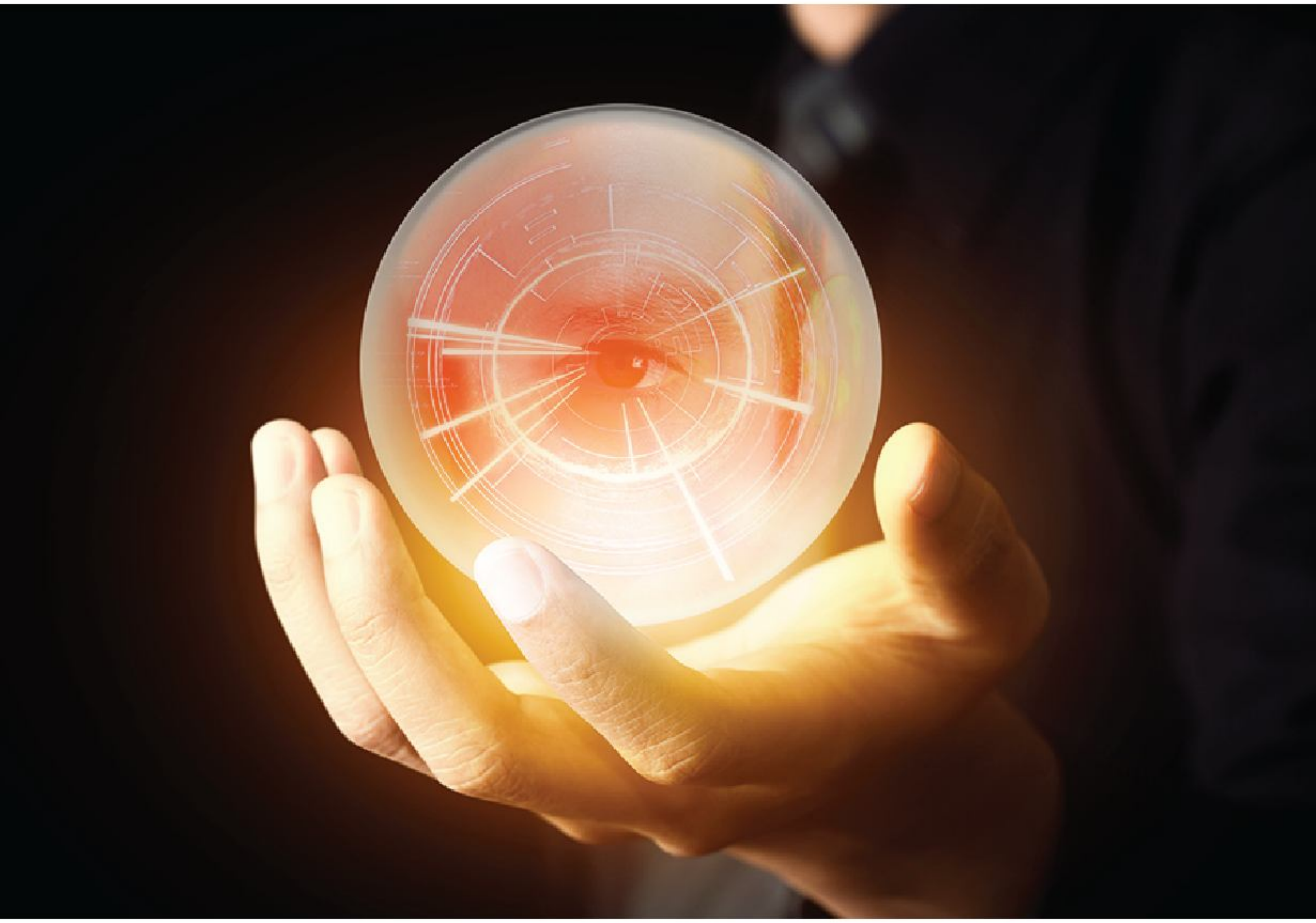
PROPHESY

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



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# D2.5 – Platform Architectures and Ecosystem Specifications

Horizon 2020
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# D2.5 – Platform Architectures and Ecosystem Specifications

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# Executive Summary

The purpose of the deliverable D2.5 – 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 1st version for the current deliverable, as part of the document the analysis of the state-of-the-art is included and generic requirements for cloud-based platforms for Predictive Maintenance are extracted and used to guide the design of the overall PROPEHSY-PdM platform architecture. Furthermore, the derived architecture is included and presented together with a comprehensive explanation of the logical view and the functionalities of the envisioned components. Moreover, a preliminary description of the concept behind the PROPHESY Ecosystem together with a first set of specifications are also included.**

Finally, the provided content will be further refined (inclusions of the process, development, data and physical views) and extended in the 2nd version of the deliverable where the additional input made available by the Tasks 2.3 and 2.4 on the "Services Platform Specifications" and "Complex Demonstrators Specifications" will be also integrated. This is considered critical from the Consortium since more detailed specification will be produced for these two aspects that significantly effects the content of the current specifications too.

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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 Services |
| **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 |

| Acronym/ Abbreviation | Title |
|---|---|
| **PROPHESY-PdM Platform** | Is the hardware and the necessary software connected to several 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.

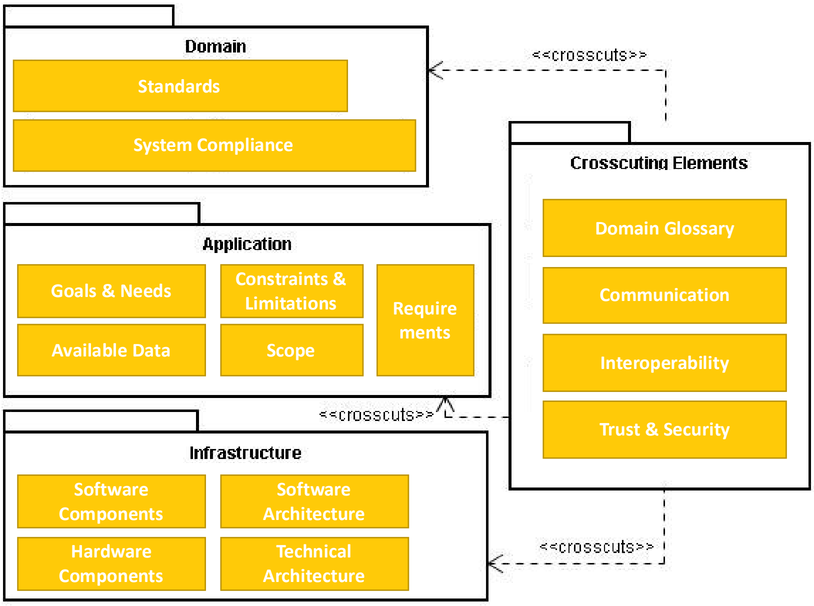


*Figure 1: Adopted RAModel, adapted from [1]*

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.

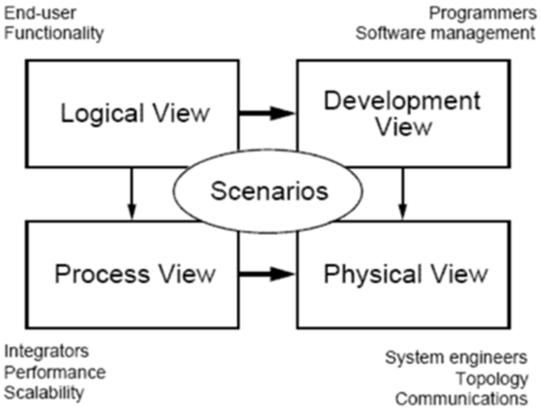


*Figure 2: Kruchten 4+1 model [2]*

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.

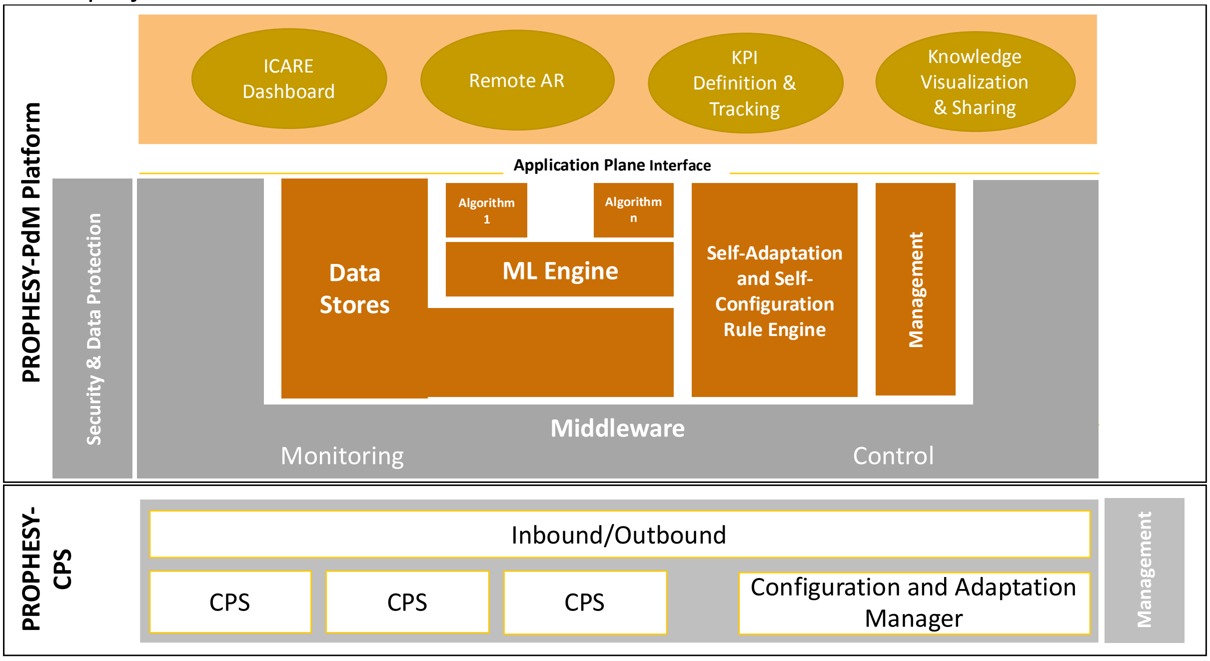


*Figure 3: PROPHESY-PdM System overall architecture*

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 the current deliverable (D2.5 – Platform Architectures and Ecosystem Specifications V1) is focused on the PROPHESY-PdM platform level and details – from one side – the PROPHESY-PdM platform main functional components, structure, relationship with the PROPHESY-CPS together with its physical instantiation, and – from the other side – provides an overview of the PROPHESY Ecosystem and how to create specific PROPHESY solutions for very domain specific PdM problems.

## 1.6 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: Ecosystem**: delivers the explanation and specification of the ecosystem associated to the PROPHESY system.
- Appendix B: 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 PORPHESY-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 a 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).

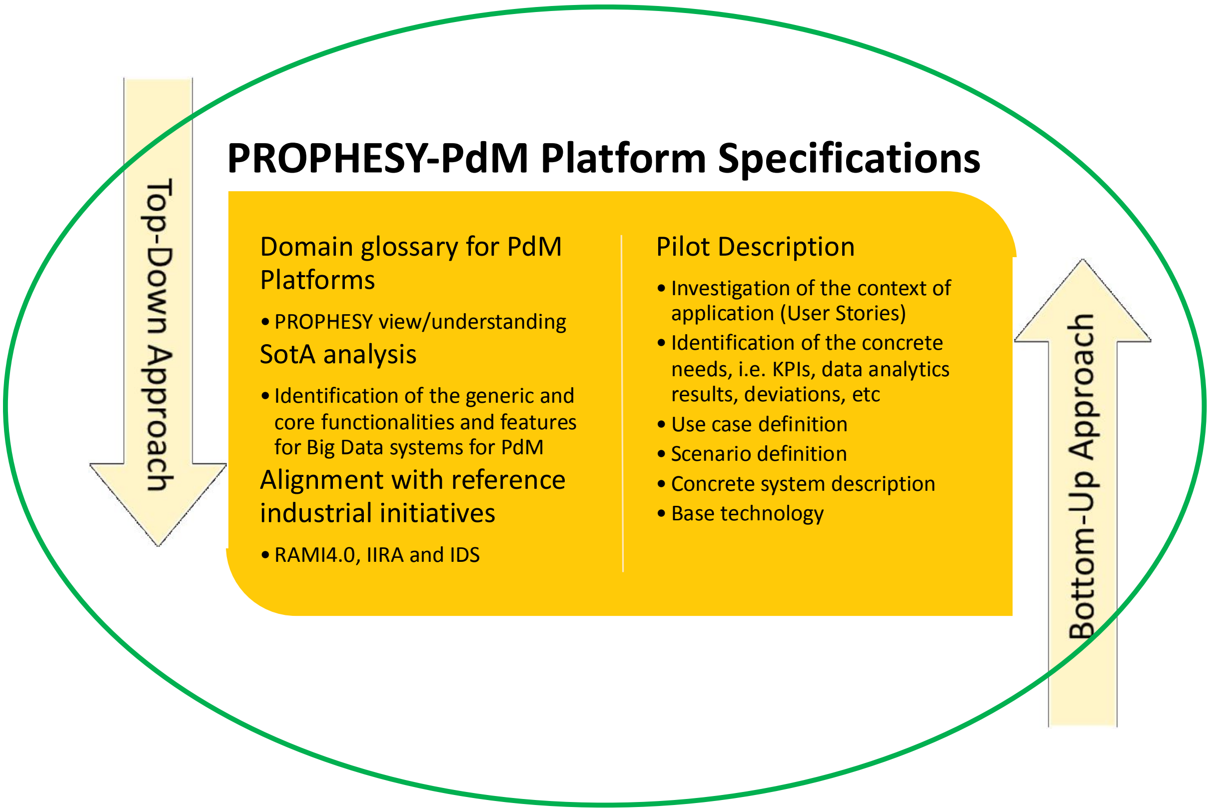


*Figure 4:PROPHESY-PdM Specification Approach*

## 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.

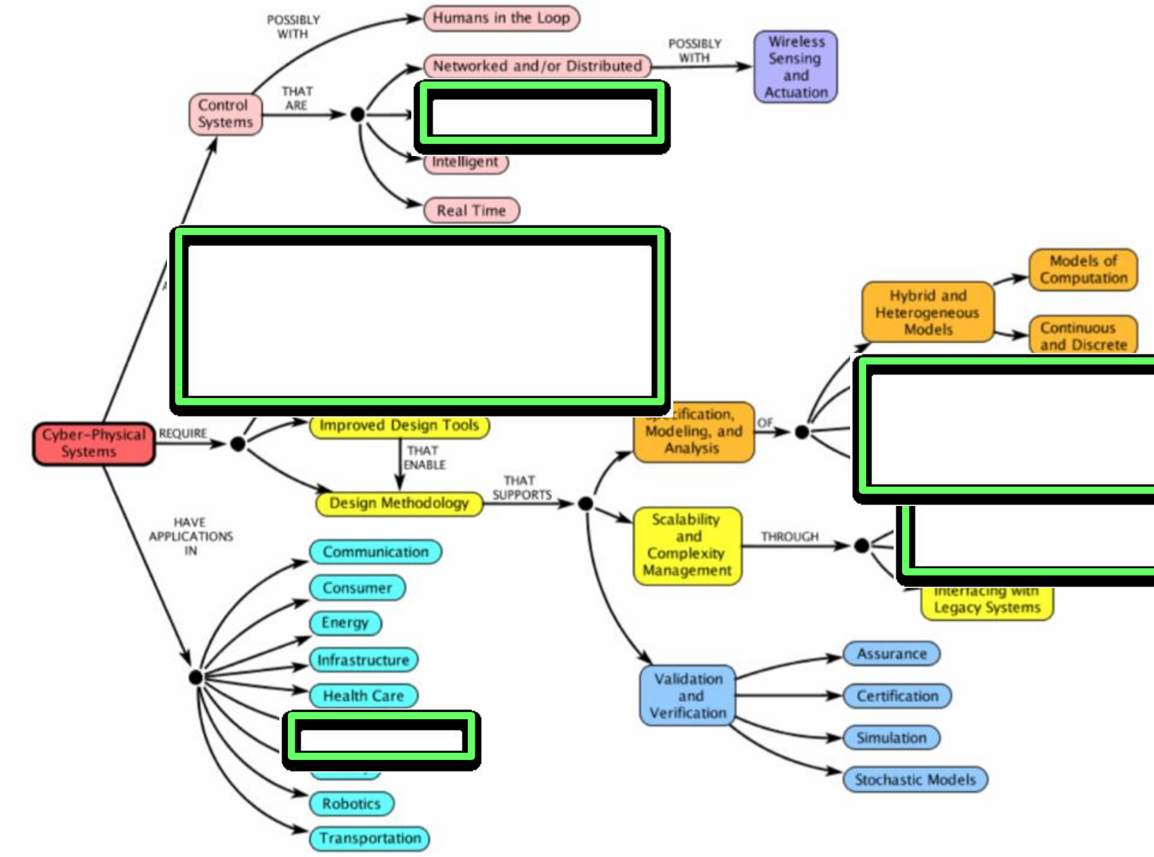


*Figure 5: CPS Taxonomy [7]*

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

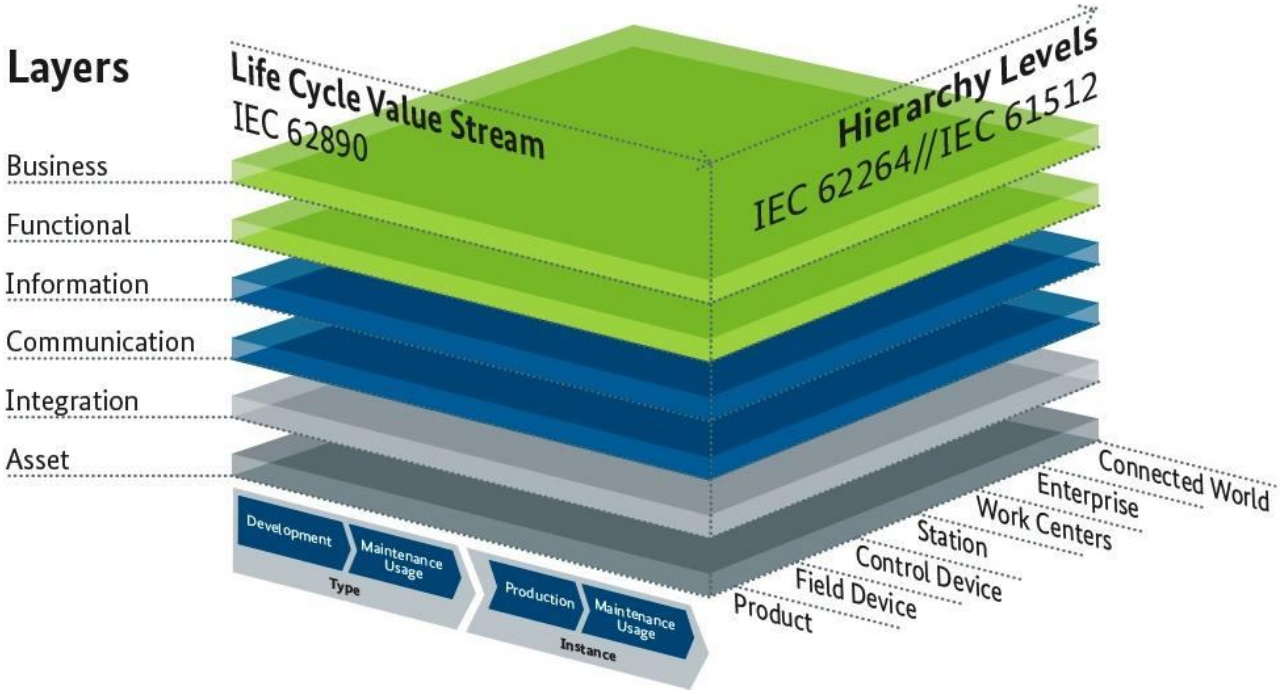


*Figure 6: Reference Architecture Model for Industrie 4.0 (RAMI 4.0) [8]*

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.

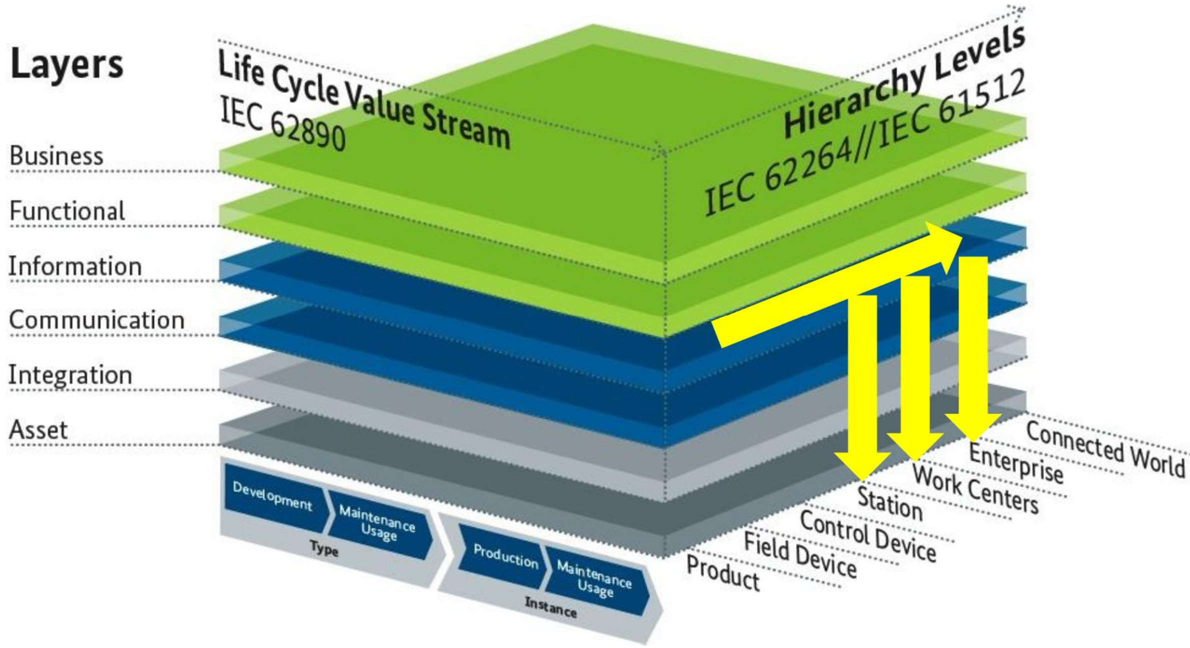


*Figure 7: Considered aspects of RAMI4.0 in PROPHESY-PdM Platform*

#### 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.

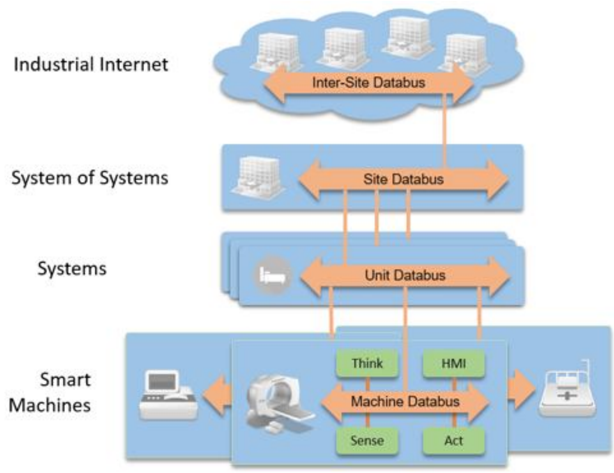


*Figure 8: Layered Databus Architecture [9]*

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.

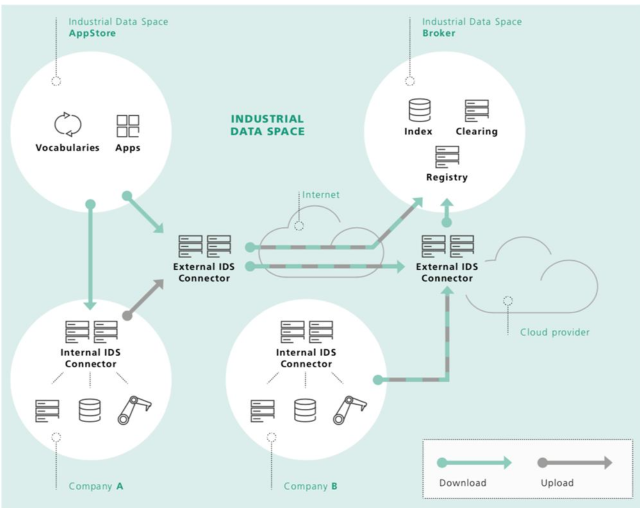


*Figure 9: IDS Generic Functional Architecture [6]*

[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.

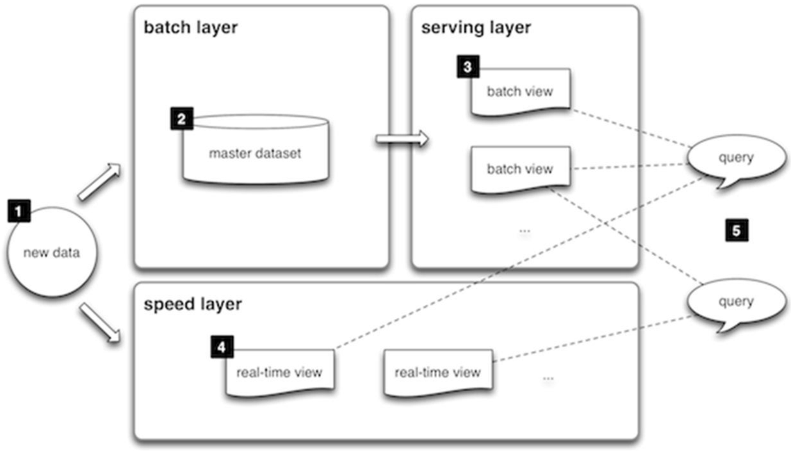


*Figure 10: Lambda Architecture High Level Perspective [10]*

The intrinsic nature of the PORPHEYS 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:<br>- root cause of failure analysis<br>- symptom analysis<br>- automatic sensor data interpretation<br>- remaining useful life estimation<br>- 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**
    - **Use the results of the data analytics processes for actively and reactively adapting its behaviour at runtime (self-configuration and self-adaptation);**
      - **Human-in-the-loop.**
    - **Exploit complex event processing technologies and high-performance computing techniques for generating real-time performance indicators;**
    - **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** |
| Production Planning & Performance Management/Monitoring through communication of autonomous systems<br>(Optimized Decision Making) | **Extract, manipulate, analyse and store the physical data provided by a network of CPSs;**<br><br>**Different levels of decisions;**<br><br>**Exploit complex event processing technologies in real industrial scenarios;**<br><br>**Compute condition prediction and prognostic reference models;** |

| | |
|---|---|
| | **Exploitation of event driven services and mechanisms for generating real-time production performance indicators.** |
| Changes in production during the ongoing production process (Intelligent Control) | **Access to physical data using sensors and affect physical processes by using actuators (CPS compliant Design);**<br><br>**Exploitation of event driven services and mechanisms for detecting any deviation from the predictive and prognostic models.** |
| Data availability (vertical and horizontal integration) | **Use global available data and services (e.g. Enterprise Resource Planning, quality databases, etc);**<br><br>**Facilitate the connection and interaction with/between CPSs and other software assets (applications, components, etc) by using communication networks and implementing network accessible components;**<br><br>**Openness.** |
| 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** |
| Acceleration through exponential technologies | **Support for on-line and off-line data analytics;**<br><br>**Exploit complex event processing technologies in real industrial scenarios;** |
| Standardization (Interoperability) | **Industrial Standard compliance**<br><br>**Harmonization and simplification of existing standards for maintenance information exchange**<br><br>**Programming-by-interface and decouple the user interfaces from the main system logic;**<br><br>**Openness.** |

| | |
|---|---|
| Standardization and reference Architectures | **Standardization of the collaboration between software assets and components to facilitate the composability of the solution;**<br><br>**Harmonization with already existing reference architectures (RAMI, IIRA, MANTIS)** |
| Migration strategies | **Support the integration of legacy systems and components;** |
| Novel cloud/edge computing patterns | **Support for system scalability and hierarchical system organization to enable the development of complex system designs** |
| Modularity and Composability | **Decentralization and distribution of the functionalities provided;**<br><br>**Openness.** |
| Security and Safety | **IT security concepts, architecture, and standards to ensure the integrity and availability of the information;**<br><br>**Data protection, integration and secure data access.** |

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.

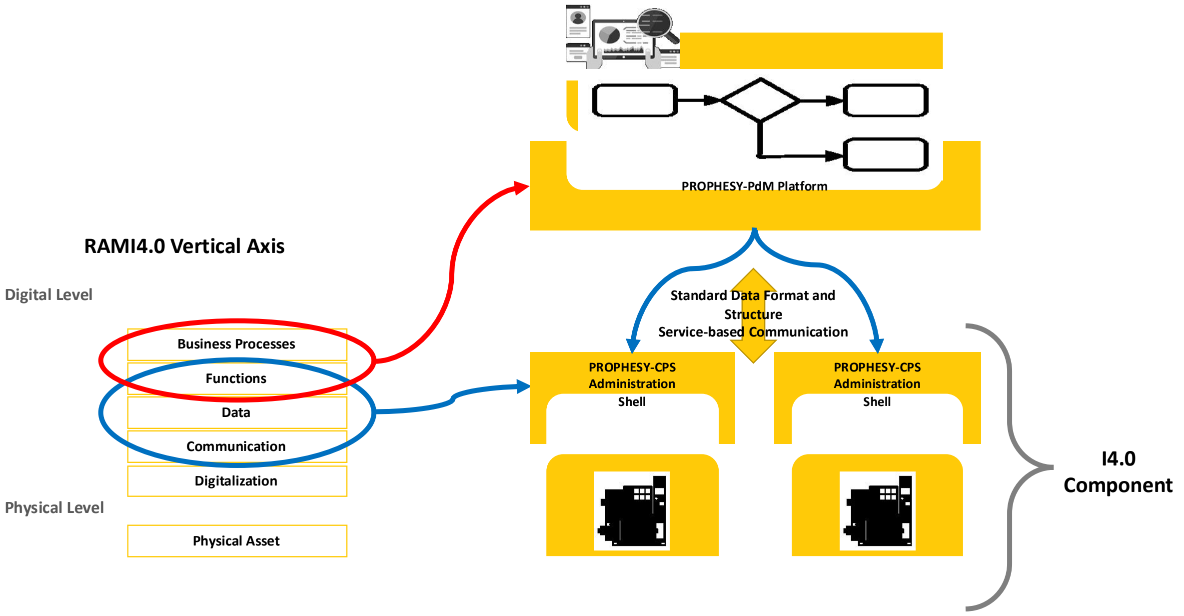


*Figure 11: How RAMI4.0 is linked to PROPHESY-CPS and PdM platform*

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).

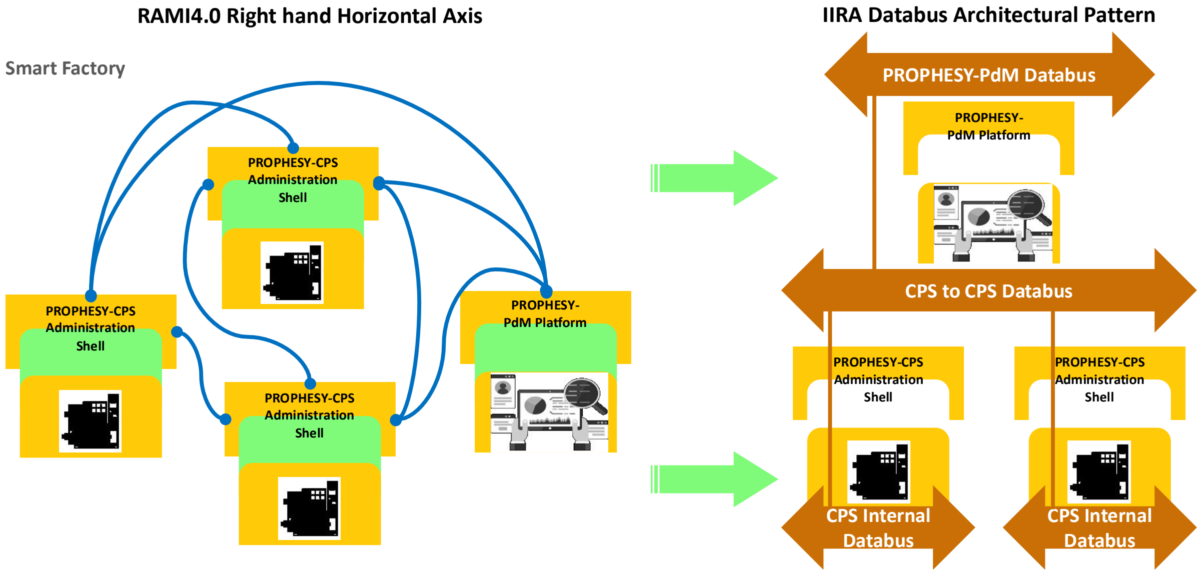


*Figure 12: How RAMI4.0 and IIRA converge into PROPHESY-PdM platform*

## 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.

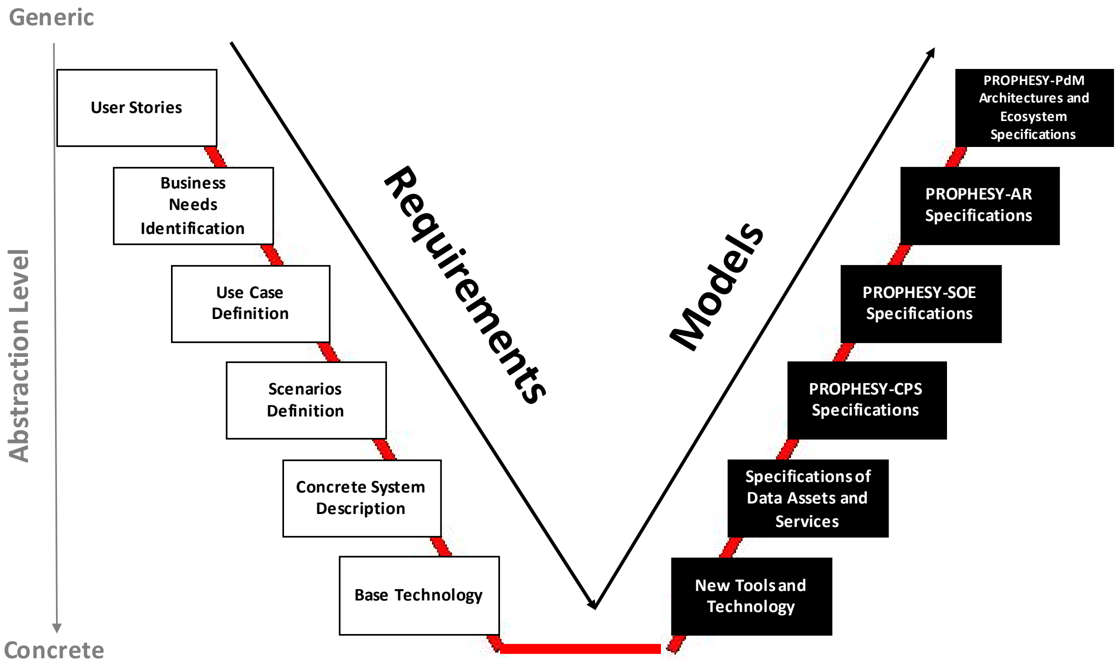


*Figure 13: Applied Approach for Requirements identification*

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). |
| 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 (e.g. discovery mechanisms, plug and (un-)plug events generation, on-demand usage of the PROPHESY-CPS, etc.). 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 (fault management, logs, system initialization, backup and store current and previous configuration, etc.) |
| Data Analysis | Support for on-line and off-line data analytics | The PROPHESY-PdM platform will ensure the data processing. It will provide a 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 |
| | Use the results of the data analytics processes for actively and reactively adapting its behavior at | |

| | | |
|---|---|---|
| | runtime (self-configuration and self-adaptation) | 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. |
| | Exploit complex event processing technologies and high-performance computing techniques for generating real-time performance indicators | |
| | Condition Prediction and Prognostic reference models | |
| 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 | The PROPHESY-PdM platform will provide a well-defined interface for the data application plane. In particular it will enable the docking of third-party applications. Moreover, dashboards for data visualization, KPIs definition and tracking will be also provided. |
| Modularity and Composability | Service Orientation | The PROPHEYS-PdM platform will be built by following SOA-based patterns and principles. Morevoer, 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 design 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 |
| | Standard compliance | |

| | | |
|---|---|---|
| | | components as well as stakeholders of the PROPHESY system. |
| 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:

- **Low Frequency Machine Learning:** provides a set of algorithms, data analysis processes and their execution engine for processing data gathered from the PROPHESY-CPSs;

- **Data Stores:** 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;
- **Self-Adaptation and Self-Configuration Rule Engine:** allows the translation of the result of the data analysis tasks into adaptations and configuration for the selected PROPHESY-CPS;
- **Management:** 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 to ensure the security and privacy of the platform. It is, thus, in charge of assuring that only legitimate applications and/or more in general clients can access the services and functionalities provided by the platform, as well as, securing all the interactions that occur between peers that are authorised to interact.

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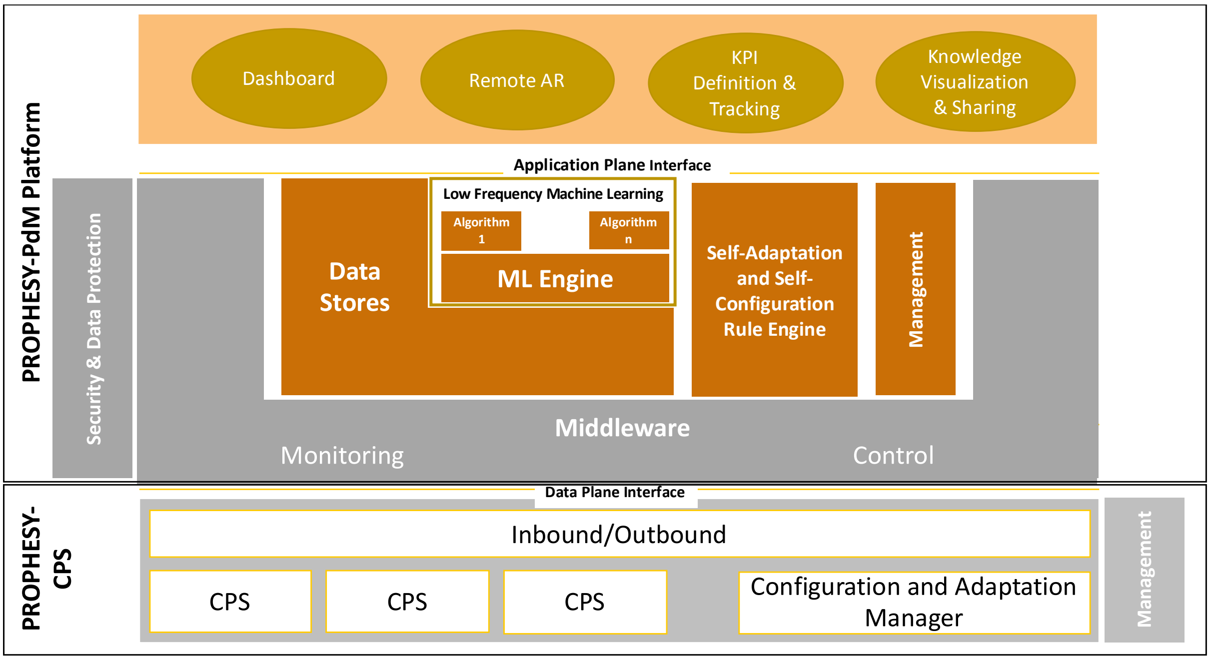


*Figure 14: Global PROPHESY Envisioned Architecture – PROPHESY-CPS and PROPHESY-PdM platform*

#### *3.2.1.1 Low Frequency Machine Learning Overview and Features*

| **Name of component** | **Low Frequency Machine Learning** |
|---|---|
| **Description** | The Low Frequency Machine Learning 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 the processing of PROPHESY-CPS events and data for all the scenarios that may require the use of significant computing resources and computational power. |
| **Features** | **Functional Properties**:<br>• Publish subscribe interfaces and technologies (such as MQTT)<br>• Application of Analytics Algorithms on Streaming Data, including machine learning algorithms.<br>• Interfacing to a message bus structure towards writing the results of its processing as new data streams.<br>• Processing structured data organized according to the PROPHESY ontology.<br>• High level decision-making process support. |
| **Need for semantics** | PROPHESY-PdM ontology presented in deliverable d2.3. |
| **Online or offline mode** | The component is specified to support online mode |
| **Expected input** | Data and Configurations from the Data Stores |
| **Interaction** | The following interaction<br>• Publish-Subscribe pattern<br>• Request-reply pattern to acquire selected datasets in some scenarios. |
| **Interfaces** | The component needs to be interfaced with:<br>• Data Stores;<br>• Self-Adaptation and Self-Configuration Rule Engine. |
| **Foreseen constraints** | N/A |
| **Software requirements** | N/A |

#### 3.2.1.2 Data Stores Overview and Features

| Name of component | Data Stores |
|---|---|
| **Description** | The Data Stores 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 Data Stores component has the following features:<br>• Store all the necessary configuration data for the PROPHESY-PdM platform and its own internal components;<br>• Store all the necessary management data to allow the proper functioning of the PROPHESY-CPS level;<br>• 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;<br>• Store the results of the global data processing performed by the Low Frequency Machine Learning;<br>• Provide access to all the previous stored data to external users in the application plane. |
| **Need for semantics** | PROPHESY-PdM ontology presented in deliverable d2.3. |
| **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;<br>• Data from the Middleware (data channel). In particular data from the PROPHESY-CPSs together with the related descirption;<br>• Management data to manage the PROPHESY-CPS level;<br>• Processed data from the Low Frequency Machine Learning component; and<br>• Decisions from the several applications within the application plane. |
| **Interaction** | The component implements a request/reply message exchange patterns. 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 need to be interfaced with:<br>• Low Frequency Machine Learning;<br>• 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 Self-Adaptation and Self-Configuration Rule Engine Overview and Features

| Name of component | Self-Adaptation and Self-Configuration Rule Engine |
|---|---|
| **Description** | The Self-Adaptation and Self-Configuration component transforms the results of the data processing tasks and processes into adaptations and configurations to be feedbacked to the physical assets through the PROPHESY-CPS. Therefore, the component is responsible for coordinating the self-* behaviour of the PROPHESY-CPSs by generating events that encapsulate actions to be executed. |
| **Features** | The component enables the translation of the decisions and result of the Low Frequency Machine learning component into adpatations/configurations that can be feedbacked to the PROPHESY-CPSs and/or to any legacy systems with the company. |
| **Need for semantics** | PROPHESY-PdM ontology presented in deliverable d2.3. Moreover, It must be clearly described, which action should be performed and why. Furthermore, the solution must support the translation from the PROPHESY-CPS domain specific ontology to the PROPHESY-PdM platform ontology. |
| **Online or offline mode** | The component is specified to support online mode |
| **Expected input** | • Decisions and commands from the Application plane;<br>• Decisions and machine learning results from the Low Frequency Machine Learning component.<br>• Information about the specific PROPHESY-CPS or CPSs to be adapted/Configured. |
| **Interaction** | The component will be designed to provide both request/reply and publish/subscribe patterns for enabling the communication with the other components within the platform. |
| **Interfaces** | The component need to be interfaced with:<br>• Low Frequency Machine Learning;<br>• Data Stores;<br>• Middleware (To receive commands from the application plane and send commands to the PORPHESY-CPS); |
| **Foreseen constraints** | Analysis of the possible technologies to be used for the implementation of this component could be complex |
| **Software requirements** | The components need to be generic enough in order to promote their openness, configurability and code re-use |

#### *3.2.1.4 Management Overview and Features*

| **Name of component** | **Management** |
|---|---|
| **Description** | The management 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:<br>• Management of the PROPHESY-CPS registration and discovery inside the PROPHESY system;<br>• Metadata describing the services and the data available;<br>• Describing/Configuring the rules attached to the usage of a certain PROPHESY-CPS. |
| **Features** | The management component has the following features and functional properties:<br>• Discover PROPHESY-CPSs and related services;<br>• Subscribe/Unsubscribe PROPHESY-CPS to the platform;<br>• PROPHESY-CPS Service registry;<br>• Support the configuration of the platform components;<br>• Allow the creation of PdM processes. |
| **Need for semantics** | PROPHESY-PdM ontology presented in deliverable d2.3. |
| **Online or offline mode** | The component is specified to support online mode |
| **Expected input** | • Data/Events from PROPHESY-CPSs for managing CPS-populated system;<br>• Data representing specific views of the registered PROPHESY-CPS;<br>• Configured PdM Processes;<br>• Configuration for the internal platform components. |
| **Interaction** | The Management 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 need to be interfaced with:<br>• Middleware. |
| **Foreseen constraints** | N/A |
| **Software requirements** | N/A |

#### 3.2.1.5 Middleware Overview and Features

| **Name of component** | **Middleware** |
|---|---|
| **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:<br>• Management channel/flow;<br>• 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. |

#### *3.2.1.6 Security and Data Protection Overview and Features*

| **Name of component** | **Security and Data Protection** |
|---|---|
| **Description** | The Security and Data protection component is responsible to ensure the security and confidentiality within the platform. It is in charge to guarantee secure communication channels between the all the elements of the PROPHESY-PdM platform, to determine and deliver access to the platform services only to legitimate users (other applications) and to provide data protection mechanisms for the all the stored data. All the security mechanisms are properly managed by the security management sub-component. |
| **Features** | The Security and Data Protection Component handles/manages:<br>1. The authentication within the platform, i.e. authenticate the consumers of the services provided by the platform;<br>2. The authorization model for managing the policies and performing the access control based on the defined access policies;<br>3. The identity management framework to enable the anonymous using and provisioning of services by trusted entities. |
| **Need for semantics** | N/A |
| **Online or offline mode** | The component is specified to support online mode |
| **Expected input** | N/A |
| **Interaction** | Manage all the interaction between i) all the components within the platform; ii) between the platform and the PROPEHSY-CPSs; and iii) between the platform and any external user within the application plane |
| **Interfaces** | N/A |
| **Foreseen constraints** | Security and Data Protection is a transversal effort, i.e. provides functionalities that are required by and thus pertain to the whole PROPHESY system. Therefore, it is not constrained to a specific component but it is bounded to the interaction between the services provided and their users. |
| **Software requirements** | N/A |

#### 3.2.1.6.1 7/19/2018 3:59:00 PMComponent Logical View

The Figure 15shows the allocation and distribution of the security and Data protection components/functions within the PROPHESY system.

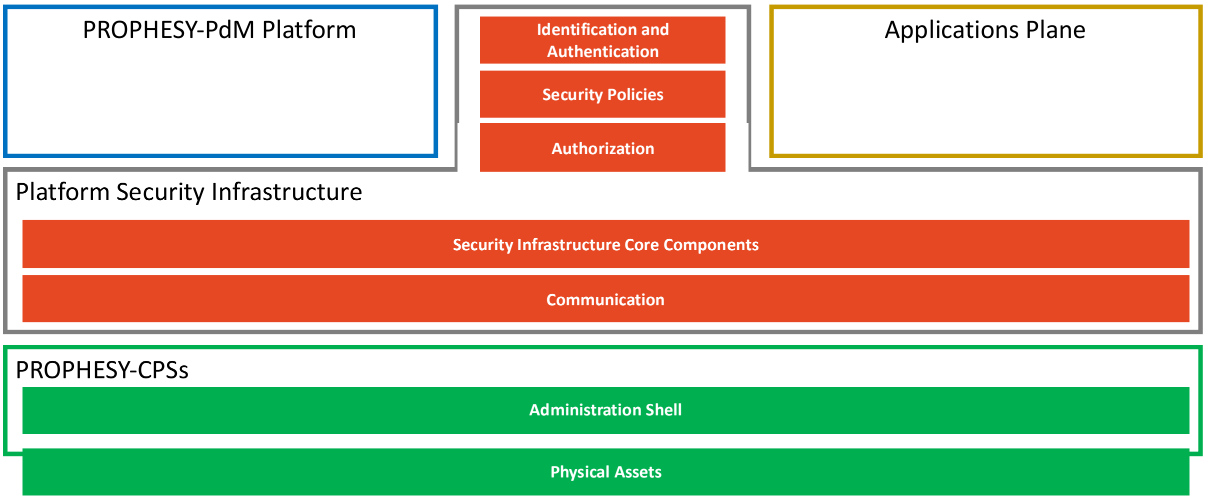


*Figure 15: PROPHESY Security Components/Functions Allocation and Distribution*

# 4 PROPHESY-PdM Platform: Ecosystem

## 4.1 Overview

One of the visions of PROPHESY is to design and develop a **service-brick oriented** ecosystem platform. In this scope, it is important to gather the exploitable assets and the other "building block" components (tools, augmented services, service bricks etc.) as illustrated in D2.3 and will be further elaborated in deliverable D6.1 in a presentable and extrovert manner.

### 4.1.1 Reasons for a Multi-Sided Platform

It is envisioned that the integrated ecosystem will be able 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 PROPHESY 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 are technologies, products or services that create value primarily by enabling 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.
- 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.
- 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

We distinguish between:
**Demand Side Stakeholders**
These include manufacturers, machine vendors, PdM and Industrial IoT services developers, IoT and I4.0 solutions integrators, ML specialists, Maintenance specialists, affiliated business entities to partners, and all other stakeholders seeking novel PdM solutions and tools, participating in the ecosystem to learn about its assets, validate the functionalities and operations of PROPHESY-SOE and the associated service bricks and tools from both a technical and a business perspective.

**Supply Side Stakeholders**
These include Consortium Partners as well as Third-party providers of PdM Solutions who register and participate in the ecosystem, offer reviews and ratings while also enhance it as contributors of additional content and software modules that can form services together with PROPHESY service bricks.

### 4.1.2 Benefits

#### *4.1.2.1 Benefits for 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.

#### *4.1.2.2 Benefits for 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

## 4.2 Ecosystem Platform Features

The following table illustrates some of the core functionalities and features that the ecosystem should include

| MSP Ecosystem Functionality | Short Description |
| --- | --- |
| **Registering Participants & Business Entities** | Registration of participants to the ecosystem |
| **Authentication and Authorization** | Ensuring authenticated and authorized access to the various services |
| **Search and discovery of service offerings** | Search engine for discovering available services based on appropriate metadata for the services descriptions |
| **Catalogue Publishing of service bricks and building blocks** | Publication and presentation of the ecosystem services, solutions, building blocks, tools, and other entities described in D6.1 |
| **Review and rating of service offerings** | Tools for rating service offerings from the end-users / participants viewpoints |
| **Provision of recommendations** | Context aware proposition of relative service offerings |
| **Access to PROPHESY Tools** | 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 etc. (As described in D6.3) |
| **PROPHESY SOE** | Access to the PROPHESY Service Optimisation Engine |
| **Manage and tracking registered services** | Access to the status of subscriptions and services |
| **Solution Presentation** | Solution presentation through examples and implemented usecases |
| **Services Presentation** | A comprehensive list of all services described in WP6 |
| **Knowledge base** | Information Services including articles, presentations, News, Blog etc. On-line training and education services in the form of self-contained presentations |
| **Exploitation 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 |
| **Libraries** | Middleware libraries for PdM and open APIs for accessing the libraries including accompanying documentation |
| **Developers’ support services** | Developers joining the project’s platform will be offered with access to APIs and annotations |
| **Training, consulting and technical support services** | These services will be offered in the form of complementary (augmented) added value services as analysed in detail within the “Service Bricks” definition in D6.1, through contacting the relevant key-persons of partners. |

| | |
|---|---|
| **Localization** | Support for an international environment through appropriate localization of the services including currency and language support |

## 4.3 Liaisons and Integration with existing ecosystems

Success of such ventures is largely dependent in the attraction of a significant number of participants (**critical mass**) to its ecosystem because 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. Special emphasis will be paid in the study of the business motivation of enterprises to participate in the PROPHESY ecosystem.

These leads to the conclusion that apart from the obvious need for an internal web portal for PROPHESY as a basis for the ecosystem, the following complementary alternatives are considered as deployment and implementation candidates for the PROPHESY Ecosystem platform and the presentation of the project service bricks, since these constitute "affiliated" ecosystems that are already launched and have started their community building efforts. In particular, synergies with the following ecosystem platforms and communities will be considered.

### 4.3.1 FAR-EDGE (www.edge4industry.eu)

The H2020 FAR-EDGE project has recently (June 2018) launched its ecosystem portal platform, which provides access to all its digital automation solutions. The project's is currently undertaking intense community building efforts, which are attracting registered participants beyond the project's communities (i.e. third parties). FAR-EDGE and the Edge4Industry community are very pertinent to PROPHESY, as they both provide platforms and tools for data collection and analytics, despite the slightly different focus of the two final applications of the two projects (i.e. predictive maintenance for PROPHESY vs. Digital Automation and Simulation for FAR-EDGE). Moreover, the two projects have partners that participate in both projects (i.e. AIT and UI) with leading roles in the community building efforts. Therefore, there are good reasons for PROPHESY to pursue collaboration and joint community building efforts with FAR-EDGE. Likewise, PROPHESY will consider linking its ecosystem and/or results to the FAR-EDGE ecosystem portal, as a means of achieving multiplier effects for the community building efforts of both projects.

### 4.3.2 IoT Catalogue (www.iot-catalogue.com)

The IoT Catalogue provides a single access point to several IoT-related results from EU projects and beyond. The platform acts as a marketplace, which provides product/catalogue services in the IoT domain. PROPHESY results such as data collection, CPS components and data analytics modules fall in the realm of the Industrial Internet of Things and therefore could find a place in the IoT Catalogue. Moreover, the IoT Catalogue is a product of one of the project partners (namely UI), which can facilitate relevant integration efforts and synergies with PROPHESY. As a result, PROPHESY results could be hosted in the IoT Catalogue. While this will ease the project's marketplace and MSP development efforts, it will deprive the project from the opportunity of developing its own (predictive maintenance) brand. This trade-off between ease of development and potential lack of branding will be evaluated and resolved as part of the project's ecosystem and marketplace development efforts in WP6.

### 4.3.3 Partners' Sandbox Exploitation Platforms

Several PROPHESY partners have developed their own exploitation platforms and sandboxes. For example an exploitation sandbox platform in under development by the project coordinator (INTRA). The project will consider integrating some of its results in these sandboxes, which can help offering some of the specified functionalities (e.g., the demonstration of data analytics over the simulated datasets).

### 4.3.4 FoF-09 Cluster Collaboration

PROPHESY is joining a cluster of Predictive maintenance project, notably the projects that were successful as part of the H2020 FoF-09 call (such as H2020 UPTIME, H2020 SERENA, H2020 Z4BREAK, H2020 PROGRAMS and H2020 PRECOM). These projects have contractual obligations for exploitation and community building activities. PROPHESY will consider collaborating with these projects towards accelerating the formation of a critical mass of stakeholders for the PROPHESY MSP.

Note however that the above ecosystem buidling synergies are not mutually exclusive. PROPHESY may consider activating and exploiting all of them, in addition to developing its own MSP.

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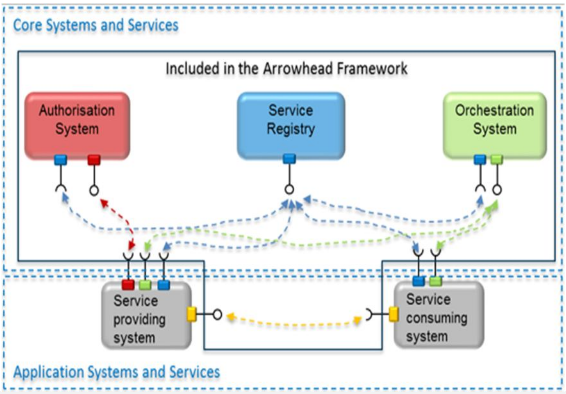
[10] M. Hausenblas and N. Bijnens, “Lambda Architecture,” *Lambda Architecture A repository dedicated to the Lambda Architecture (LA). We collect and publish examples and good practices around the LA.*, 2017. .

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

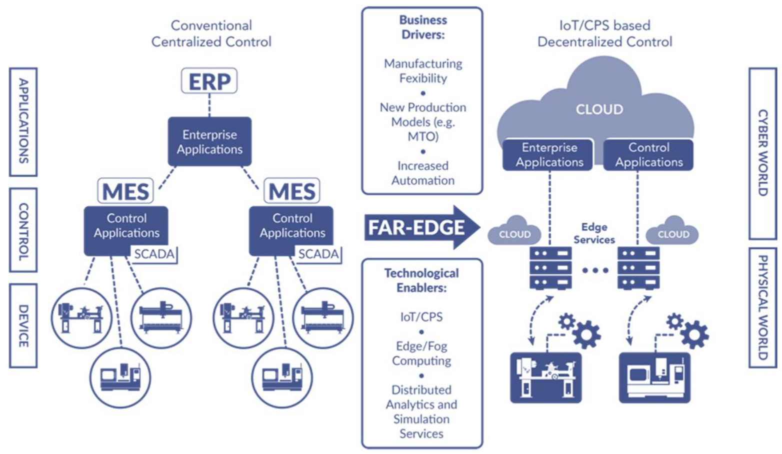
## A.1 European Research Projects

### 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** | <br> |
| **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;<br>• 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. |

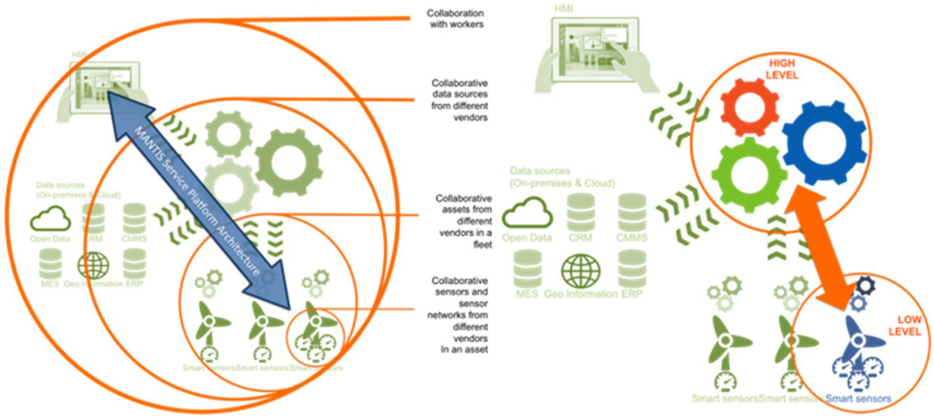
[3] http://www.arrowhead.eu

### 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;<br>• 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 |

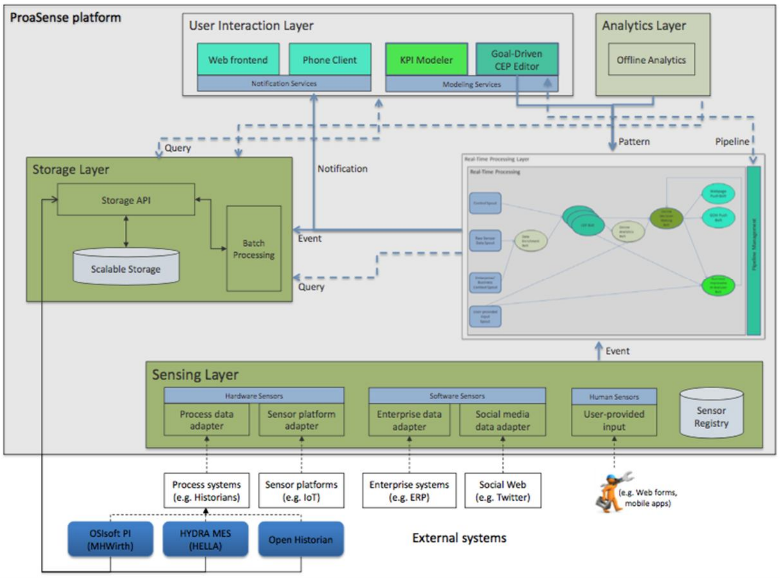
[4] http://www.faredge.eu/#/

### 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; |

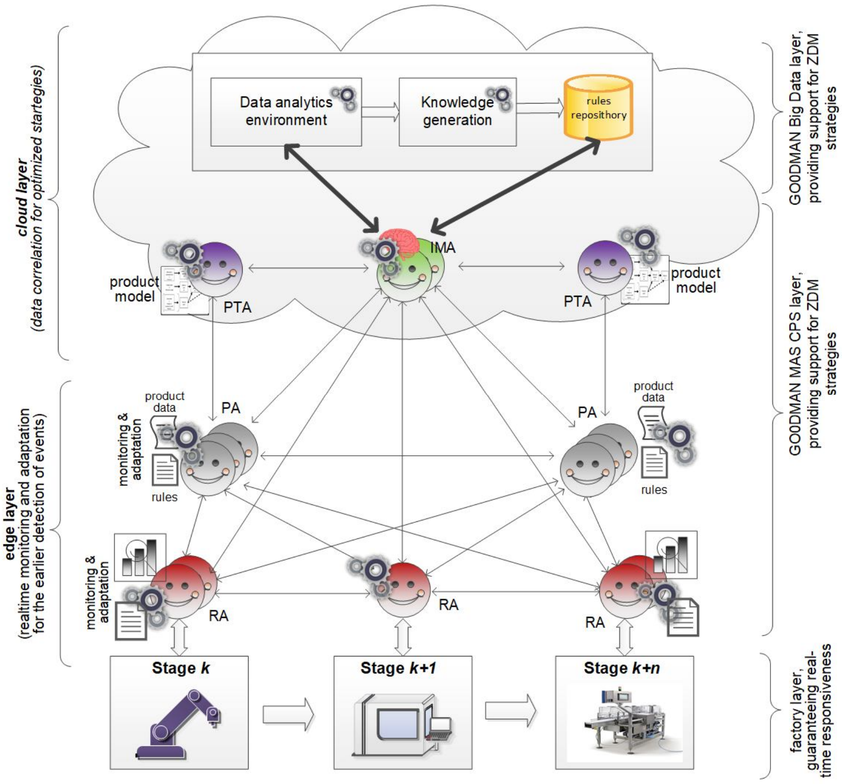
[5] http://www.mantis-project.eu

### A.1.4 ProaSense[6]

| STUDY | PROASENSE |
|---|---|
| **DESCRIPTION** | The ProaSense project was aimed to support an efficient transmission from Sensing to Proactive enterprise by:<br>• Exploiting the power of big enterprise data;<br>• Extracting actionable meaning from the data by deeply applying big data analytics;<br>• 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;<br>• The ProaSense Observe-Orient-Decide-Act (OODA) loop for situational awareness for supporting proactive maintenance and monitoring;<br>• The ProaSense event model, i.e. the identification of the relevant events and their structure;<br>• The Key Performance Indicators (KPI) modelling language; and<br>• The tool for KPI definition, monitoring and tracking. |

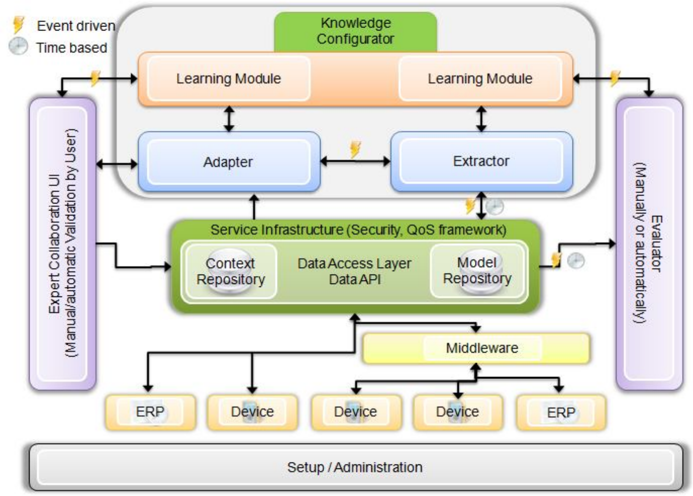
[6] http://www.proasense.eu

### A.1.5 GO0DMAN[7]

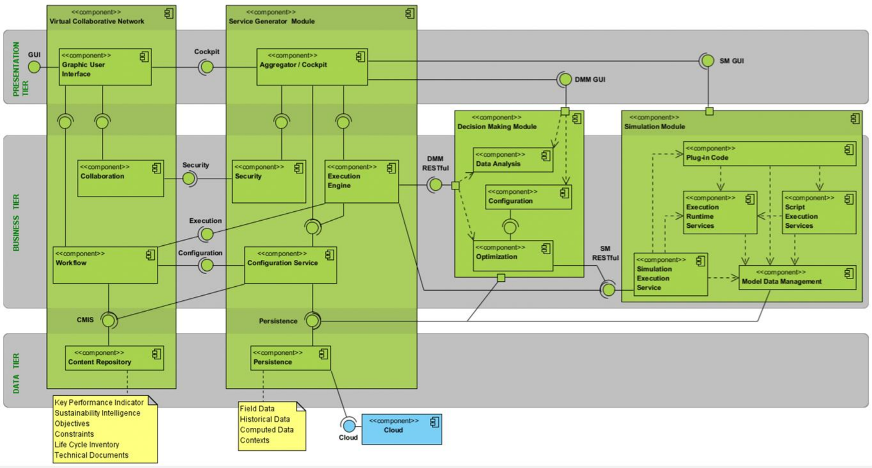
| **STUDY** | **GO0DMAN** |
|---|---|
| **DESCRIPTION** | The GO0DMAN project aims to integrate and combine process and quality control for multi- stage manufacturing systems using a distributed system architecture built upon an agent-based CPS and smart inspection tools designed to support ZDM strategies.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

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

### A.1.6 Self-Learning

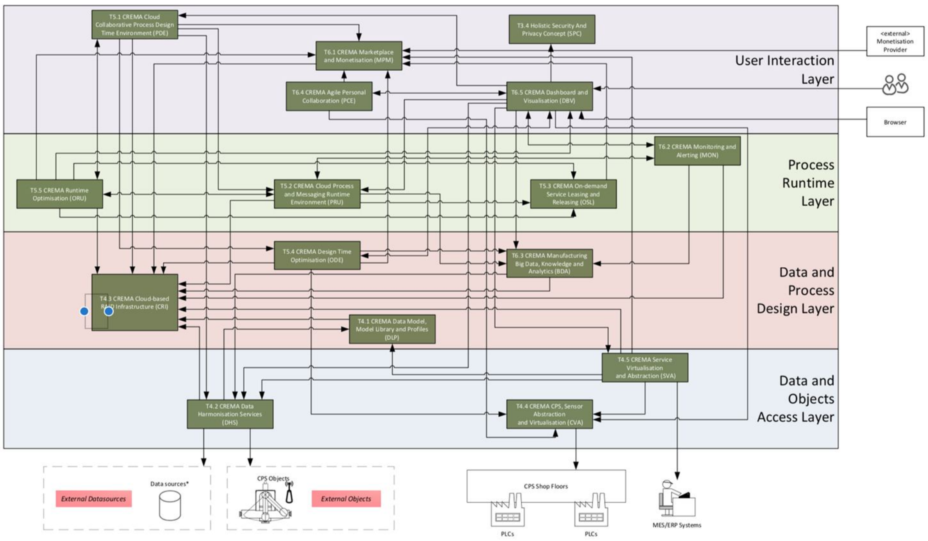
| STUDY | SELF-LEARNING |
|---|---|
| **DESCRIPTION** | The strategic objective is to strengthen EU leadership in production technologies in the global marketplace by developing innovative self-learning solutions to enable tight integration of control & maintenance of production systems. The project 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;<br>• Self-Adaptation and Self-Configuration of machine tools scheduling plans;<br>• Self-Adaptation, Configuration and learning tasks triggered by system expert. |

### A.1.7 EPES

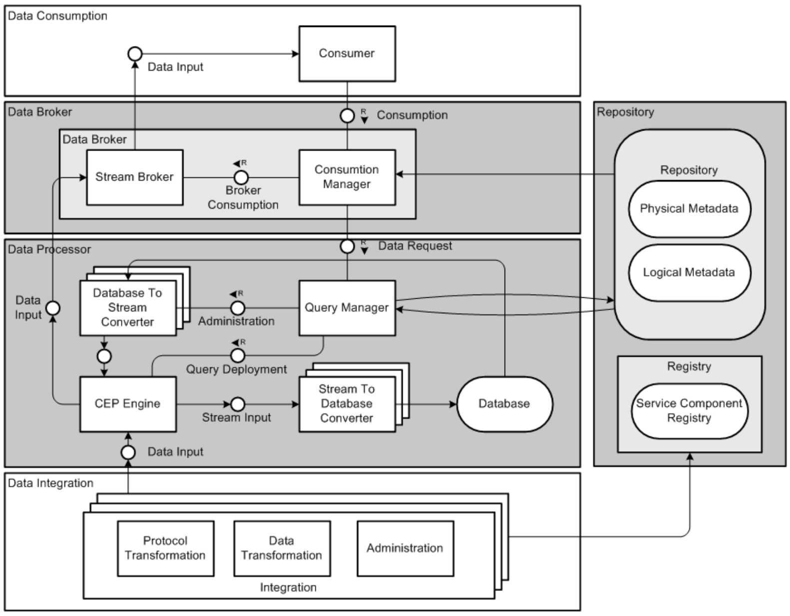
<table>
<tr><th>STUDY</th><th>EPES</th></tr>
<tr><td>DESCRIPTION</td><td>EPES provides service oriented ICT solutions to generate services, which improve the performance of highly customized industrial processes, products and services (PPS) during their life cycle, in cases in which no standard, off- 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.</td></tr>
<tr><td>THE FRAMEWORK/ ARCHITECTUR E</td><td>


</td></tr>
<tr><td>INPUT FOR PROPHESY-PDM</td><td>
<ul>
<li>Identification of the main requirements and desired features/characteristics for cloud-based platforms;</li>
<li>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.</li>
</ul>
</td></tr>
</table>

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

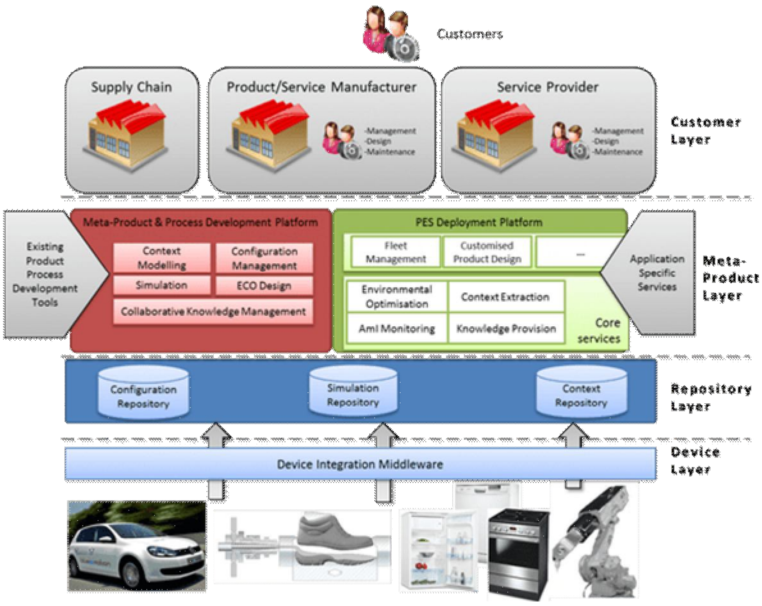
### A.1.9 KAP

<table>
<tr><th>STUDY</th><th>KAP</th></tr>
<tr><td>DESCRIPTION</td><td>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.</td></tr>
<tr><td>THE FRAMEWORK/ ARCHITECTURE</td><td>
</td></tr>
<tr><td>INPUT FOR PROPHESY-PDM</td><td><ul><li>Identification of the main requirements and desired features/characteristics for cloud-based platforms;</li><li>Architecture and design principles for CEP and data streams processors;</li><li>KPI definition, identification and online processing.</li></ul></td></tr>
</table>

### 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:<br>• Optimizing maintenance strategies based on the prediction of potential failures and schedule maintenance operations in convenient periods and avoid unexpected breakdowns<br>• Operation: Managing energy as a production resource and reduce its consumption<br>• Product reliability: Providing the machine tool builder with real data about the behaviour of the product and their critical components<br>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;<br>• 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;<br>• A secure ICT solution and service-based platform;<br>• Integration methodology and approach. |

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