-CPSs. In particular, all process raw data (positions, torque, vibration, etc.) must be stored within the needed sample rate. Furthermore, there must be solutions for gathering data from different devices, pre-process data to extract just the key information, covert binary data to a standard format; • Store the results of the global data processing performed by the Low Frequency Machine Learning; • Provide access to all the previous stored data to external users in the application plane.
Need for semantics	The data model presented in deliverable D3.3 – Digital Modelling and Interoperability and deliverable D2.1 – PROPHESY-CPS Specifications.
Online or offline mode	The component is specified to support offline mode, online mode is not required
Expected input	• New configurations from the Middleware (management channel) for the internal components of the platform; • Data from the Middleware (data channel). In particular data from the PROPHESY-CPSs together with the related description; • Management data to manage the PROPHESY-CPS level; • Processed data from the Low Frequency Machine Learning component; and • Decisions from the several applications within the application plane.
Interaction	The component implements a request/reply message exchange pattern. It exposes a set of services/operations for the other components of the platform communicate with it. It will also provide a publish/subscribe communication channel to enable the connection and the integration with both the PROPHESY-CPSs level and the application plane.
Interfaces	The component needs to be interfaced with: • Low Frequency Machine Learning; • Middleware;
Foreseen constraints	Depending on the signal configuration and number of machines and – thus – on the system topology, the memory requirement for the data to be stored can be very large.
Software requirements	N/A

3.2.1.3 Administrative Overview and Features

Name of component	Management
Description	The administrative component provides the necessary mechanisms to run and operate a CPS-populated system. It spans all the other components of the platform and is capable to react during the operational phase to any changes in the PROPHESY-CPS, i.e. adding/removing/updating PROPHESY-CPSs. Some practical examples of the goals of the component are: • Management of the PROPHESY-CPS registration and discovery inside the PROPHESY PdM system; • Describing/Configuring the rules attached to the usage of a certain PROPHESY-CPS.
Features	The administrative component has the following features and functional properties: • Discover PROPHESY-CPSs and related exposed data; • Register/Unregister PROPHESY-CPS to the platform; • PROPHESY-CPS Service registry; • Support the configuration of the platform components; • Allow the creation of PdM processes.
Need for semantics	The data model presented in deliverable D3.3 – Digital Modelling and Interoperability and deliverable D2.1 – PROPHESY-CPS Specifications.
Online or offline mode	The component is specified to support online mode
Expected input	• Data/Events from PROPHESY-CPSs for managing CPS-populated system; • Data representing specific views of the registered PROPHESY-CPS; • Configured PdM Processes; • Configuration for the internal platform components.
Interaction	The administrative component will rely on the Middleware component to implement/support event/message-based communication patterns. It will also provide request/reply communication channels to enable the user to interact with it.
Interfaces	The component needs to be interfaced with: • Middleware.
Foreseen constraints	N/A
Software requirements	N/A

3.2.1.4 Middleware Overview and Features

Name of component	**Middleware (aligned with the outcomes of WP3 and in particular of the Tasks 3.4 and technical description included in D3.7 – "PROPHESY-CPS Middleware Infrastructure V1")**
Description	The Middleware component delivers the basic mechanism for the integration of all the components within the PROPHESY-PdM platform as well as between the PROPHESY-PdM platform and the PROPHESY-CPSs. Therefore, it provides interoperability services to enable the connection of the PROPHESY-CPS to the platform (communication protocol and standard data models) and the information flow without direct coupling the producer and the consumer of the information.
Features	This functional component tackles all the needs for integration between all the platform components as well as between the platform and the PROPHESY-CPSs. It provides two types of communication channels, namely: • Management channel/flow; • Data channel/flow.
Need for semantics	No need for semantic since it provides the communication infrastructure and mechanisms
Online or offline mode	N/A
Expected input	N/A
Interaction	N/A
Interfaces	Based on the specific technology used for the middleware client to interact with it will be provided.
Foreseen constraints	N/A
Software requirements	Analysis of the possible technologies to be used for the implementation of the component by taking into account the needs of the interacting components.

3.2.1.5 Security and Data Protection Overview and Features

Name of component	**IoT anomaly detection system (aligned with the outcomes of WP3 and in particular of the Tasks 3.6 and technical description included in D3.11 – "Security, Trustworthiness and Data Protection Framework V1")**
Description	The anomaly detection system is responsible of auditing the communications between peers within the platform to detect information integrity and veracity breaches. Data inconsistencies can lead to taking incorrect decisions as they are not based on the actual state of the process.
Features	The IoT anomaly detection system monitors incoming

	connections from the field and detects the following anomalies: • Anomalous data readings 1. Anomalous connection features, such as, increased jitter and/or latency or downed host.
Need for semantics	N/A
Online or offline mode	The component is specified to support online mode
Expected input	N/A
Interaction	Manages the interactions between the platform and the PROPHESY.
Interfaces	N/A
Foreseen constraints	N/A
Software requirements	Current version is built on top of Apache Nifi and Apache Spark.

Name of component	**Cyphertext-Policy Attribute-based-encryption for Access Control system (aligned with the outcomes of WP3 and in particular of the Tasks 3.6 and technical description included in D3.11 – "Security, Trustworthiness and Data Protection Framework V1")**
Description	Access Control allows to apply restrictive policies on data access and usage. Due to the confidential nature of the data managed by PROPHESY-PdM, it is paramount to restrict access only to the authorized parties to prevent incorrect data usage such as leaks.
Features	Ciphertext-Policy Attribute-based-encryption allows efficient fine grained access control by: • Identifying users or data consumers with a set of arbitrary attributes • Data is encrypted and only decrypted and made accessible to users with the correct attribute. Data remains encrypted for other users, as well as external attackers. • The system is scalable and adapts well in distributed filesystems.
Need for semantics	N/A
Online or offline mode	The component is specified to support online mode
Expected input	N/A
Interaction	The system interacts with the storage system within the PdM
Interfaces	N/A
Foreseen constraints	N/A
Software requirements	Current version is built on top of Hadoop File System.

4 PROPHESY-PdM Platform: Process View

The communication between PROPHESY-CPS and PROPHESY PdM platform ensures the data flow, i.e. data and control commands, between the platform and CPS layers. Inspired by the IIC-IIRA, the PROPHESY-PdM platform manages information and operations domains. The latter represents the collection of the functions and – thus – flow of data (management flow) responsible for the management and monitoring of the CPS layer. The former represents the collection of functions and – thus – flow of data (information flow) responsible for gathering data from the CPS layer while transforming, persisting, modelling and analyzing those data to get better and/or new knowledge from about the overall system. By taking into account the this, two main flows of data are envisioned, namely:

a) Operations flow: e.g. register/unregister PROPHESY-CPSs, monitoring PROPHESY-CPS status, etc.;
b) Information flow: is a bi-directional channel used to:
    a. ingesting data streams produced from the PROPHESY-CPS about the underlying physical assets. This involves:
        i. data persistence and storage; and
        ii. data distribution.
    b. send configuration/control commands (e.g. learning models, etc.) to the registered PROPHESY-CPSs;

The first category is used for the connection of PROPHESY-CPSs to the PDM platform system and achieved through a management interface. This interface uses the request – reply communication pattern and is exposed through a SEI providing the necessary methods. The next two categories ensure the exchange of data and control commands between PROPHESY-PdM platform and the PROPHESY-CPS. The selected message exchange pattern for this communication is an event/message-based communication where events and/or messages are exchanged between the PROPHESY-CPS and the PROPHESY-PdM platform and supported by a selected middleware technology.

4.1.1 Request-Reply Communication

PROPHESY - PDM API	Description
CPS Management	This interface is used by the PROPHESY-CPS in order to register / un-register to the PROPHESY-PdM platform. Also, this interface provides a mechanism to the CPSs to announce their functionality (discoverability to platform components). The specific structure and format of the data provided is still under discussion/investigation.

4.1.2 Event/Message-based Communication

PROPHESY - PDM API	Description
Configuration	The configuration API is used for sending configuration commands (for example a new ML configuration) to the registered PROPHESY CPSs. These configuration commands are presented as events.
Data Streaming interface	This interface is used by PROPHESY-PDM for receiving streamed data which come from a PROPHESY CPS. These data are presented as events/messages and are published by the PROPHESY-CPS during the runtime according to its internal configuration and internal status. The structure and format of the sensing data events/messages are still under discussion/investigation.

4.2 Internal Interfaces

Based on the logical architecture of section 3.2.1 (Figure 14) the main components of PROPHESY-PdM platform are:

- **Machine Learning Model Generator** which provides a set of algorithms, data analysis processes and their execution engine.
- **Persistence** which provides the necessary repositories and data stores.
- **Administration** which combines all the necessary elements that are needed to run and govern a CPS-populated system;
- **Middleware** which provides the basic integration mechanism between the PROPESY-PdM platform and PROPHESY-CPSs – from one side – and – from the other side – between all the components/modules within the PROPEHSY-PdM platform.

From a process view, the components of the PROPHESY-PdM platform, support the following processes:

- Data store
- Administration
- Data Streaming

Data store is used for storing/updating/retrieving data to or from persistence. To perform these actions, two interfaces are used: a) a request - reply (Data store rest API) which is used to store data or retrieve data and b) an event driven (Data store event/message) which is used to store data streams come from CPSs. These interfaces can be added over the persistence layer and can be consumed by other components, such as ML, middleware, administration component. Also, it can be used from PROPHESY-AR components.

Administration processes are focused on the administration of internal components such as data flows configuration or ML configuration. These processes are triggered by Administration component through:

a) a request-reply interface (Data streaming management API) for configuring internal data flows between middleware and other components acting as consumers; and
b) a request-reply interface for the ML configuration (ML configuration).

Finally, Data streaming processes support a) streams between platform components and b) a mechanism for delivering configuration commands to CPSs. Both of these uses a common event-based interface (Data stream and command event/ message).

4.2.1 Request-Reply Communication

PROPHESY - PDM API	Description
Data store Rest API	This interface is used for manipulating (store, update, retrieve) data to the persistence component. This interface can be used from any component in the PROPHESY-PdM platform in order to have access to the stored data. The structure and the format of these data will be based on the model presented in the deliverable D3.3.
Data Streaming Management API	This interface manipulates data flows (create, update, delete). Data flows are responsible for delivering data streams or configuration commands from the producers to the consumers. Producers or consumers can be platform components or CPSs. This interface is used from administration component.
ML configuration	This interface is responsible for the ML Engine configuration. It is responsible for receiving configuration commands and deploying machine learning tasks.

4.2.2 Event/Message-based Communication

PROPHESY – PDM API	Description
Data store event/message	This interface is used for manipulating (store, update, retrieve) data streams to the persistence component. These data streams are a) produced from HF-ML or b) received by CPSs. The structure and the format of these data will be based on the model presented in the deliverable D3.3.
Data stream and command event messaging	The “Data stream and command event messaging” is used for manipulating and routing two types of streams a) data streams produced by CPSs and LF-ML and b) configuration commands and events which are used by administration component. These commands are used for the interaction with CPS.

5 PROPHESY-PdM Platform: Data View

In PROPHESY, digital models have already been defined and specified in deliverable D3.3 – Digital Modelling and Interoperability. As a matter of fact, in D3.3 an whole interoperability infrastructure has been defined and specified according – from one side – to the data integration and interoperability requirements of the PROPEHSY project, and – from the other side – to the technologies deployed in the considered production environment. Furthermore, data interoperability and integration problem has also been handled within the deliverable D2.1 – PROPHESY-CPS specifications, where the concept of the Administration Shell has been deeply studied and introduced to facilitate the finding, accessing and interpreting vendor specific as well as run-time data of physical assets. As a matter of fact, the Administration Shell is the Industry 4.0 answer to unite all the data generated by physical assets during their lifecycle. In this context, since the PROPHESY-PdM platform is set upon the PROPHESY-CPSs layer, all its internal components and sub-components will be specified to adhere to the PROPHESY-DM and PROPHESY-CPS data specifications.

6 PROPHESY-PdM Platform: Ecosystem

6.1 The MSP Structure

The following numbered subsections, map to the analytical structure schema of the Multisided Platform that is the basis that will host the PROPHESY ecosystem. Conversely, when viewed as an ecosystem portal, the very same structure serves as a provision of the site-map i.e. the backbone of all content offered to supply and demand side stake holders, organized in tree-like entities. In a simplified view, one could envision each of the following numbered sections as levels of cascading menus and submenus within the ecosystem portal. It should be noted that the MSP portal that will host the ecosystem is currently being built and is at beta stage already. The sections below are the specifications upon which it is being built and enhanced with content.

The following sections adhere fully to, and also build upon, all the "Ecosystem Platform Features" presented as a table in the previous version of the current deliverable (D2.5, chapter 6.2). Moreover, they take into account the developments of work performed on Service Bricks (i.e. WP6 D6.1) and PdM Solutions (i.e WP3, WP4 and WP5). Finally, the intention is to showcase all the tools developed within the WP6 tasks, and especially focus on the PdM calculators being developed, as well as the PROPHSEY SOE. An effort has been made to encompass as much content as possible -both from the PROPHESY project progress- as well as related work of affiliated entities of the ecosystem. Hence the schema is intentionally broad in order to accommodate all such diverse content entries and make sure that a proper ecosystem can be sustained through its structure.
It should be stressed that the PdM ecosystem -being an MSP- strategically differs from the PROPHESY portal (prophesy.eu) in the sense that this is a much broader offering, far beyond the project's scope, envisioning to create an entire ecosystem of PdM related knowledge and stakeholders the will perform supply and demand of content, knowledge, services and solutions.

6.2 PdM Services

Services are presented bearing in mind the notion of service bricks which is the cornerstone of further aggregations (tools, augmented services, solutions etc.) as defined in the strict taxonomy of D6.1. Moreover, we note augmented services i.e. focused consulting and training on PdM, i4.0 and Maintenance, CPS systems and all business aspects related to them from KPIs to cost benefit and ROI Analysis. As a final comment, the tools being implemented for that scope (although being themselves services callable by potential portal visitors and available to the ecosystem community) have been categorized under the "solutions" section in their own sub-section, since one can view them as autonomous offerings (solutions) to the PdM community.

Services include the following sub-menus:

6.2.1 Service Bricks

6.2.1.1 The complete service Brick and Connector List

As analyzed in the relevant deliverable 6.1 appendices, fully depicted as tables with all their properties, for reference reasons.

6.2.1.2 Selected indicative Service Bricks (one per section)

It is true that some service bricks have a wider nature and can better depict the work of PROPHESY and the additions of the consortium to the PdM community by showcasing substantial added value. In that sense, on the sub menu there will be independent entries of the following:

Table 4: Service Brick devoted pages

Complete SB	Leader of Content in the ecosystem
Sensors Systems	ICARE
Data Collection	ICARE, MMS, MAG
Digital Modelling	AIT
Maintenance Data Analytics	AIT, MONTRAGON, TUE
Augmented Reality	OCULAVIS
MANTIS Solutions	MONTRAGON

Each of them will have a whole page devoted in the form of tabs that will fully present the SBs, their impact, potential target groups, ways of access to them as well as relevant contact persons for them specifically, following the paradigm of other successful ecosystems (example edge4industry.eu)

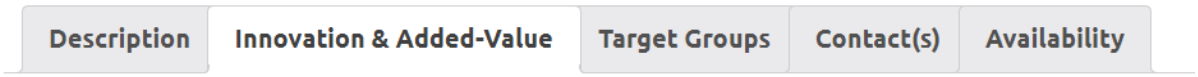

Figure 15: Service Brick Tabs of information

Obviously, the structure proposed is easily expandable, if more service bricks are deemed indicative and important to be included as the project progresses.

6.2.2 Augmented PdM Services

These services offered initially by project partners, but envisioned to also be enhanced by other active ecosystem members in the future in their respective fields of expertise are expected to be:

6.2.2.1 PdM and IoT Developers' support services

Developers joining the project's platform will be offered with access to APIs and annotations

6.2.2.2 Technical support

In the same context, articles in the knowledgebase will focus on technical aspects of PdM deployments based on the PROPHESY paradigm

6.2.2.3 Machine Learning & AI for Maintenance

The knowledgebase will also include specialized articles of experts on ML and AI for PdM.

6.2.2.4 Predictive Maintenance Business Models

At the present time, 3 business models are being examined closely, and their outcome both in scientific articles as well as tangible quantitative data will be placed in this section.

It should be noted that all such training and consulting services will have their accompanying content published under the knowledgebase section of the ecosystem. All, these services will be offered in the form of complementary (augmented) added value services (beyond the content exhibited within the ecosystem), through contacting the relevant key-persons of partners.

6.2.3 Service Search

Search and discovery of service offerings i.e. Search engine for discovering available services based on appropriate metadata for the services descriptions.

6.3 PdM Solutions

In plain terms, solutions are showcases of what the joint effort of PROPHESY development can achieve within the PdM ecosystem realm. Moreover, it has been decided for them to include the sub section of stand-alone tools and calculators, since they can be independently called by the ecosystem members and all external stakeholders, both for evaluation as well as independent use. Their stand-alone nature makes them -in a sense- independent offered solution by PROPHESY and the ecosystem as a whole. Hence solutions will include the following sub-categories:

6.3.1 Showcases and Applications

We will at first include the tangible PROPHESY use cases at hand, with the strong intention to also present many more tangible use cases and applications from affiliated partners and other ecosystem members, in order to enhance the impact of the PdM ecosystem. Being an MSP, it is crucial to build both critical mass as well as relevant content focused on interesting applied cases of the predictive maintenance industry 4.0 world, accompanied by indicative multimedia.

6.3.1.1 PROPHESY MVP Demo

This will be the first project demonstrator as it is prepared for M18.

6.3.1.2 PROPHESY at PHILIPS

The full deployment of PROPHESY at PHILIPS Drachten

6.3.1.3 PROPHESY at JLR

The full deployment of PROPHESY at Jaguar Land Rover Wolverhampton

Note: Multimedia, presentations and relevant texts will be combined in each subpage. Links to cost benefit, calculations and KPIs of each showcase and application (when available) will be provided in conjunction with the next section.

6.3.2 Tools

The main benefit of posting tools in the ecosystem is the ability for stakeholders to use, evaluate and consider the use of the KPI Calculator tool, the Cost-Benefit Tools and The Solution Composition tool, the PROPHESY SOE, the ML algorithms etc. (As described in D6.3) for general evaluation in PdM cases. We expect to present:

6.3.2.1 ML Simulation Tools

Simulation as a Service, or for instance an API to use the PROPHESY ML, and all Analytics and Machine learning algorithms, for an external stakeholder to be able to assess their functionality and consider building solutions with them

6.3.2.2 PdM Specific Calculators

These are a cornerstone of several linked deliverables of PROPHESY, but also an independent and invaluable tool for any interested 3rd party stakeholder, being able to provide clear business insights with tangible calculations and quantitative data.
Calculators will be built both in:

I. Downloadable locked Excel (.xls) files / spreadsheets
II. Calculator webforms accessible to registered members.

So far, we plan for the following calculators to be included:

- CALC 1 (investment)
  - Investment Analyzer (IRR, MIRR, ROI, NPV, Payback, comparison)
- CALC 2 (cost)
  - PdM cost optimizer, CM to PM comparison
  - Replacement asset value, Cost, TMC, savings
- CALC 3 (efficiency)
  - OEE, % Asset Utilization, % uptime vs downtime etc
- CALC 4 (comparison)
  - RUL before vs RUL after
  - Breakdown and cost before vs after
  - KPIs to Benefit (money).
  - Example: how does improving RUL by 1000 strokes translate into savings?
- CALC 5 (Cost Breakdown Analysis)
  - Calculate Cost of PDM Deployment (Total Cost of Ownership)

6.3.2.3 PdM Specific KPI selector

Based on the work devised within D6.1 this is an invaluable tool extending beyond PROPHESY and applicable to many general PdM cases. Alternatively, this table can be merged within the business consulting on PdM as described in the relevant section.

6.3.2.4 The PROPHESY SOE

A dedicated page on the presentation of the concepts and the usage of the PROPHESY Service Optimization Engine.

6.4 PdM Community

6.4.1 Forum

Intrinsically a meeting point of ecosystem members, and hence this is considered to be the cornerstone of ecosystem critical mass building. It is expected to include:

I. Comment feature – in order to increase user engagement.
II. Comments on all solutions, services, tools, calculators, articles, knowledgebase and sub-entities (hence being the first form of supply side feedback on the PdM ecosystem effort)
III. Search bar – (metadata will be useful on categorizing).
IV. Sidebar – show latest or most popular blog posts, call-to-action, or related posts.
V. Social Media Share – allow users to easily share articles and general content.
VI. Review and rating of service offerings (Tools for rating service offerings from the end-users / participants viewpoints)

6.4.2 Affiliations

At first links with explanatory short text on the following (at least) are expected:

I. PROASENSE
II. MANTIS
III. ARROWHEAD
IV. GOODMAN
V. EPES
VI. PROSECO
VII. KAP
VIII. CREMA
IX. Self-Learning
X. POWER-OM
XI. FAR-EDGE
XII. Iot-Catalogue
XIII. Intrasoft Exploitation Sandbox
XIV. FoF-09 Cluster

All affiliations will be presented in a table including:

i. Logo
ii. Link
iii. Short Description
iv. Members affiliated and registered to the PROPHESY ecosystem (assuming privacy issues addressed of course)

6.4.3 News

It is quite obvious and self-explanatory that this will include the following subsections:

I. Ecosystem news
II. industry news,
III. PdM News
IV. Advice and Scientific posts,
V. client and ecosystem member stories

6.4.3.1 Blog

Posting among others articles not only restricted on PROPHESY but on all PdM activities of the registered ecosystem partners, affiliates and programs/projects. A close collaboration with dissemination activities of WP8 is expected at the first stages until the ecosystem builds its own critical mass.

6.4.3.2 Newsletter

As produced bi-monthly (initially being part of the dissemination tasks of WP8), probably augmented in some cases with news of the ecosystem community activities. Newsletter Signup module is crucial and will also be placed on the footer for easy access, as many visitors won't be ready to engage, but they will be offered the opportunity to subscribe and consequently sign up later or keep in touch. Email capture is a critical element for every MSP especially when building communities that target a critical mass!

6.5 PdM Knowledgebase

Information Services including articles, presentations, News, Blog etc. On-line training and education services in the form of self-contained presentations. We expect focus on:

- Machine Learning & AI for Maintenance
- Predictive Maintenance Business Models
- Technical Support
- Business Decision Support on PdM
- Cost-Benefit evaluations and ROI analyses
- KPI selection criteria
- Developer support
- Service Bricks
- Solution Composition

The knowledgebase will include sections with relevant material such as:

6.5.1 Articles

Including Whitepapers, publications, general content based on PROPHESY deliverables etc.

6.5.2 Presentations

The same content concise as basis for training and marketing purposes

6.5.3 Multimedia

Mainly Videos and Images

6.5.4 Training

All the training material will be based on the re-purposing and modification of the above articles, presentations and videos of the knowledgebase.

6.5.5 Libraries

Middleware libraries for PdM and open APIs for accessing the libraries including accompanying documentation

6.6 User Section

This is the typical section devoted to the attributes of the specific logged on user within the ecosystem, with content curated on specific interests, as well as administrative issues of the user account. Hence it includes the following sections (although not necessarily being structured as a site-map tree since these are quite independent functions that can be implemented within a different "top menu"). Typically, this is implemented on the upper right corner as common practice in most MSP Portals.

6.6.1 Login / Single sign-on

Registering Participants & Business Entities, as well as Authentication and Authorization, including:

I. Facebook, Google and LinkedIn fast one click registration which has been proven to be more friendly and less time consuming than usual registration forms
II. First time registration
III. Account deletion / cancellation (according to GDPR demands)
IV. User authentication, etc.
V. Captcha / Anti-Spam (definitely)

6.6.2 User Account / Profile

Including forms for user to perform typical account tasks such as :

I. E-mail change keeping same account name
II. Password change
III. Personal info change (option to remain anonymous)
IV. Contact preferences (whether ecosystem admins or other users are allowed to contact or even see – edit content)
V. Content preferences (out of which curated content can be provided based on sections the user selects as most interesting)
VI. Other typical account and privacy settings

6.6.3 Localization and Language selection

At the time, launch (currently in beta) is in English, yet gif flags for language selection have reserved space on the upper right corner as i18n is part of the ecosystem specs.

6.6.4 Provision of recommendations

User specific, context aware proposition of relative service offerings based on profile and preferences mentioned above.

6.7 Home Section

Likewise, this is a non "site-map" structured tree of content, yet a typical upper left corner entity, as common in most such ecosystems hosted by multisided platform portals. Hence it is expected to include

6.7.1 Main Home Layout

6.7.1.1 Page Header:

I. **Domain name** – (Reserved edge4industry.eu).
II. **Logo** – TBD for the ecosystem, different than PROPHESY logo as this refers to the entire PdM ecosystem being produced.
III. **TagLine** – a concise description of what the ecosystem does (max 8-10 words).
IV. **Phone Number** – a clickable phone number (skype of admin now for beta launch only).
V. **Call-to-Action** – tell visitors what you would like them to do.
VI. **Top Navigation** – discreet options to find the top pages on your site (fully described in the above sections as a sitemap guide).
VII. **Bread Crumb Navigation** – help visitors navigate hierarchically. Assisted through 3 level site menus.

6.7.1.2 Above the Fold:

I. **Image or Slider** – visually display unique selling points and differentiators at first based on Usecases multimedia.
II. **Reviews and Testimonials** – short scrolling text box with possible testimonials of external to PROPHESY, ecosystem members who have used the MSP offered services and are in a position to evaluate its offered solutions and knowledgebase.
III. **Youtube Video frame box**: Video as opposed to images is known to be even better to build trust with visitors.
IV. **Other Important Information** – To be defined based on visitor statistics. Probably news of new platform launches that deserve to be showcased as first page.

6.7.1.3 Below the Fold:

I. **Curated Content** – Curated content based on the logged member, your unique selling proposition described for visitors and search.
II. **Main Features** – of solutions and services as well as the knowledge base (covered in the relevant entities above).
III. **Search Bar** – Free text search of ecosystem portal
IV. **Login / User Sign on** – See relevant section above
V. **Language Selection** – Self-explanatory. See relevant section above
VI. **Internal Links** – to your website's inner pages. (optional only if specific pages are found to be common landing pages of many visitors)

6.7.1.4 Footer:

I. **Navigation** – Optional secondary navigation to common pages.
II. **Social Media** – assist people in getting to know the ecosystem via social channels.
III. **Online Chat Feature** – (optional) instant communication while the visitor is researching.

IV. **Contact Information** – Self-explanatory. Links to relevant section.

6.7.2 Contact

Leading to the:

- Portal Admin
- MSP contact person on GDPR (DPO)
- PROPHESY Program Office
- (PROPHESY dissemination and exploitation members can be separate links if needed)

All other affiliated projects and initiatives will instead be contacted through the community/affiliations sub-section for reasons of simplicity

6.7.3 FAQ

Self-Explanatory. Formatted as a drop-down html list.

6.7.4 About

Mainly explaining the purpose of the initiative as a vision of an extension of PROPHESY into a wider PdM Ecosystem with a reference to all affiliates registered (see community section) both for honorary as well as for practical reasons.

6.7.5 Legal and GDPR disclaimers

A specific text has already been devised on the subject. Extra care should be taken when taking into account liability issues stemming from the contractual agreement of the project as well as conflicting interests among PROPHESY partners with other affiliated projects, platforms and initiatives.

6.8 Technical Specifications of the MSP development

Although these belong more in the web development implementation realm, it is worth noting that the PROPHESY Multi-sided Platform that will be hosting the Ecosystem, is being developed in order to adhere to all best-known practices of modern high traffic portals as follows:

I. W3C Web Accessibility Initiative (WAI),
II. I18n,
III. SSL certificate,
IV. Social Media Integration,
V. Mobile and Responsive versions,
VI. Hamburger menu on mobile site
VII. User personalization of UX/UI,
VIII. User personalization on curated and proposed content,
IX. GDPR, Privacy, Legal sections (and visitor as well as member approval)
X. A world renowned and easily maintainable CMS by multiple partner parties.
XI. Backend with Admin Dashboards and stats,
XII. WYSIWIG editor for non-tech savvy members submitting content on the CMS
XIII. Contrasting color theme with corporate orientation
XIV. Spell checker – (ex. Grammarly)

XV. Optimized code for fast page loading (typical)
XVI. Search Engine Optimization (typical)
XVII. Title and meta description updates
XVIII. Automatic sitemap creation – and submission to common webmaster tools.
XIX. Easy to update URL structure – (short, concise URLs that aren't using querystrings and numbers are easier to share and more attractive to click on).
XX. Reliable Server and Hosting:
XXI. Automatic website backup feature
XXII. Cross-browser compatibility
XXIII. Google Search Console integration
XXIV. Google Analytics Integration – (even better Google Tag Manager integration with Google Analytics configured.)
XXV. Microformats – Schema.org tagging for Google to read, Twitter card data for twitter, and Open Graph tagging for Facebook, to enhance visibility when the ecosystem portal is shared or found on search and social media.
XXVI. Site Caching
XXVII. CDN – Since Content Delivery Networks will speed up the MSP considerably.
XXVIII. No Local videos. (Usage of video hosting service, as opposed to loading videos on local server)
XXIX. No background music.
XXX. No Flash
XXXI. No Click to Enter pages (unless there are legal restrictions)
XXXII. Robots.txt – (i.e. Let the search engines know what they can and can't index, and where to find sitemap)
XXXIII. Landing Pages –Destination pages for each motivated visitor who has clicked a call-to-action is critical to conversion success.
XXXIV. Podcasts – Podcasting continues to drive results with communities. Efforts like the PdM ecosystem can target leads for interviews, capture testimonials from clients and members, educate visitors, and build authority in the specific industry.
XXXV. Google Map Registration (for all partners and affiliations)
XXXVI. Logo Bar – A logo bar is critical so prospects can see who else the ecosystem is working with. An image rotator widget can be useful for this very reason.
XXXVII. Premium Resources – (infographics, white papers, and case studies)
XXXVIII. Mobile Standards – Facebook Instant Articles, Apple News, and Google Accelerated Mobile Pages, which are new, integrated content standards.

6.9 Ecosystem Scope and Overview

6.9.1 Reasons for a Multi-Sided Platform hosting a PdM Ecosystem

It is envisioned that the integrated ecosystem will be able to expand much beyond PROPHESY and address the general PdM community. To this scope it will attempt to provide solutions, services, evaluation of produced service bricks, access to simulation and what-if-analysis, together with PdM augmented business consulting, technical assistance and/or training services, on top of other PdM related information to various types of stakeholders. The services of the PROPHESY ecosystem can be offered in the scope of "multisided

platforms" (MSP) which in principle enable direct interactions among stakeholders or participant groups.

The scope of the Ecosystem includes:

- An integrated platform to present the end results of PROPHESY in a coherent manner but to also encompass relevant and affiliated efforts of 3rd party stakeholders.
- A generic and modular MSP or even marketplace-like platform, including all the assets, services, service bricks, other building blocks (as described in WP6) of the project.
- To build an extensive multi-stakeholder community around it, that will assist in the dissemination and sustainability of PROPHESY and PdM knowledge in general.
- To attract a significant number of participants (**critical mass**) to its ecosystem and through this to increase the value offered to manufacturers, PdM solution integrators and other stakeholders.
- To provide a liaison point for similar initiatives with well-established related platforms existing communities and ecosystems, starting from communities where the partners are actively involved and to any similar ecosystems of the partners' such as research and commercial i4.0 and PdM platforms
- The ecosystem should be a "presentation hub" while at the same time facilitating the sustainability, enhancement and improvement of the PROPHESY services following the end of the project's lifetime. The PROPHESY services and the ecosystem around them can become the core of the project's exploitation strategy

6.9.2 Envisioned Impact

6.9.2.1 Critical Mass

It is generally accepted that the size of community is the predominant metric for sustainability. In order to increase exposure, PROPHESY will try to liaise with business partners of the consortium partners, will try to offer its PdM services to existing already established communities and ecosystems, starting from communities where the partners' are actively involved and to the IoT ecosystems of the partners' commercial platforms. These are mentioned in detail within "affiliations" section of the Ecosystem.

6.9.2.2 External stake holders

The ecosystem should become a meeting place for developers, ML specialists, Maintenance Consultants, PdM decision makers, relevant service providers, PdM and Industrial IoT services developers, I4.0 solutions integrators, OEMs and other related stakeholders. Moreover, this ecosystem will enable stakeholders to benefit from the services of the project, learn about them and evaluate them.

6.9.2.3 PROPHESY Partners

- The ecosystem should constitute a focal point of gathering results, innovations, services, and an extensive knowledgebase.

- Other (similar or affiliated) PdM applications and deployments by external supply-side stakeholders or by related projects and ecosystems can feature many cross-platform and cross-vertical interactions. Through stakeholder interaction and even evaluation of offered services by external stakeholders, the process should enable partners to constantly improve PROPHESY tools and services features.

Moreover, following the establishment of an ecosystem around the project's results, the project will pursue a number of exploitation (or even consider monetization) modalities that would allow the consortium to sustain and gradually expand the scope of the ecosystem as these will be analyzed in Task 8.3

7 References

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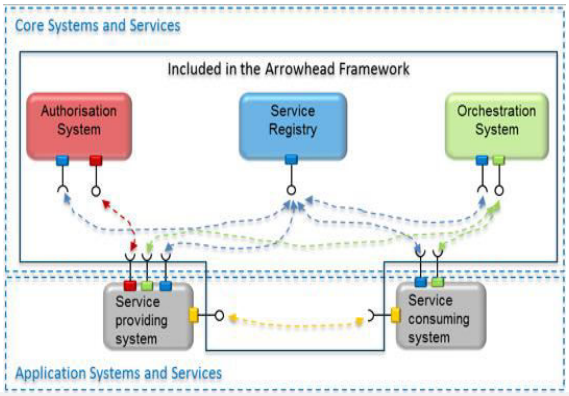
[2] P. B. Kruchten, "The 4+1 View Model of architecture," *IEEE Softw.*, vol. 12, no. 6, pp. 42–50, Nov. 1995.
[3] N. Rozanski and E. Woods, *Software Systems Architecture: Working with Stakeholders Using Viewpoints and Perspectives*. Addison-Wesley, 2012.
[4] M. A. Cusumano and A. Gawer, "The Elements of Platform Leadership," *MIT Sloan Manag. Rev.*, vol. 43, no. 3, pp. 51–58, 2002.
[5] S. Jansen, A. Finkelstein, and S. Brinkkemper, "A sense of community: A research agenda for software ecosystems," in *2009 31st International Conference on Software Engineering - Companion Volume*, 2009, pp. 187–190.
[6] B. Otto *et al.*, "Industrial Data Space - Digital Sovereignity over Data." Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e.V. Hansastr. 27 c 80686 München, Germany, 2016.
[7] UC Berkeley EECS Dept, "Cyber-Physical Systems," *Ptolemy Project - Heterogeneous, modeling and design*, 2012. [Online]. Available: https://ptolemy.berkeley.edu/projects/cps/. [Accessed: 06-Jun-2018].
[8] ZVEI, "The Reference Architectural Model RAMI 4.0 and the Industrie 4.0 Component," *Industrie 4.0*, 2015. [Online]. Available: http://www.zvei.org/en/subjects/Industry-40/Pages/The-Reference-Architectural-Model-RAMI-40-and-the-Industrie-40-Component.aspx. [Accessed: 11-Nov-2015].
[9] Industrial Internet Consortium, "The Industrial Internet Reference Architecture," Technical Report, 2015.
[10] M. Hausenblas and N. Bijnens, "Lambda Architecture," *Lambda Architecture A repository dedicated to the Lambda Architecture (LA). We collect and publish examples and good practices around the LA.*, 2017.

Appendix A Relevant Projects/Initiatives for boosting the PROPHESY-PdM Platform Specification

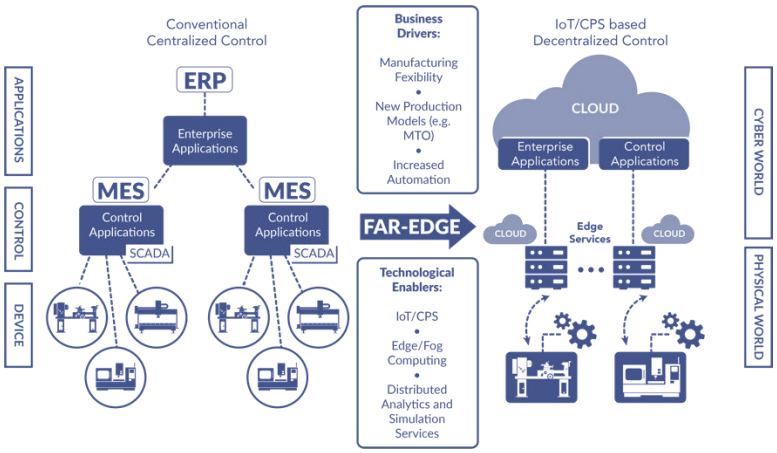
A.1 European Research Projects

A.1.1 Arrowhead[3]

STUDY	ARROWHEAD
DESCRIPTION	The Arrowhead project is aimed to provide an intelligent middleware that can be used to allow the virtualization of physical machines into services. It includes principles on how to design SOA-based systems, guidelines for its documentation and a software framework capable of supporting its implementations. The design guidelines provide generic "black box" design patterns on how to implement application systems to be Arrowhead Framework compliant. It already solves relevant issues regarding interface, protocol and semantic interoperability.
THE FRAMEWORK/ ARCHITECTURE	
INPUT FOR PROPHESY-PDM	• The Arrowhead framework is an intelligent middleware that can be easily applied for creating CPS. Each physical entity (ex. CNC machine, robot, etc.) can be virtualized as an Arrowhead compliant service and registered into the Arrowhead Framework. Within the Arrowhead Framework each service providing system is discoverable and invokable; • The Arrowhead framework faces several interoperability issues to enable integration of the information between heterogeneous components by deeply analysing the message exchange patterns, the most used communication protocols and semantic data representation.

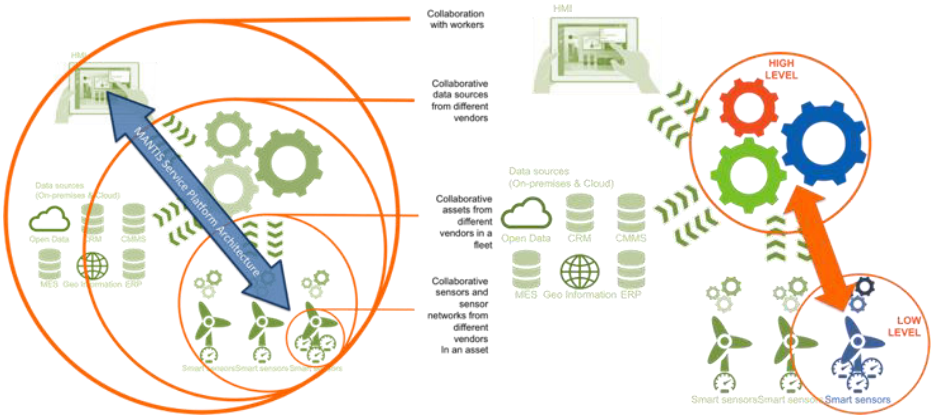
[3] http://www.arrowhead.eu

A.1.2 FAR-EDGE[4]

STUDY	FAR-EDGE
DESCRIPTION	FAR-EDGE is a joint effort of leading experts in manufacturing, industrial automation and FI technologies towards the smooth and wider adoption of virtualized factory automation solutions based on FI technologies. It will research a novel factory automation platform based on edge computing architectures and IoT/CPS technologies. FAR-EDGE will provide a reference implementation of emerging standards-based solutions for industrial automation (RAMI 4.0, Industrial Internet Consortium reference architecture), along with simulation services for validating automation architectures and production scheduling scenarios. FAR-EDGE will lower the barriers for manufacturers to move towards Industrie 4.0, as a means of facilitating mass-customization and reshoring. Emphasis will be paid in the study of migration options from legacy centralized architectures, to emerging FAR-EDGE based ones.
THE FRAMEWORK/ ARCHITECTURE	
INPUT FOR PROPHESY-PDM	• Identification of the main requirements and desired features/characteristics for cloud-based platforms; • The Far-Edge Data Collection & Data Analytics solution is an open source solution that allows data collection from streaming & static data sources, which can be dynamically registered and used in analytics tasks. It leverages Apache Kafka for the streaming part (customized and deployed in both the demonstrators envisioned in PROPHESY)

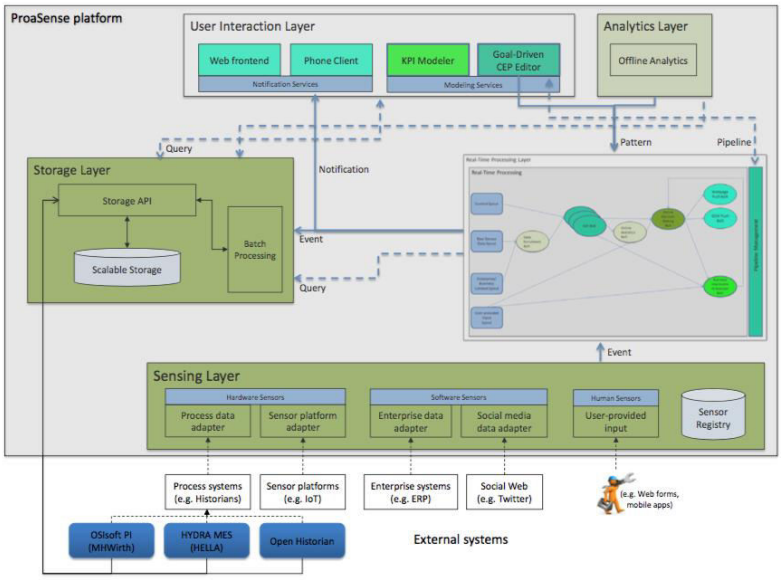
[4] http://www.faredge.eu/#/

A.1.3 MANTIS[5]

STUDY	MANTIS
DESCRIPTION	The MANTIS project aims to develop a CPS based proactive maintenance service platform architecture for enabling the creation of collaborative maintenance ecosystems. The proposed MANTIS platform will provide a practical mean for implementing collaborative maintenance strategies in a CPS-populated system. The generic focus is on an architecture that enables service-based business models and improved asset availability at lower costs through continuous process and equipment monitoring, together with data analysis.
THE FRAMEWORK/ ARCHITECTURE	
INPUT FOR PROPHESY-PDM	• Identification of the main requirements and desired features/characteristics for cloud-based platforms (used as the foundation of the PROPHESY-PdM platform specification);

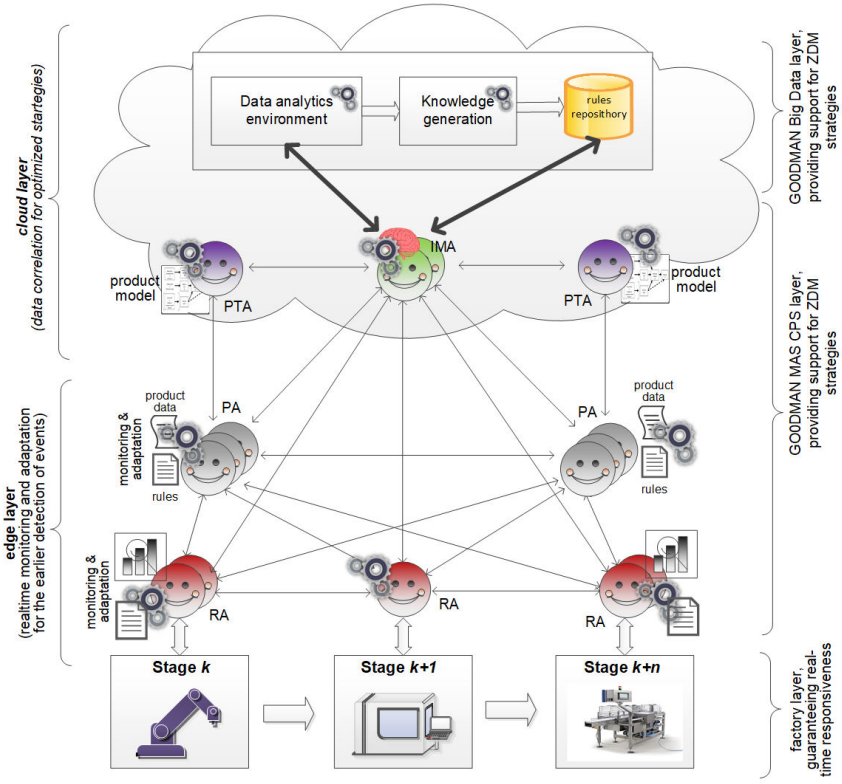
[5] http://www.mantis-project.eu

A.1.4 ProaSense[6]

STUDY	PROASENSE
DESCRIPTION	The ProaSense project was aimed to support an efficient transmission from Sensing to Proactive enterprise by: • Exploiting the power of big enterprise data; • Extracting actionable meaning from the data by deeply applying big data analytics; • Increasing the strategic value of data analysis for the decision making by dynamically extracting patterns of interest and adapting the system according to these patterns;
THE FRAMEWORK/ ARCHITECTURE	
INPUT FOR PROPHESY-PDM	• Identification of the main requirements and desired features/characteristics for cloud-based platforms; • The ProaSense Observe-Orient-Decide-Act (OODA) loop for situational awareness for supporting proactive maintenance and monitoring; • The ProaSense event model, i.e. the identification of the relevant events and their structure; • The Key Performance Indicators (KPI) modelling language; and • The tool for KPI definition, monitoring and tracking.

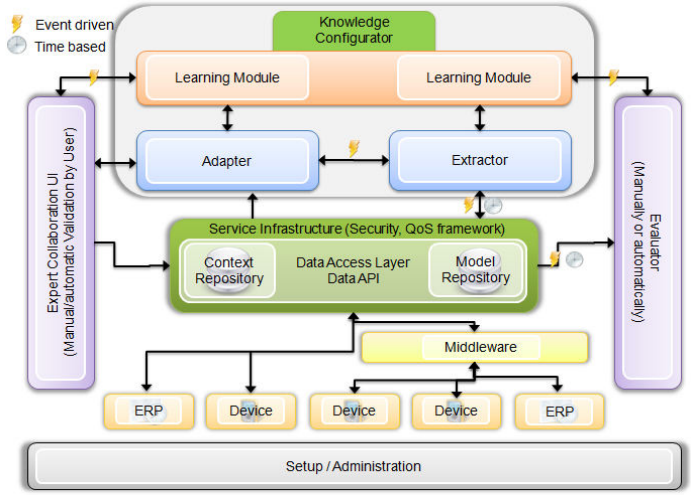
[6] http://www.proasense.eu

A.1.5 GO0DMAN[7]

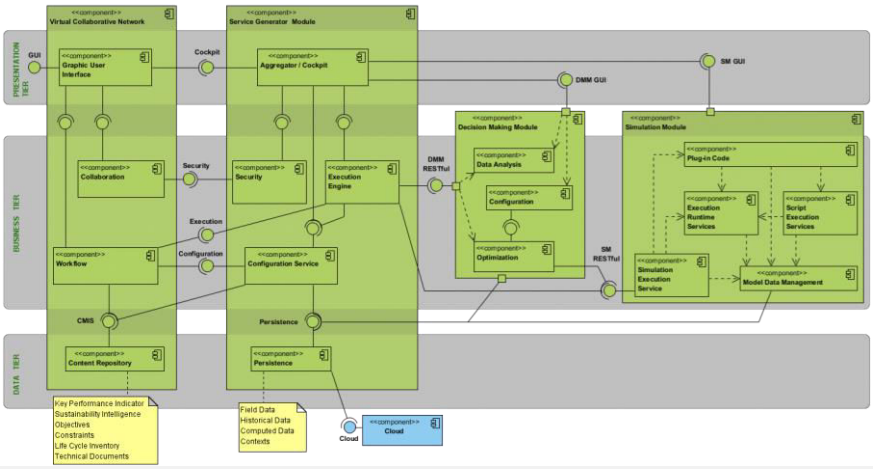
STUDY	GO0DMAN
DESCRIPTION	The GO0DMAN project aims to integrate and combine process and quality control for multi- stage manufacturing systems using a distributed system architecture built upon an agent-based CPS and smart inspection tools designed to support ZDM strategies.
THE FRAMEWORK/ ARCHITECTURE	
INPUT FOR PROPHESY-PDM	• Identification of the main requirements and desired features/characteristics for cloud-based platforms; • The multi-agent infrastructure; • The data analytics processes that provide early detection/identification of deviations while allowing to prevent the occurrence of defects and their propagation; • Alignment with Industry 4.0 trends and inn particular RAMI4.0.

[7] http://go0dman-project.eu/

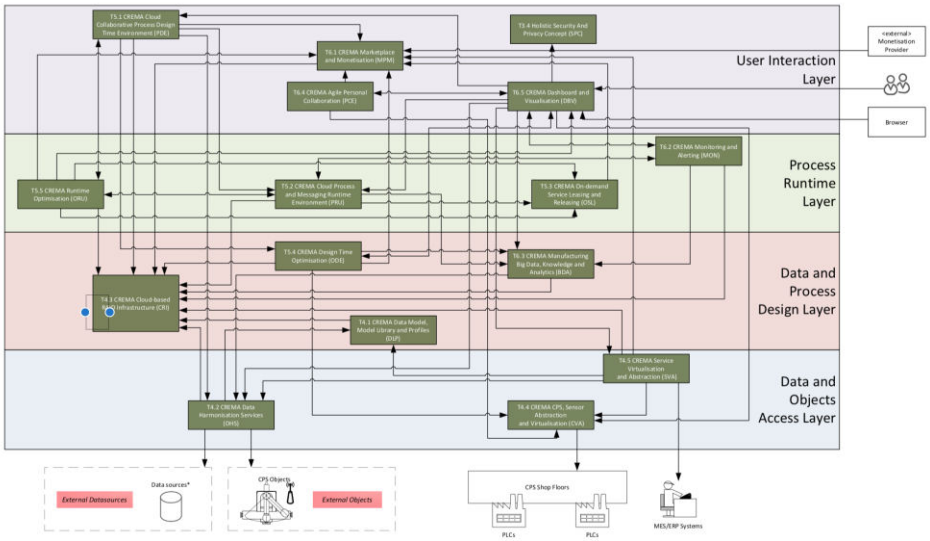
A.1.6 Self-Learning

STUDY	SELF-LEARNING
DESCRIPTION	The strategic objective is to strengthen EU leadership in production technologies in the global marketplace by developing innovative self-learning solutions to enable tight integration of control & maintenance of production systems. The project will develop highly reliable and secure service-based self-learning solutions aiming at that integration. The Methodology addressing organisational aspects of such a radical change in production systems, within extended enterprise concept, applying lean principles will be elaborated.
THE FRAMEWORK/ ARCHITECTURE	
INPUT FOR PROPHESY-PDM	• Identification of the main requirements and desired features/characteristics for cloud-based platforms; • Self-Adaptation and Self-Configuration of machine tools scheduling plans; • Self-Adaptation, Configuration and learning tasks triggered by system expert.

A.1.7 EPES

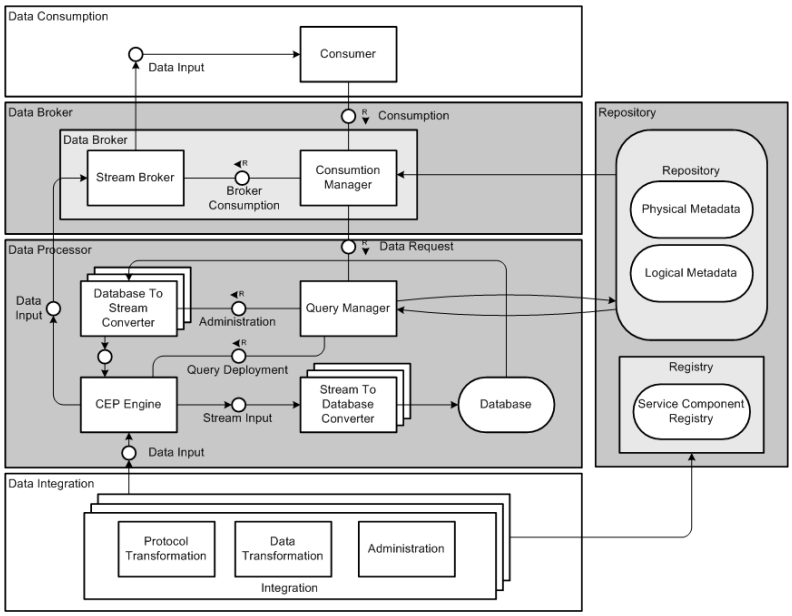
STUDY	EPES
DESCRIPTION	EPES provides service oriented ICT solutions to generate services, which improve the performance of highly customized industrial processes, products and services (PPS) during their life cycle, in cases in which no standard, off- the-shelf solutions can be applied. In many sectors, PPS improvements require an efficient combination and reconfiguration of software services to meet varying requirements along the product/process life cycle and effectively take into account different ecological constraints. EPES framework allows industries to evaluate the performance of engineered products considering their whole lifecycle rather than only early stages.
THE FRAMEWORK/ ARCHITECTURE	
INPUT FOR PROPHESY-PDM	• Identification of the main requirements and desired features/characteristics for cloud-based platforms; • The Decision-Making Module (DMM) Data Analytics component provides an interesting input to support and guide the user/system expert during the decision making process.

A.1.8 CREMA

STUDY	CREMA
DESCRIPTION	CREMA is aimed at simplifying the establishment, management, adaptation, and monitoring of dynamic, cross-organisational manufacturing processes following Cloud manufacturing principles. CREMA will develop the means to model, configure, execute, and monitor manufacturing processes, providing end-to-end support for Cloud manufacturing by implementing real systems and testing and demonstrating them in real manufacturing environments.
THE FRAMEWORK/ ARCHITECTURE	

INPUT FOR PROPHESY-PDM	• Identification of the main requirements and desired features/characteristics for cloud-based platforms;
	• The CREMA Service Oriented Architecture platform and its components:
	  ○ Data and Objects Access Layer;
	  ○ Data and Process Design Layer;
	  ○ Process Runtime Layer;
	  ○ User Interaction Layer.

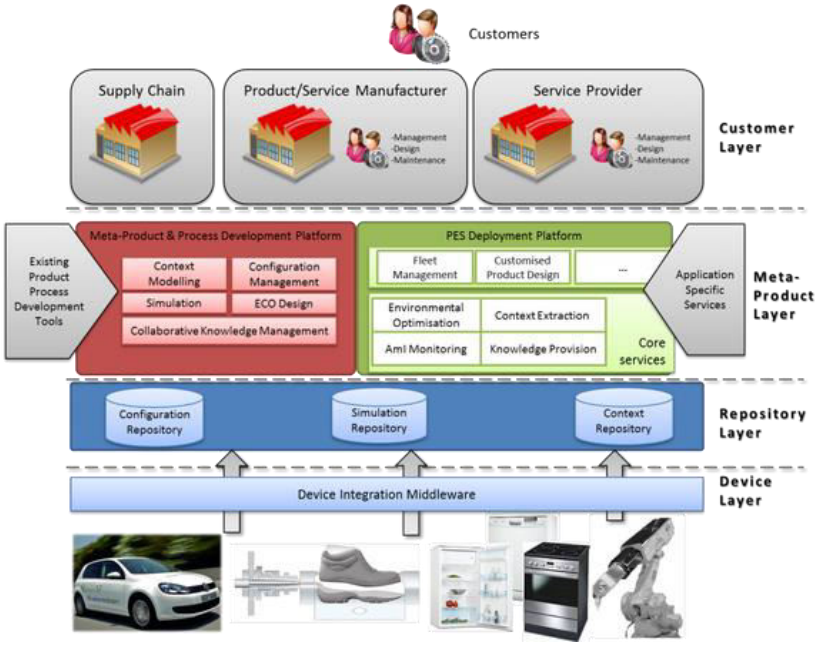
A.1.9 KAP

STUDY	KAP
DESCRIPTION	The KAP project will deliver energy management standards and a technology framework for next generation, sustainable manufacturing. KAP stands for Knowledge of past performance, combined with Awareness of the present state, which together can support Prediction of future outcomes. This philosophy forms the basis of a framework that will enable every existing resource to be used as efficiently as possible through the effective co-ordination of man, machine, material and method. To achieve this goal the project will define a range of sustainable manufacturing standards. Measurements will be gathered through a factory-wide network of sensors. Complex Event Processing (CEP) and data stream analysis will compute on-the-fly production performance indicators (PPIs) for real-time monitoring. Data mining in combination with OLAP will support problem diagnosis and resolution.
THE FRAMEWORK/ ARCHITECTURE	
INPUT FOR PROPHESY-PDM	• Identification of the main requirements and desired features/characteristics for cloud-based platforms; • Architecture and design principles for CEP and data streams processors; • KPI definition, identification and online processing.

A.1.10 POWER-OM

STUDY	POWER-OM
DESCRIPTION	Power-OM propose to use the electric current consumption monitoring and profiling, as an easy to implement condition based maintenance (CbM) technique, and manage it also as a way to improve the overall business effectiveness, under a triple perspective: • Optimizing maintenance strategies based on the prediction of potential failures and schedule maintenance operations in convenient periods and avoid unexpected breakdowns • Operation: Managing energy as a production resource and reduce its consumption • Product reliability: Providing the machine tool builder with real data about the behaviour of the product and their critical components This universal solution should also be compatible with the added value information that could come from existing sources (control) and sensors used at the machine, and jointly this will preserve current and future investment in the field.
THE FRAMEWORK/ ARCHITECTURE	
INPUT FOR PROPHESY-PDM	• Identification of the main requirements and desired features/characteristics for cloud-based platforms; • Techological baseline for the definition of the platform components.

A.1.11 PROSECO[8]

STUDY	PROSECO
DESCRIPTION	The PROSECO project aimed to provide a novel methodology and a comprehensive ICT solution for collaborative design of product-services (Meta Products) and their production processes. The effective extension of products with new services, so called Product Extension Services (PES), in different sectors (automotive, home appliances, automation equipment etc.) will be achieved by means of Ambient Intelligence (AmI) technology, Lean and Eco-design principles and applying Life Cycle Assessment techniques.
THE FRAMEWORK/ ARCHITECTURE	
INPUT FOR PROPHESY-PDM	• Identification of the main requirements and desired features/characteristics for cloud-based platforms; • A secure ICT solution and service-based platform; • Integration methodology and approach.

[8] https://www.proseco-project.eu