Ref. Ares(2021)6730862 - 02/11/2021

AI·PROFICIENT

Artificial intelligence
for improved production efficiency,
quality and maintenance

Deliverable D1.5

D1.5: AI-PROFICIENT system architecture

WP 1: Pilot site characterization, requirements and system architecture

T1.5: AI-PROFICIENT system architecture

Version: 1.1

Dissemination Level: PU

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 957391.

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Disclaimer

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Title: D1.5 AI-PROFICIENT system architecture

Lead Beneficiary:	IMP
Due Date:	31.10.2021.
Submission Date	31.10.2021.
Status	Final
Description	AI-PROFICIENT system architecture
Authors	IMP, UL, TEK, CON, INEOS, INOS, ATC, IBE, TF, VTT
Type	Report
Review Status	PC + TL accepted
Action Requested	For acknowledgement by partners

VERSION	ACTION	OWNER	DATE
0.1	Initial Table of Contents	IMP	13.07.2020.
0.2.	Contribution by partners	UL, TEK, CON, INEOS, INOS, ATC, IBE, TF, VTT	14.07-10.09.2021.
0.3	Recommendation by the ethics team	UL	15.09.2021.
0.4	Changes according to ethics recommendations	IMP, UL, TEK, CON, INEOS, INOS, ATC, IBE, TF, VTT	16.09. – 01.10.2021.
0.5	Internal review by WP leader	CON	11.10.2021.
1.0	Draft ready for review by the project coordinator	IMP	15.10.2021.
1.1	Final version	IMP	28.10.2021.

Executive Summary

The Deliverable D1.5 is a public document of AI-PROFICIENT project delivered in the context of WP1, Task 1.5 with regard to the AI-PROFICIENT system architecture.

The aim of this document is to provide the architecture of the AI-PROFICIENT platform following the “ethics by design approach”. First, the relation to other tasks and work packages of the project is presented in order to provide the clear view of the information flow between this and other tasks. After summarizing the main project objectives and ethics by design approach, the state-of-the-art is provided. The aim of the state-of-the-art section is to outline the widely used standard architectures, EU projects and commercial products in the area of Industrial Internet of Things and smart manufacturing. Next, different parts of the architecture are presented: middleware, integration with the plant systems, and integration with external systems. Specific emphasis is given to the approach to integrate with the legacy equipment in the plants, especially having in mind the security constraints and data access policies at the plants. Then, a high-level overview of the services to be developed in the corresponding tasks are presented, where specific emphasis is given to service input/output and dependency on other services. Finally, the HMI specification and ethics team recommendations are presented.

2 Introduction

1.1 Scope

The aim of this document is to design the AI-PROFICIENT system architecture following an "ethics by design" approach and its service-oriented architecture. The AI-PROFICIENT platform envisions the build-up of service-oriented middleware which will interface on one side with AI services. On the other side, it will integrate with the manufacturing assets and operators as well as the new hardware provided by the project. In this regard, the aim of this task is to develop a high-level design of the underlying modules and services that comprise the AI-PROFICIENT solution.

It is important to note that the ethics by design approach with considerations in relation to pilot demonstration scenarios defined in Task 1.3 will be followed. More specifically, user interaction and use of AI-PROFICIENT solution regarding ethical impacts will be considered as primary requirement. The aforementioned goal will be reach by following AI-HLEG guidelines, user surveys and meetings between the stakeholders which is led by Project Ethics Officer.

The design process will take as an input the requirements provided in Deliverable D1.4. Moreover, it will include the high-level specification of AI services, in terms of the input and output data, information processing, and the interaction between the different platform components and their orchestration. A specific emphasis will be put on the exploitation of data coming from other legacy information sources. In addition, the specification will include the data acquisition and the data storage layer to ensure access to the required information on quality, operation, maintenance, condition, and alarms. Through the user-centred approach, specification of human-machine interaction, e.g. conversational interfaces for shop-floor assistance, will also be performed.

2.1 Audience

The intended audience for this document is the members of AI-PROFICIENT consortium, Project Officer as well as the general public, since this document is public. More specifically, the consortium members in charge of development, integration, AI service deployment and platform implementation are expected to use the content presented here.

2.2 Structure

The present document is divided into the following sections:

- **Section 1** provides the introduction to the content presented in this document
- **Section 2** illustrates the methodology followed in this document
- **Section 3** provides the state of the art in relation to platform architectures used in similar context
- **Section 4** aims to provide the proposed system architecture with other related components
- **Section 5** concludes the document

2 Methodology

The section will provide the relation of task 1.5 with other WP and tasks. Next it provides the summary of project requirements and functionalities from D1.4 and finally the Ethic by Design approach related to the present deliverable.

2.1 Relations to other tasks and work packages

As can be seen in Figure 1, Task 1.5 is related to other tasks from WP1 and other work packages. In particular, Task 1.3 provides the specification of the pilot specific demonstration scenario. Next, the output of Task 1.4 where project requirements and KPIs definition is taken as an input for this deliverable. The present document will be used as an input to the subsequent activities within the following work packages:

- WP2 Smart components and local AI at system edge
- WP3 Platform AI analytics and Decision-making support
- WP4 Human-machine interfaces, explainable AI and shop-floor feedback
- WP5 AI-PROFICIENT system integration and deployment

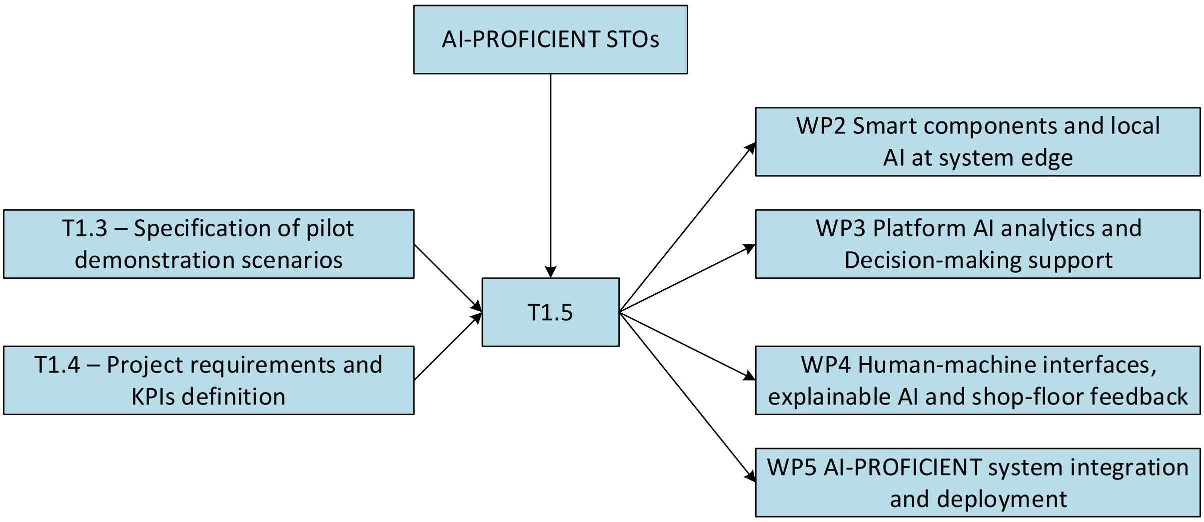

Figure 1: Relation of Task 1.5 with other tasks and work packages

2.2 AI-PROFICIENT Project objectives

AI-PROFICIENT project has a number of scientific and technical objectives (STOs), which have served as a basis for platform requirements defined in Task 1.4. In relation to the aforementioned STOs, the list of project requirements from Deliverable D1.4 are summarized in Table 1 below.

Table 1: Project requirements (D1.4)

Reference_STO	***Project Requirement_STO***
STO1	Integration of advanced AI technologies with production processes in IIoT environment. Leveraging the Industrial IIoT (IIoT) environment and digital retrofit of existing assets, AI-PROFICIENT will integrate the self-learning and self-prognostic AI services with the manufacturing systems and processes.
PR1_STO1	Integration of AI services under fully connected IIoT environment.
PR2_STO1	Deployment of system edge HW and SW components (for digitalization and integration).

PR3_STO1	Contribution to standardization in domain of AI and M2M interfacing.
STO2	AI for early detection of the process anomalies and provision of fault diagnostics. AI-PROFICIENT will embed the deep learning techniques and complex event processing capabilities for early-stage fault detection and diagnostics to improve OPE and product quality and provide failure prevention capabilities.
PR1_STO2	Development of prescriptive and predictive AI analytics for FDD.
PR2_STO2	Deployment of AI services for early-stage anomalies detection.
PR3_STO2	Empirical data exploration for AI model optimization and rule-base specification.
STO3	AI-based decision support for proactive maintenance at component and system level. To extend the Remaining Useful Life (RUL) of production assets, AI-PROFICIENT will provide a maintenance decision support by combining the predictive AI analytics with physical process modelling and digital twins.
PR1_STO3	Development of AI services for provision of proactive maintenance.
PR2_STO3	Deployment of proactive maintenance at both component and system level.
PR3_STO3	Optimization of predictive AI analytics based on empirical data.
STO4	Joint human-machine approach to improved production planning and execution. AI-PROFICIENT will deliver a multi-objective generative optimization approach, leveraging the human knowledge and feedback for reinforcement AI learning, in order to improve the production execution and scheduling.
PR1_STO4	Deployment of generative optimization service for production scheduling and execution.
PR2_STO4	Deployment of human interaction means for reinforcement learning.
PR3_STO4	Development of physical models and digital twins of underlying processes.
STO5	Demonstrators as case studies and early adopters. AI-PROFICIENT will be demonstrated in 3 production plants, operating different production processes, serving as a showcase of positive technical, financial and environmental impact of integrating the advanced AI technologies with manufacturing systems.
PR1_STO5	Perform demo case studies in operating conditions.
PR2_STO5	Integration of predictive and prescriptive AI analytics with manufacturing systems.
PR3_STO5	Use case validation analysis and impact assessment.
STO6	Ethical and legal aspects recommendation for effective human-machine collaboration. In co-creation with the end-users, AI-PROFICIENT will perform assessment of ethical and legal obstacles, deliver, and promote recommendations for trustworthy AI systems and improved human-machine interaction.
PR1_STO6	Analysis of ethical and legal aspects and provision of recommendations for manufacturing domain.
PR2_STO6	Deployment of suitable techniques to enable explainable and transparent AI.
PR3_STO6	Promotion of drawn conclusions at conferences, workshops and beyond.

Furthermore, D1.4 defines the general functionalities that AI-PROFICIENT project will deliver, which are summarized in Table 2.

Table 2: Functionalities to be provided by the AI-PROFICIENT project and their related ID.

AI-PROFICIENT Functionalities	***ID***
Monitoring	_MON
Diagnostic and anomaly detection	_DIA
Health state evaluation	_HEA
Component prognostics	_PRO
Hybrid models of production processes and digital twins	_HYB
Predictive Production quality assurance	_PRE
Root-cause identification	_ROO
Early anomaly detection	_EAR
Opportunistic maintenance decision-making	_OPP
Generative holistic optimization	_GEN
Future scenario based Lifelong self-learning system	_LSL
Human feedback	_HUM
Explainable and transparent decision making	_ETD

In the project, except the Monitoring functionality, all the other functionalities will be provided thanks to the development of services that are described in Section 4.4 of the present deliverable.

The monitoring functionality aims at gathering data from existing (legacy) system in addition to data collected from new devices and smart components. This functionality is described in more details in Sections 4.1, 4.2 and 4.3 of this document.

2.3 Ethics by design

A platform can be defined as a collection of assets shared between a set of products, including components, processes, knowledge, and people [1]. If so, then in relation to AI-PROFICIENT platform design and Task 1.5, it is relevant to ask: are the activities of the operators (and also process engineers) in the project and their knowledge and experience being viewed, as an integral part of the platform during its design phase? And how are these being viewed? If the architecture of complex systems is "an abstract description of the entities of a system and how they are related" [2] then the active relation of the human entities of the system to other entities – particularly their knowledge and experience – needs to be considered and described.

Humans are processes. By default, they are not fixed components, unless an abstraction is made toward their bodily physicality, as mere objects. They exhibit agency which causes unpredictability and emergent behaviour in system architectures [2]. Historically the tendency has often been to try to limit this unpredictability by regularizing or reducing the potential actions of the human process within the system [3].

Our suggestion is that the design process becomes un-ethical insofar as and in whatever ways it begins to view the human process as a fixed component and designs the system accordingly. Value is inherently non-static. Treating the human process in fixed ways devalues the human as an ongoing process of value generation.

To prevent this, insofar as possible:

- Review the proposed human relations to fixed and unfixed non-human entities of the system
- Correct and re-work areas where the design of the system is tending to engage humans as fixed components

- Make the best use of the character of the human process as the primary variable entity of the platform (i.e. give the human interesting variable tasks within the platform whenever possible, both in physical action and in meaningful use of acquired knowledge and experience).
- Create the 'set of stable constraints' [1] (the design rules), which govern the relationships among the components of the platform with the human – now and future – always in mind as a process entity in the system.

In other words, design and adapt the architecture of the platform around the human need for value, instead of assuming that the human will adapt to a platform designed to diminish their role. The human will adapt if they have to, but it isn't ethical to expect and promote this. This suggestion is thus the reverse of the human role defined in some of the original uses of the term Human in the Loop, e.g. [3] as a component of the system whose tasks are to be simplified in order to become more and more a fixed component. Some recommendations toward promoting this change of viewpoint follow below in Section 4.6.

3 State of the art

In the sequel, we provide the state of the art analysis with respect to standard architectures, commercial products and related project. Our aim is to investigate the features and benefits of the already available solutions which will serve as a basis of the AI-PROFICIENT platform architecture.

3.1 Standards

AI-PROFICENT platform reference architecture has to be considered as a reference (smart manufacturing) architecture for Industry 4.0 (I4.0) well mapped to the industrial automation pyramid. However, the boundaries between the different levels of this pyramid have increasingly become blurred due to the production flexibility and plant complexity required by such new industry type (see Figure 2). Indeed, emerging (digitalized) technologies are changing the way manufacturing systems are structured and operated, new concepts are inserted in solutions such as IoT, cloud computing, Big Data, AI tools, additive manufacturing, collaborative robotics, mobile technologies, among others. These disruptive technologies enable autonomous communications among multiple industrial devices distributed throughout a factory and on the Internet.

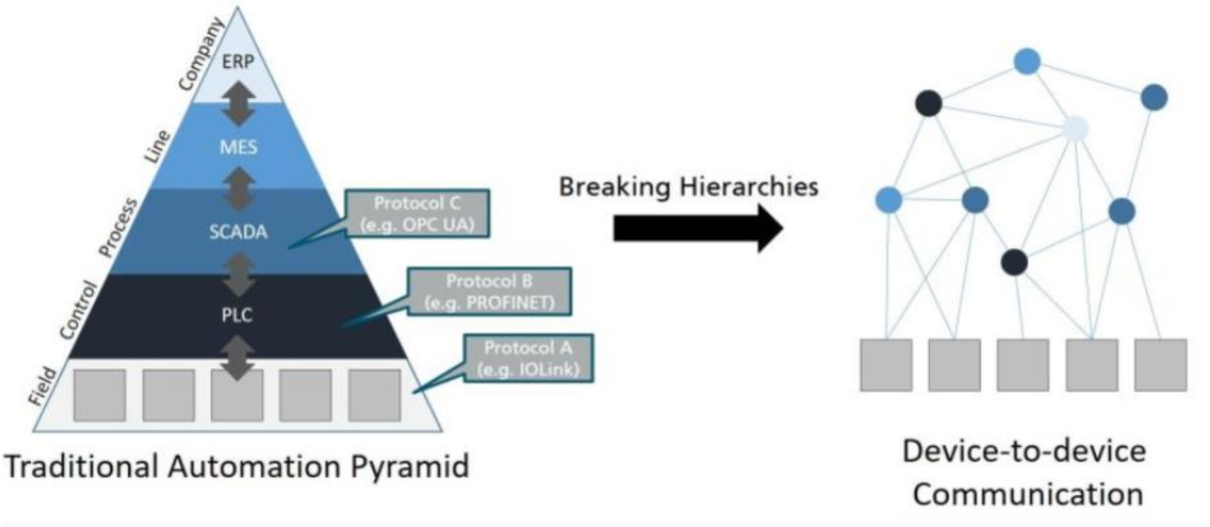

Figure 2: Transition from traditional industrial automation pyramid to cross-layer entity-to-entity communication [5]

Although these technologies are changing the type of interactions planned (towards Cyber Physical Production Systems - CPPS) between the automation levels, the levels themselves (e.g., field or edge, control, enterprise) are most of the time the structuring elements of the reference (model) architectures. An architecture is the initial step for the design of systems. It consists of a description (model) of the basic arrangement and connectivity of the parts of a system, which can either be a physical or conceptual objects or entities [4]. Reference models represent a common structure and language to describe and specify system structure and, therefore, are beneficial to promote common understanding and system interoperability. In the architectural definition of a digital manufacturing platform such as promoted by AI-PROFICIENT, the alignment to these reference models is positive because they provide a framework for the standardization of relevant technical systems, from development, through integration, to operation. Thus, the liaison with reference models provides the right orientation to system architecture definitions and fosters component orchestration, collaboration with relevant organizations, and internationalization. It is the way chosen by the AI-PROFICIENT project to be compliant to the known reference architectures in order to build our platform with full credibility, or even in complementarity, but in no case in contradiction.

For the most part, reference architecture for I4.0 are based on approved basis such as the Computer Integrated Manufacturing Open System Architecture (CIMOSA) [6] and the ISA SP95 standard [7], at least to some extent.

The most current well-known reference (Smart Manufacturing) architectures [8] are the following:

- **Reference Architecture Model Industry 4.0 (RAMI 4.0)** [9]: The architecture provides a common understanding of the relationships between various individual parts such as layers, lifecycle, and hierarchy levels of the Smart Manufacturing solutions landscape (Figure 3b). RAMI 4.0 is based on the Smart Grid Architecture Model (SGAM), a model developed for purposes of communication in networks of renewable energy sources which seems suitable for I4.0 applications as well. It also provides a common viewpoint for different applications too. More precisely, the RAMI 4.0 proposes six-layer descriptions (Business, Functional, Information, Communication, Integration, Asset) of functions differing in perspectives and levels of control found in manufacturing system.
- **The Industrial Internet Reference Architecture (IIRA) [10]**: It is providing a five-layer description of the functions in an industrial system, their interrelation, structure, and interactions (Figure 3a):
  - Business layer: functions that allow operation in any industrial system.
  - Application layer: functions that allow the management, monitoring and optimization of control systems through application logic.
  - Information layer: functions that support the provision, transformation, modelling and implementation of data.
  - Operations layer: functions that are responsible for provisioning, managing, monitoring components throughout their life cycle.
  - Control layer: functions that enable the control of an industrial system.

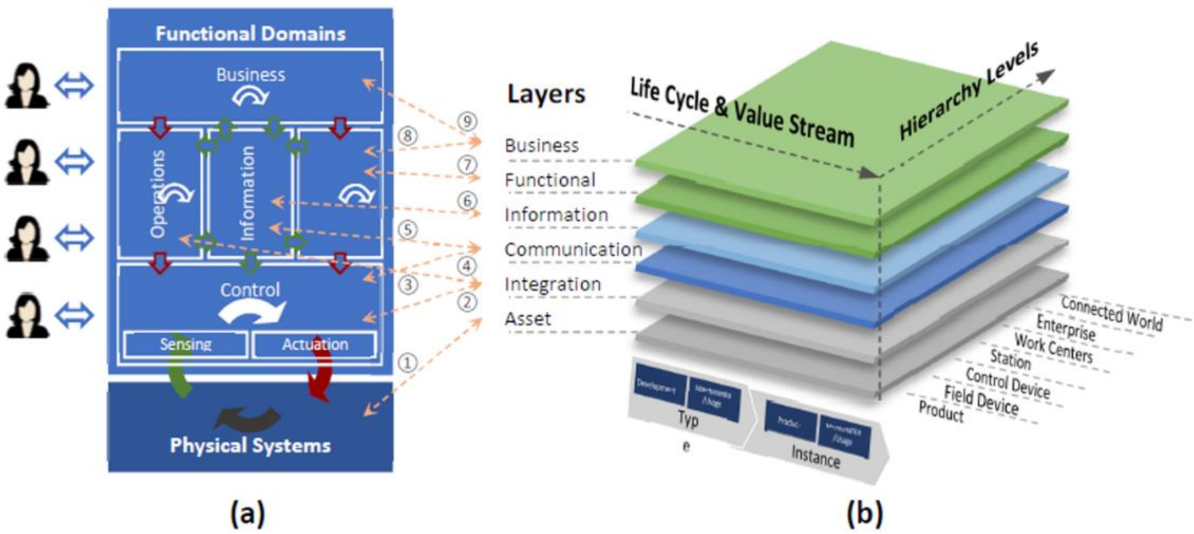

Figure 3: (a)The functional viewpoint of IIRA; (b) RAMI4.0. [18]

- **IBM industry 4.0 architecture [11]**: It is proposing, as for our AI-PROFICIENT project, a manufacturing solution based on three levels:
  - Edge level: is widely considered a trade-off and balance between enterprise constraints, management and operations considerations, latency and performance requirements, and data privacy constraints.
  - Plant, factory or shop floor level: the practice is to implement in each plant a service bus, often called a plant service bus (PSB), to manage local activities and connectivity with the physical environment: PLC, SCADA, OPC.
  - Enterprise or back-end level: at the enterprise level, enterprise or industry specific applications are deployed for various needs: asset management, maintenance management, consolidated data historian, ERP, optimization, production scheduling, PLM, and supply chain management.

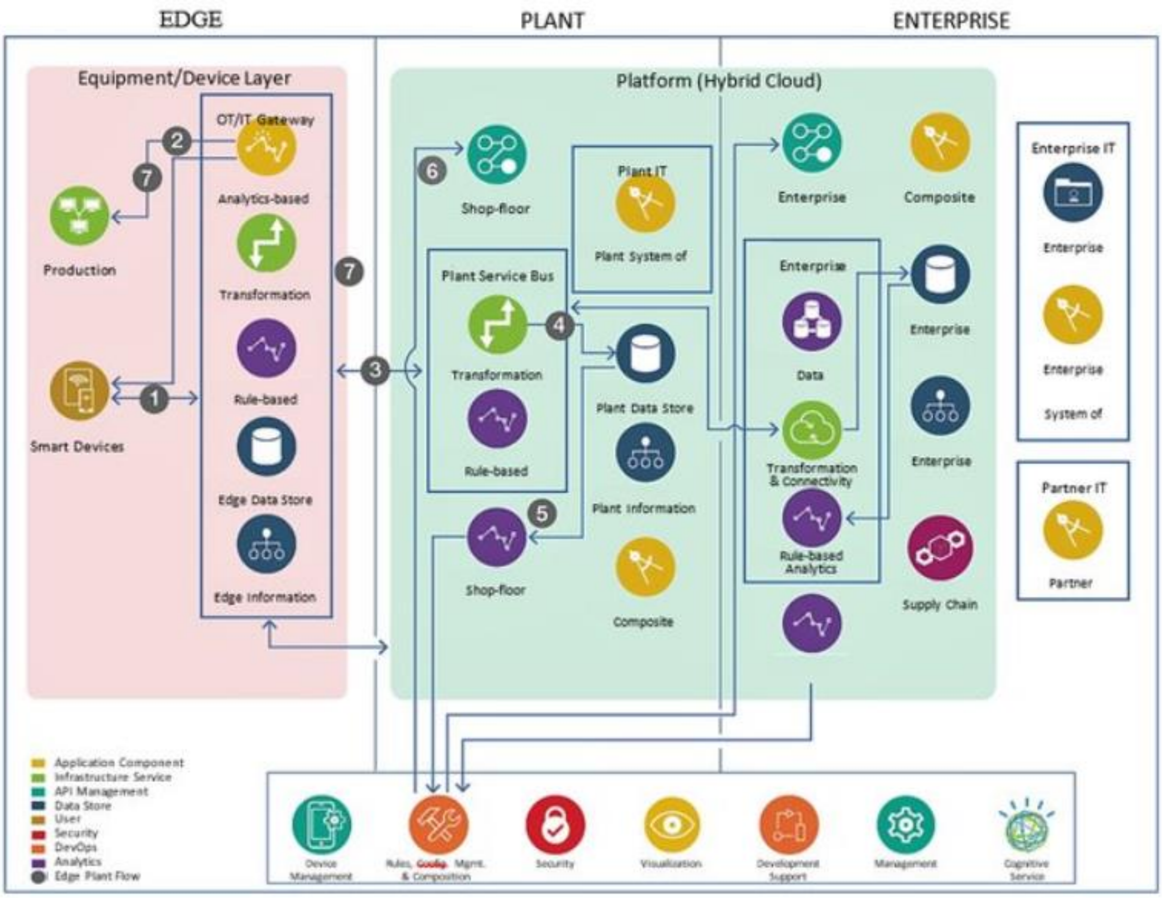

Figure 4: The IBM Industry 4.0 Architecture [11]

- **Intelligent Manufacturing System Architecture (IMSA) [12]:** It is an architecture proposed in China. It is constructed from three dimensions namely Lifecycle, System hierarchy, and Intelligent functions. The lifecycle refers to chain integration, consisting of a series of mutually connected value creation activities. All activities in the lifecycle are associated and mutually influence each other. From lower to upper levels, the system hierarchy refers to equipment level, control level, workshop level, enterprise-level, and cooperation level. The system hierarchy of intelligent manufacturing also represents the intelligence and Internet protocol of equipment and network flattening. The intelligent functions include five layers which are resources elements, system integration, interconnection, information fusion, and new business patterns.
- **Smart Manufacturing Ecosystem (SME) [13]**: It is issued from a common work of National Institute of Standards and Technology (NIST) and International Society of Automation (ISA). The Smart Manufacturing Ecosystem is organized along four dimensions.
  - Product lifecycle: covering phases such as design, process planning, production engineering, manufacturing, use & service, to EOL & recycling
  - Production lifecycle: covering phases such design, build, commission, operation & maintenance, to decommission & recycling.
  - Business: The supply chain cycle is from source, plan, make, deliver and return.
  - Manufacturing pyramid: this dimension is based on the IEC/ISO 62264 model.
- **Industrial Value Chain Reference Architecture (IVRA) [14]**: It is observing Smart Manufacturing units from 3 views:
  - Asset view: The view shows assets valuable to manufacturing enterprises. Four classes of assets (personnel, process, product and plant) are distinguished.
  - Activity view: The activity view is composed of the cycle of Plan, Do, Check and Action, which is the core methodology of total quality management and business process continuous improvement.

- Management view**:** The management view shows targets of management. Quality, cost, delivery accuracy, and environment are included.

- **Stuttgart IT-Architecture for Manufacturing (SITAM) [15]**: The SITAM architecture encompasses the entire product life cycle: Processes, physical resources, (i.e., CPS and machines), IT systems as well as web data sources provide the foundation for several layers of abstracting and value- adding IT. The integration middleware encapsulates these foundations into services and provides corresponding data exchange formats as well as mediation and orchestration functionalities. The analytics middleware and the mobile middleware build upon the integration middleware to provide predictive and prescriptive analytics for structured and unstructured data around the product life cycle and mobile interfaces for information provisioning. Together, the three middleware's enable the composition of value-added services for both human users and machines.
- **LAsim Smart Factory (LASFA) [16] :** LASFA is based on RAMI 4.0's layers and presents four building blocks (Business Process Management; MES + Digital Twins; Digital Twins for processes, logistics, and products; and Control-process communication + Production processes), which contain well-known systems (e.g., ERP, MES, and PLM), digital twins, and the information/data flow among them.
- **5C Architecture [17]**: The 5C Architecture is based on automation processes models, and it is centred in a data acquisition model for industrial devices. It is well representative of the new Cyber-Physical Systems (CPS). In that way, these 5 levels are Smart Connection, Data-to-Information Conversion, Cybernetic, Cognition, Configuration.

These previous significant reference architectures can be easily map to the industrial automation pyramid as shown in Figure 5.

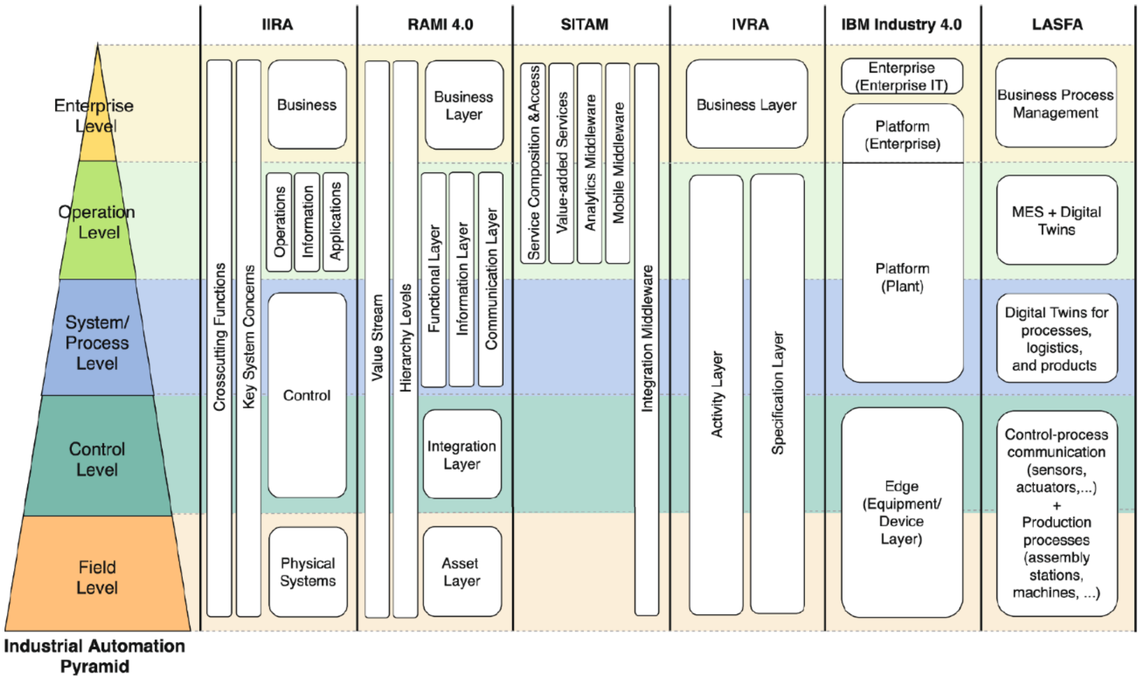

Figure 5: Mapping of Industry 4.0 reference architectures to the industrial automation pyramid [21]

In addition to the previous ones, others reference architectures with specific focus can be mentioned such as ISD (Industrial Data Space), Industrial Internet Integrated Reference Model (I3RM), IEC-TC 65/AHG 3 Smart Manufacturing Reference Architecture, the IEEE 2413 IoT Reference Architecture, the ISO/IEC CD 30141 Internet of Things Reference Architecture, the one M2M Architecture, and the Industrial Value Chain Reference Architecture. Work has also been done by the Manufacturing Enterprise Solutions Association, commonly known as MESA, although they have recently partnered with the Industrial Internet Consortium [18]. Most of these architectures are referred to Platform Industry 4.0 and Industrial Internet Consortium (IIC), two of the largest organizations that research on topics related to Industry and the Industrial Internet respectively.

Regarding the main differences among the architectures [19] [20], each one has its specificity and contributes to some knowledge by covering different levels of automation pyramid [19] [20]. For example, RAMI 4.0 and IVRA establish concepts and the overall organization of smart factories. IIRA, RAMI 4.0 and IVRA are more architectures involving consortia, IBM Industry 4.0 a commercial architecture while SITAM and LASFA are academic ones. SME architecture is more complete than RAMI 4.0 and IMSA. It covers additional sub-dimensions' criteria such as manufacturing mode development, new materials, communication technology development, data storage technology development and capability/performance. SME, RAMI4.0 and IMSA are also defined in connection with each other (see Table 3).

Table 3: Comparison of SME, RAMI 4.0 and IMSA Reference Architectures [20]

Dimension	Sub -dimensions	SME	RAMI 4.0	IMSA
Business / Management	System Hierarchy	X	X	X
	Product Lifecycle	X	X	X
	Business (Supply Chain) Lifecycle	X	X	X
	Production Lifecycle	X	X	X
	Manufacturing Mode Development	X		
Industrial Technology Revolution	New Equipment	X	X	X
	New Manufacturing Process Techniques	X	X	X
	New Energy			
	New Materials	X		
Information Technology Revolution	Function Layers	X	X	X
	Communication Technology Development	X		
	Network Technique Development	X		X
	Data Storage Technology Development	X		
	Database Technology Development		X	X
	IT Infrastructure Development		X	X
	CAX / Simulation Technology Development	X	X	
Human/Organization Promotion	Organization Management Scope	X		
	Human Resource Talent Levels			
	Capability/Performance	X		

More precisely, RAMI 4.0 puts together different dimensions of the Industry 4.0 space, describes all crucial components of Industry 4.0. and is based on international standards: IEC 62890 (for lifecycles of products and production) as well as IEC 62264 and IEC 61512 (both for hierarchy levels of companies and factories regarding their various functionalities).

More pragmatically the consideration of the dimensions and/or layers in general within these reference architectures lead to the use of a combination of software, hardware, technologies and tools to support the required level of automation on I4.0 (see Figure 5). For example, well-known generic technologies are HTTP, OSAP/REST, XML, SysML, MySQL/ SPARQL, and concepts are cloud, AAS or digital twins. More particular technologies well adapted for I4.0 systems, and that can be used for AI-PROFICIENT platform, are illustrated in Table 4.

Table 4: Examples of platforms, technologies, and tools used in Industry 4.0 reference architectures [21]

Reference architecture	Software platforms	Technologies	Tools
IIRA	N/A	IIoT, M2M, Big Data, Data analytics, OPC UA	N/A
RAMI 4.0	OPC UA server, ABB RAPID language, Java-based OPC, UA CAEX XML, Jena API, Java JEE, Graph DB, Mongo DB, RDF store, SSN ontology, MS Azure, Apache ActiveMQ, JADE, ZigBee, Hadoop, Beagle Bone Blue (BBBlue), OpenCV, RCPY library, Robot control library	PLC, CAD/3D, MQTT, OPC UA, DDS, AML Data model, IoT Gateway, Ontology Knowledge repository, M2M, Big Data, Data analytics, Cloud ERP, RFID, Publish-subscribe middleware, Digital twin manager Reasoner, MES, PLC, OLTP, SDN	Automation system workbench vueOne simulator vMan, OPC UA toolkit, Sparx RAMI 4.0 toolbox
SITAM	WSO2's Application Server and Business Process Server, Alfresco CMS, Neoj4, Apache UIMA	Analytics middleware Mobile middleware, Knowledge repository, SOA, KPI mgmt., NoSQL	N/A
IVRA	N/A	IoT	N/A
IBM Industry 4.0	Watson IoT	IoT, MES, PLC, OPC UA, MQTT	Core enterprise asset management (EAM), Maximo APM
LASFA	N/A	RFID, ERP	Sparx RAMI 4.0 toolbox

In that way, all architectures analysed strive for **standardization**, which refers to those architectures that promote communication and understanding among stakeholders and/or intend to improve system/technologies/software/tools **interoperability**. Indeed, standardization and interoperability are two major concerns of the reference architecture. So, Figure 6 illustrates the standards/protocols commonly used in the architecture reference models and related standards/protocol in line with Industry 4.0 automation layers.

Function description	Architecture reference models	Standards and protocols
Physical Industrial Asset	RAMI 4.0 Asset Layer IIRA Physical System5 C Smart Connection Level	ISO/TS 14649-201, IEC 61360
Virtual representation of assets and functions for industrial control systems	RAMI 4.0 Integration and Functional Layers IIRA Control Domain5 C Cybernetic Level	ModBus, ISO 15926, ISO 15746
Standardized communication for data, assets and services	RAMI 4.0 Communication Layer IIRA Connectivity Crosscutting Function 5C Cybernetic Level	RFC 2616 (HTTP), IEC 61784, IEC 29182-1, RFC 7540 (HTTP2), TCP, UDP, IP, 6LoWPAN, CoAP, MQTT, DDS, IEC 62541 (OPC UA), Web Services, oneM2M, TSN, 5G
Data processing for collecting, transformation, modeling and analyzing	RAMI 4.0 Information Layer IIRA Information Domain 5C Data-to-Information Conversion Level	IEC 62714, IEC 24760, ISO 19629 **Semantics:** SPARQL, RDF(S), OWL, RIF/SRWL
Runtime environment for applications, assets technical functionality, in addition to management and maintenance functions	RAMI 4.0 Functional Layer IIRA Application and Operation Domains 5C Cognition Level	IEC 62337, ISO 19629
Business functions and support to business models	RAMI 4.0 Business Layer IIRA Business Domain5 C Configuration Level	ISO 19439, B2MML, ISO 22400, ISO 13374, ISO 15704

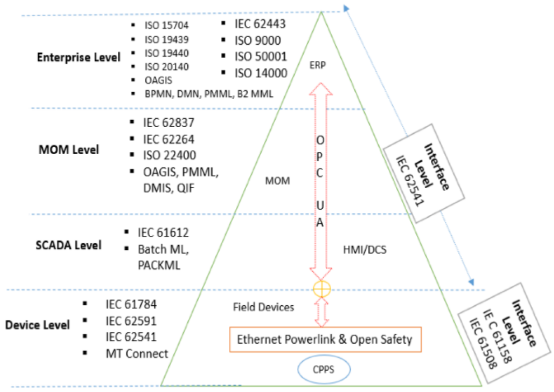

Figure 6: (a) Architecture reference models and related standards/protocols [22] in line with I4.0 automation layer [20] (b).

These standards/protocols are addressing interoperability issues defined as the ability of two or more entities to interact and cooperate. ISO 16100 defines interoperability as "the ability to share and exchange information using a common syntax and semantics to meet an application specific functional relationship across a common interface". In smart manufacturing, interoperability takes two general forms. The first form corresponds with vertical integration (Factory Integration), e.g., interoperability between the manufacturing software, the shop–floor departments, the processes performed by different equipment, the various shop–floor systems, and so forth. The second form corresponds with horizontal integration (Cloud-Manufacturing Interoperability); the interoperability between smart automation devices, cloud services, cloud platforms, and enterprises [23]. Beyond these 2 levels of interoperability, the reference architectures and so our project too must also be compliant more globally with European Interoperability Reference Architecture (EIRA) [24].

In conclusion with regards to the development and use of reference architectures in the way to implement smart manufacturing platform and more precisely the AI-PROFICIENT one, several issues not solved today should be paid attention as underlined in [18] [21] [8]:

- RAMI4.0 provides a systematic approach for describing smart objects as I4.0 components through specifying a list of characteristics enabled by an administration shell. The focus of RAMI4.0 and other relevant developments, however, has primarily been on how smart objects communicate, and not necessarily on how they interact in an autonomous and adaptive fashion to enable plug-and-produce work.
- Mechanisms for dynamic and decentralized mapping of smart objects onto microservices (i.e., the allocated architecture) have not been clearly addressed by any of the current reference architectures.
- None of the current reference architectures specifies how humans inhabit and interact with the emerging manufacturing systems and environments (i.e., human-machine symbiosis).
- Interoperability is still a big current challenge in smart manufacturing. Even the existing reference architectures, which in most cases present layers/ levels, building blocks, and/or communication among them, do not detail exactly how such communication should occur or which data should be exchanged among diverse components of large Industry 4.0 systems.
- Hence, many decisions must be made during the adoption of current architectures in industry projects. There is still no consensus on how to deal with legacy industrial systems, which often need to continue operating.
- Another issue to keep in mind is that reference architectures should also encompass both legacy systems and quality issues.
- There is also a need to change the mindset regarding reference architectures since they should address not only the general architecture (composed of building blocks as in many existing architectures) but also local architectures (e.g., of a set of systems that are part of a specific level/layer that forms a building block).
- They should also combine technologies that make the components (machines, devices, PLC, robots, software systems like ERP and digital twins, and others) as independent as possible and, at the same time, as connectable as possible at runtime in order to achieve a balance between independence and connectivity among components.

The aforementioned challenges will be taken as an input for the development of the AI-PROFICIENT platform and its components in related tasks and work packages.

3.2 EU projects

Apart from AI-PROFICIENT, 8 additional projects have been funded by the ICT-38-2020 topic. At the moment of writing this deliverable, all these projects have less than a year since their official kick-off, so the public information available is rather limited. Below, a short description of each project is provided, as well as a link to their official webpage in CORDIS.

- **MAS4AI** (Multi-Agent Systems for Pervasive Artificial Intelligence for assisting Humans in Modular Production Environments). The project will develop a system that allows the deployment and synchronization of different AI agents in manufacturing for autonomous modular production and human assistance. By incorporating AI technologies, the project will optimize manufacturing costs and adapt routes, tools and parameters. https://cordis.europa.eu/project/id/957204
- **TEAMING** (Human-AI Teaming Platform for Maintaining and Evolving AI Systems in Manufacturing). It aims to make a breakthrough in smart manufacturing. By introducing a new human and AI teaming framework, manufacturing processes will be optimized: the greatest strengths of both these elements can be maximized while safety and ethical compliance guidelines are examined and maintained. https://cordis.europa.eu/project/id/957402
- **STAR** (Safe and Trusted Human Centric Artificial Intelligence in Future Manufacturing Lines). The project will aim to research and integrate leading-edge AI technologies like active learning systems, simulated reality systems, explainable AI, human-centric digital twins, advanced

reinforcement learning techniques and cyber-defence mechanisms, to allow the safe deployment of sophisticated AI systems in production lines. https://cordis.europa.eu/project/id/956573

- **KnowlEdge** (Towards AI powered manufacturing services, processes, and products in an edge-to-cloud-knowlEdge continuum for humans [in-the-loop]). The project will address the need for new AI solutions that are agile, reusable, distributed, scalable, accountable, secure, standardized and collaborative. The proposed new framework will ensure the secure management of distributed data and facilitate knowledge exchange. To achieve its goal, the project will combine innovative technologies from data management, data analytics and knowledge management. https://cordis.europa.eu/project/id/957331
- **ASSISTANT** (leArning and robuSt deciSIon SupporT systems for agile mANufacTuring environments). The project aims to develop breakthrough solutions for the manufacturing industry, using artificial intelligence to optimize production systems. One of the keystones of ASSISTANT is the creation of intelligent digital twins. By combining machine learning, optimization, simulation, and domain models, ASSISTANT develops tools and solutions providing all required information to help production managers design production lines, plan production, and improve machine settings for effective and sustainable decisions that guarantee product quality and safety. https://cordis.europa.eu/project/id/101000165
- **EU-Japan.AI** (Advancing Collaboration and Exchange of Knowledge Between the EU and Japan for AI-Driven Innovation in Manufacturing). The project will develop a platform-based approach to connect relevant stakeholders from the EU and Japan and support knowledge exchange on innovative AI applications for manufacturing. In addition to other tools, this platform will include an open-information hub. The project will also organize workshops to address current needs, consider future requirements and stimulate a long-term cooperation. https://cordis.europa.eu/project/id/957339
- **XMANAI** (Explainable Manufacturing Artificial Intelligence). The project will focus on explainable AI, a concept that contradicts the idea of the 'black box' in machine learning, where even the designers cannot explain why the AI reaches at a specific decision. XMANAI will carve out a 'human-centric', trustful approach that will be tested in real-life manufacturing cases. The aim is to transform the manufacturing value chain with 'glass box' models that are explainable to a 'human in the loop' and produce value-based explanations. https://cordis.europa.eu/project/id/957362
- **COALA** (COgnitive Assisted agile manufacturing for a LAbor force supported by trustworthy Artificial Intelligence). The project will design and develop a cutting-edge Digital Intelligent Assistant for the manufacturing sector. At its core is the privacy-focused, open-source voice assistant, Mycroft. COALA will integrate, for instance, augmented quality analytics, an experimental mechanism for explainable AI, and features for the assistance of on-the-job training. An AI-focused change management process and guidelines for professional worker education will complement the technical work. The project will significantly decrease the costs of failures in manufacturing and will reduce training time for workers. https://cordis.europa.eu/project/id/957296

Likewise, a set of relevant EU-funded research and development projects' output and gained experience will be leveraged in the development activities planned for AI-PROFICIENT. This set of projects include, among others, the following H2020 projects:

- **AI4EU** (A European AI On Demand Platform and Ecosystem - https://cordis.europa.eu/project/id/825619). Develops the first European AI on-demand platform and ecosystem comprised of the AI tools, data sources and computational resources. AI-PROFICIENT will build upon the results of AI4EU, by exploiting and integrating with the platform AI enablers, tools and algorithms.
- **Co-Factor** (Cooperate, Communicate and Connect to boost smart Components for tomorrows Industry - https://cordis.europa.eu/project/id/637178). Clustered projects which were focused on speeding-up the industrial up-take of results in domain of the "smart components". The results of Co-FACTOR projects will be considered for adoption and advancement in the field of smart components and edge AI tools.
- **MANTIS** (Cyber Physical System based Proactive Collaborative Maintenance - https://cordis.europa.eu/project/id/662189). Developed a proactive maintenance service platform based on Cyber Physical Systems that allows to estimate future performance, and

schedule maintenance. Proactive maintenance services of AI-PROFICIENT will leverage and advance the MANTIS concepts to combine edge and system level AI insights.

- **Cogniplant** (Cognitive platform to enhance 360º performance and sustainability of the European process industry - https://cordis.europa.eu/project/id/869931). Digital twin models for the optimization of production processes in areas such as the steel industry and related applications. Human interaction tools (e.g. visual analytics and conversational interfaces) will be coupled with digital twins to improve the Explainable AI concepts within AI-PROFICIENT.
- **Twin-Control** (Twin-model based virtual manufacturing for machine tool-process simulation and control - https://cordis.europa.eu/project/id/680725). The digital twin model as foundation for the virtual smart components (e.g. linear axis, milling head) and the link between the virtual machine and the real machine behaviour and health. The process modelling will go beyond prediction in AI-PROFICIENT and Remaining Useful Life, to become "prescriptive" by correlating with other operation data of the plant (e.g. operations and quality).
- **BigDataEurope** (Integrating Big Data, Software and Communities for Addressing Europe's Societal Challenges - https://cordis.europa.eu/project/id/644564). Development of the Big Data Integrator (BDI) platform: an easy-to-setup, easy-to-use and adaptable (cluster-based and standalone) platform for fast deployment of Big Data frameworks and tools. The flexibility and adaptability of the BDI platform (as Docker ecosystem) allows it to be easily configured for the integration with the AI-PROFICIENT platform and its components.
- **DISRUPT** (Decentralized architectures for optimized operations via virtualized processes and manufacturing ecosystem collaboration - https://cordis.europa.eu/project/id/723541). Development of a decision support platform for Industry 4.0 by combining the modelling, simulation and optimization concepts. DISRUPT platform enablers (modelling, simulation and optimization) will be considered in AI-PROFICIENT for potential advancement of shop floor assistance.
- **SusPIRE** (Sustainable Production of Industrial Recovered Energy using energy dissipative and storage technologies - https://cordis.europa.eu/project/id/680169). A smart management tool was developed to achieve higher productivity and energy recovery rate as possible from residual heat streams in plants. The Underlying edge AI concepts to reduce the scrap production and save energy will be adopted and enhanced for production processes of project pilots.
- **A4Blue** (Adaptive Automation in Assembly for BLUE collar workers satisfaction in Evolvable context - https://cordis.europa.eu/project/id/723828). Development of a new generation of sustainable, adaptive workplaces dealing with evolving requirements of manufacturing processes. The AI-PROFICIENT project can benefit from the expertise in human-machine interaction and conversational interfaces acquired during the project.
- **BrainedFactory** (Smart Manufacturing Platform for Industrial Part Production through Artificial Intelligence, Big Data & Robotics - https://cordis.europa.eu/project/id/816098). Smart Factory platform integrating the Industry 4.0 and digital transformation to streamline and improve the whole process. It provides quotations, process engineering and manufacturing of industrial parts with maximum customisation in process design, lead time and production cost reduction, higher production plan capacity, scalability, stability, less errors during the process and predictive maintenance.
- **AUTOWARE** (Wireless Autonomous, Reliable and Resilient Production Operation ARchitecture for Cognitive Manufacturing - https://cordis.europa.eu/project/id/723909). Build three distinct pillars to form a multi-sided ecosystem. (1) From the BeinCPPS, leverage a reference architecture (fully aligned with CRYSTAL and EMC2 CPS design practices and ARROWHEAD cloudification approach) across I4MS competence domains (cloud, CPPS, robotics), acting as a glue that will attract potential users and developers to a friendly ecosystem for business development, more efficient service development over harmonized architectures (smart machine, cloudified control, cognitive planning- app-ized operation). (2) To leverage a number of SME enablers; e.g. augmented virtuality, reliable wireless communications, CPPS trusted auto-configuration, smart data distribution and cognitive planning to ease cognitive autonomous systems. Finally, to leverage digital automation investments. Finally, to leverage digital automation investments. AUTOWARE brings together the best of breed ARTEMISIA/ECSEL platforms, I4MS innovation, SAFIR business platforms and neutral experimental sites (robotics & process).

- **GO0D MAN** (aGent Oriented Zero Defect Multi-stage mANufacturing - https://cordis.europa.eu/project/id/723764) The main idea of GO0D MAN project is to integrate and combine process and quality control for a multi –stage manufacturing production into a distributed system architecture built on agent-based Cyber-Physical Systems (CPS) and smart inspection tools designed to support Zero-Defect Manufacturing (ZDM) strategies. Data analytics tools provide a mean for knowledge build-up, system control and ZDM management. Real time and early identification of deviations and trends, performed at local level, allow to prevent the generation of defects at single stage and their propagation to down-stream processes, enabling the global system to be predictive (early detection of process faults) and proactive (self-adaptation to different conditions).
- **SAFIRE** (Cloud-based Situational Analysis for Factories providing Real-time Reconfiguration Services https://cordis.europa.eu/project/id/723634) - The SAFIRE project will provide technology and infrastructure to enable Reconfiguration as a Service for dynamic smart factory systems and manufactured smart products that take advantage of cloud-based services and computing power to continually optimize the performance of manufacturing systems and products with respect to key performance characteristics including throughput, power consumption, utilisation, maintenance and other factors. A key objective of the project is to develop cloud-based analytics and reconfiguration capabilities that extend the operating systems of smart factories.
- **COMPOSITION** (Ecosystem for Collaborative Manufacturing Processes – Intra- and Interfactory Integration and Automation - https://cordis.europa.eu/project/id/723145). COMPOSITION will create a digital automation framework (the COMPOSITION IIMS) that optimizes the manufacturing processes by exploiting existing data, knowledge and tools to increase productivity and dynamically adapt to changing market requirements. This technology acts as the technical operating system for business connections between factories and their suppliers. Furthermore, it opens a new space for third party entities to actively interact in the supply chain, e.g. by providing services to improve cycle time, cost, flexibility or resource usage.
- **PreCoM** (Predictive Cognitive Maintenance Decision Support System - https://cordis.europa.eu/project/id/768575). The project will deploy and test a predictive cognitive maintenance decision-support system able to identify and localize damage, assess damage severity, predict damage evolution, assess remaining asset life, reduce the probability of false alarms, provide more accurate failure detection, issue notices to conduct preventive maintenance actions and ultimately increase in-service efficiency of machines by at least 10%.
- **VIMS** (Virtual IoT Maintenance System - https://cordis.europa.eu/project/id/878757). The EU funded VIMS project aims to develop a ground-breaking digital ecosystem for entire industrial and manufacturing maintenance systems. VIMS will link the IIoT platform with its virtual replica – the digital twin of the production line. Via data analyses through machine learning and artificial intelligence, it will obtain a wholistic picture. Augmented reality and virtual reality will then permit remotely controlled predictive and optimised maintenance processes
- **IMOCO4.E** (Intelligent Motion Control under Industry 4.E - https://cordis.europa.eu/project/id/101007311). MOCO4.E targets to provide vertically distributed edge-to-cloud intelligence for machines, robots and other human-in-the-loop cyber-physical systems having actively controlled moving elements. They face ever-growing requirements on long-term energy efficiency, size, motion speed, precision, adaptability, self-diagnostic, secure connectivity or new human-cognitive features. IMOCO4.E strives to perceive and understand complex machines and robots. The two main pillars of the project are digital twins and AI principles (machine/deep learning).
- **OPTIMAI** (Optimizing Manufacturing Processes through Artificial Intelligence and Virtualization - https://cordis.europa.eu/project/id/958264). Industry is the backbone of the European economy. Enabling technologies like artificial intelligence (AI) and digital twins (DT) are powering remarkable growth potential and driving the next generation of industry. Using these technologies, the EU-funded OPTIMAI project will strive to strike an optimal balance between fast, cheap and reliable production choices that have a big impact on the competitiveness of an industry. To this end, the project will develop smart instrumentation of production with AI-enabled sensors for quality inspection and monitoring.

During further phases of the AI-PROFICIENT project, the consortium member will closely monitor the outcomes of the aforementioned projects that are currently active. Possible synergies will be considered, especially with AI4EU, for which a separate Task 5.4 in HESTIA project is devoted. Within that task, the focus will be on building upon the results of AI4EU by exploiting the available data sets and AI on-demand platform services.

3.3 Commercial products

AI-PROFICIENT deals with Industrial IoT and production plants digitization. Such market have attracted many different actors to this field. On the market, there already exist a number of commercial products focused on this promising field. In the sequel, we list the most prominent ones:

PTC ThingWorx represents a platform for applications development for the IoT. It consists of the following components:

- ThingWorx Foundation which connects the subsequent components and contains rapid application development tools. This component contains security and DevOps services as well as connection services for tunnelling servers. Additional subcomponent, ThingWorx Foundation Edge, also contains a server software for IoT edge devices, and a software development kit for PTC's AlwaysOn Protocol.
- ThingWorx Utilities aimed to help business customers to define, monitor and manage the connected products in addition to creating and managing business processes related to the IoT devices. The connectors can be reused in new business processes and devices.
- ThingWorx Analytics contains simulation and predictive analytics features in order to help the end users obtain value from data which are collected from devices. This component can also detect anomalies and patterns in real-time data, predict equipment failure and optimize them by automatically detecting the reasons of different outcomes.
- Kepware KepServerEX represents an IoT gateway and network software for integration of the industrial systems, such as supervisory control and data acquisition (SCADA) and manufacturing execution system (MES) software.

Oracle IoT cloud service enables secure and reliable bidirectional communication between IoT devices and the cloud. The devices can be connected to the cloud directly via Internet, or indirectly through a gateway. Oracle IoT Cloud Service attaches a unique digital identity to each device in order to establish trust relationships between different devices and applications. In addition, it enforces authentication and authorization for end-to-end communication security ensuring proof of origin of data. It is based on a cross-protocol functionality which allows a user to directly address any device connected to the cloud, regardless of firewall restrictions or used communication protocol. Oracle IoT Cloud provides reliable communication between the cloud and end-user devices, even over unreliable communication networks or with devices that connect intermittently.

Microsoft Azure IoT uses a central communication node, an IoT Hub which provides two-way device to device communication. By using advanced hub capabilities, a complex IoT solutions can be created to enable the user to manage industrial machinery, monitor premises and maintain smart homes. In addition, user can monitor the network, track different events and receive alarms if predefined conditions occur. In order to securely transfer data, Azure IoT Hub uses SAS token-based authentication of two basic standards-based types:

- For secure authentication —Individual X.509 certificate
- For simple enrolment — X.509 CA authentication

Azure IoT SDK supports:

- Communication protocols: HTTPS, AMQP, AMQP over WebSockets, MQTT, MQTT over WebSockets protocols
- Programming languages: C, C#, Java, Python, Node.js
- Operating systems: Linux, Windows, and real-time operating systems

AWS IoT provides the cloud services that connect the IoT devices to other devices and AWS cloud services. AWS IoT provides device software which aims to integrate the IoT devices into AWS IoT-based solutions. For the devices that can connect to AWS IoT, AWS IoT can connect them to the cloud services that AWS already provides. AWS IoT Core supports these protocols:

- MQTT (Message Queuing and Telemetry Transport)
- MQTT over WSS (Websockets Secure)
- HTTPS (Hypertext Transfer Protocol - Secure)
- LoRaWAN (Long Range Wide Area Network)

AWS IoT provides the following interfaces that can be used by the application developers:

- AWS IoT Device SDKs which allows to build applications on the devices that then send messages to and receive messages from AWS IoT.
- AWS IoT Core for LoRaWAN enables connecting and managing the long-range WAN (LoRaWAN) devices and gateways.
- AWS Command Line Interface (AWS CLI) allows to run commands for AWS IoT on Windows, macOS, and Linux. These commands enable a developer to create and manage thing objects, certificates, rules, jobs, and policies.
- AWS IoT API enable building IoT applications by using HTTP or HTTPS requests. These API actions allow the developer to programmatically create and manage thing objects, certificates, rules, and policies.

InfluxData TICK stack is purpose-built to handle the massive volumes and countless sources of time-stamped data produced by sensors, applications and infrastructure. It is a software suit composed of the following components:

- Telegraf is an open-source server agent aimed at collecting and sending metrics from a wide array of inputs and writing them into a wide array of outputs. It is plugin-driven for both collection and output of data, making it easily extendable with additional data sources. It is written in Go programming language, which means that it is compiled into a standalone binary which can be executed on any system without any needs for external dependencies. For example, Telegraf can be used for collection of data from the MQTT broker and storing them into Influx database.
- InfluxDB is an open-source time series database which is particularly suitable of ingesting and retrieving a large number of data points in a scalable manner. In AI-PROFICIENT project, InfluxDB could be used as the main storage of all the measurements collected by the field level devices (smart components and sensors).
- Chronograf represents the user interface and administrative component of the InfluxDB platform. It allows a user to quickly visualize the data stored in InfluxDB and rapidly create interactive dashboards with real-time visualizations. In AI-PROFICIENT project, Chronograf can be used for basic inspection of collected data by partners involved in the development, while the end users of the platform will rely on custom built user interfaces.
- Kapacitor is a real-time streaming data processing engine which can process both stream and batch data from InfluxDB, acting on this data in real-time.

In addition to commercial version, InfluxData TICK stack also offers an open-source version, which will be considered as a potential candidate for the AI-PROFICIENT platform development. TICK stack offers a suite of components that can be combined in different ways to enable data acquisition, storage and processing that are suitable for the use cases envisioned in AI-PROFICIENT project. By basing our platform on an open-source well tested and proven software, an uptake of AI-PROFICIENT solution after the project end will be ensured.

The state of the art in platform architectures, commercial products and related projects have provided the basis for further consideration with respect to AI-PROFICIENT platform design and future project activities.

4 System architecture

Deliverable D1.4 provides functional requirements and KPIs definition. The requirements provided therein have been taken as the input to the platform architecture design. They are provided in Table 5 below:

Table 5: Functional requirement related to platform design

Reference	Functional requirement
FR1_CONTI2_EAR	Early anomaly detection on extruder restart (duration/setup).
FR2_CONTI2_ROO	Root cause identification of anomalies during past extrusion restart processes.
FR3_CONTI2_HYB	Extrusion restart model.
FR4_CONTI2_ETD	Explainable decision support for operators.
FR5_CONTI2_PRE	Predictive production readiness assurance.
FR6_CONTI2_HUM	Human feedback on restart settings suggestion.
FR7_CONTI2_LSL	Lifelong self-learning systems.
FR8_CONTI2_HUM	Display setting suggestion through interface.
FR1_CONTI3_MON	Monitor the components of the process that induce tension in the tread.
FR2_CONTI3_DIA	Detect deviation that may induce tension in the tread.
FR3_CONTI3_DIA	Diagnosticate the potential component causing the deviation.
FR4_CONTI3_PRO	Prognosticate the remaining useful life before tension in the tread reach unacceptable threshold or breakdown.
FR5_CONTI3_HUM	Display information to the relevant user.
FR1_CONTI5_MON	Monitor quality of the cuts.
FR2_CONTI5_MON_OPP	Monitor cutting system.
FR3_CONTI5_HEA_OPP	Estimate cutting blade's health status.
FR4_CONTI5_DIA	Diagnosticate causes of failure other than wear in the blade system.
FR5_CONTI5_PRO_OPP	Prognosticate the wear based on planned cuts.
FR6_CONTI5_HUM	Display information to the relevant user in an understandable way.
FR7_CONTI5_HUM	Integrate human feedback on algorithm development.
FR1_CONTI7_MON_OPP	Monitor the loading of the treads into the trolley.
FR2_CONTI7_MON	Monitor the positioning of the treads in the trolley.
FR3_CONTI7_DIA	Detect deviations that may induce an improper loading of the tread into the tray.
FR4_CONTI7_DIA_OPP	Diagnose the component potentially causing the deviation of the treads.
FR5_CONTI7_PRO_OPP	Prognosticate the RUL of the component before the malfunctioning component will cause incorrect loading.
FR6_CONTI7_HUM	Display information to the operator responsible for the loading.

FR7_CONTI7_LSL	Keep a time series record of the measurements for training and adapting the deviation detection and prognostics algorithms.
FR8_CONTI7_LSL	Keep an image log for development and post deployment troubleshooting of the image processing.
FR1_CONTI10_MON	Process monitoring
FR2_CONTI10_ROO_GEN_ETD	Root cause identification
FR3_CONTI10_EAR	Early anomaly detection
FR4_CONTI10_HYB_ETD	Quality metrics prediction
FR5_CONTI10_GEN	Decision support regarding retuning of control parameters in the process (based on holistic generative optimization approach)
FR6_CONTI10_HUM_ETD	User interface
FR7_CONTI10_HUM	Human feedback on provided recommendations
FR1_INOES1_MON	Monitor measured temperatures
FR2_INOES1_HYB	Estimate peak temperatures with the digital twin.
FR3_INOES1_DIA	Diagnose the causes of peak temperatures and temperature fluctuations.
FR4_INEOS1_HUM	Display information to the relevant user in an understandable way.
FR5_INOES1_HUM	Advice the operator on actions to avoid oscillations.
FR6_INOES1_HUM	Integrate human feedback on algorithm development.
FR7_INOES1_HYB	Through modelling, analyse effects of process control and control loop on temperatures.
FR8_INOES1_	Improve the control loop.
FR1_INOES2_DIA	Detect when the label on the big bag and therefore the additive does not match the one to be used in the quality system.
FR2_INOES2_HUM	Display information to the relevant user in an understandable way.
FR3_INOES2_HUM	Integrate human feedback.
FR4_INEOS2_LSL	Keep an image log for development and post deployment troubleshooting of the image processing.
FR_INEOS3_MON	Monitoring process parameters
FR_INEOS3_HYB	Process digital twin
FR_INEOS3_ROO_ETD	Explainable root cause identification
FR_INEOS3_GEN	Optimal process control settings
FR_INEOS3_HUM	Operator’s feedback
FR_INEOS3_HUM	User interface

For the design of the platform, we have reviewed and considered the standard reference architectures in Section 3.1, EU projects in Section 3.2 and commercial solutions in Section 3.3. Hence, by crossing the solutions presented in Section 3 with the AI-PROFICIENT functional requirements, we have identified the following approaches as the optimal ones for the AI-PROFICIENT platform:

- IBM industry 4.0 architecture [11] used as a basis for the grouping of different AI-PROFICIENT platform components
- The AI4EU project platform will be integrated as a Platform-as-a-service layer to the AI-PROFICIENT platform

- InfluxData TICK stack will be used for the data storage layer time series database

More detailed platform implementation plan will be elaborated within WP5, especially in Task 5.1 – Smart component integration and IIoT interoperability and Task 5.5 – AI-PROFICIENT platform deployment.

In this Section 4, the aim is to provide the overall architecture description, where each module will be described in the subsequent subsections. As we can see in Figure 7, the platform consists of the following main groups of components:

- Platform middleware (Section 4.1)
- Plant systems (Section 4.2)
- External systems (Section 4.3)
- AI services (Section 4.4)
- Human interaction and decision support (Section 4.5)

In the sequel, each of the abovementioned components will be described in detail.

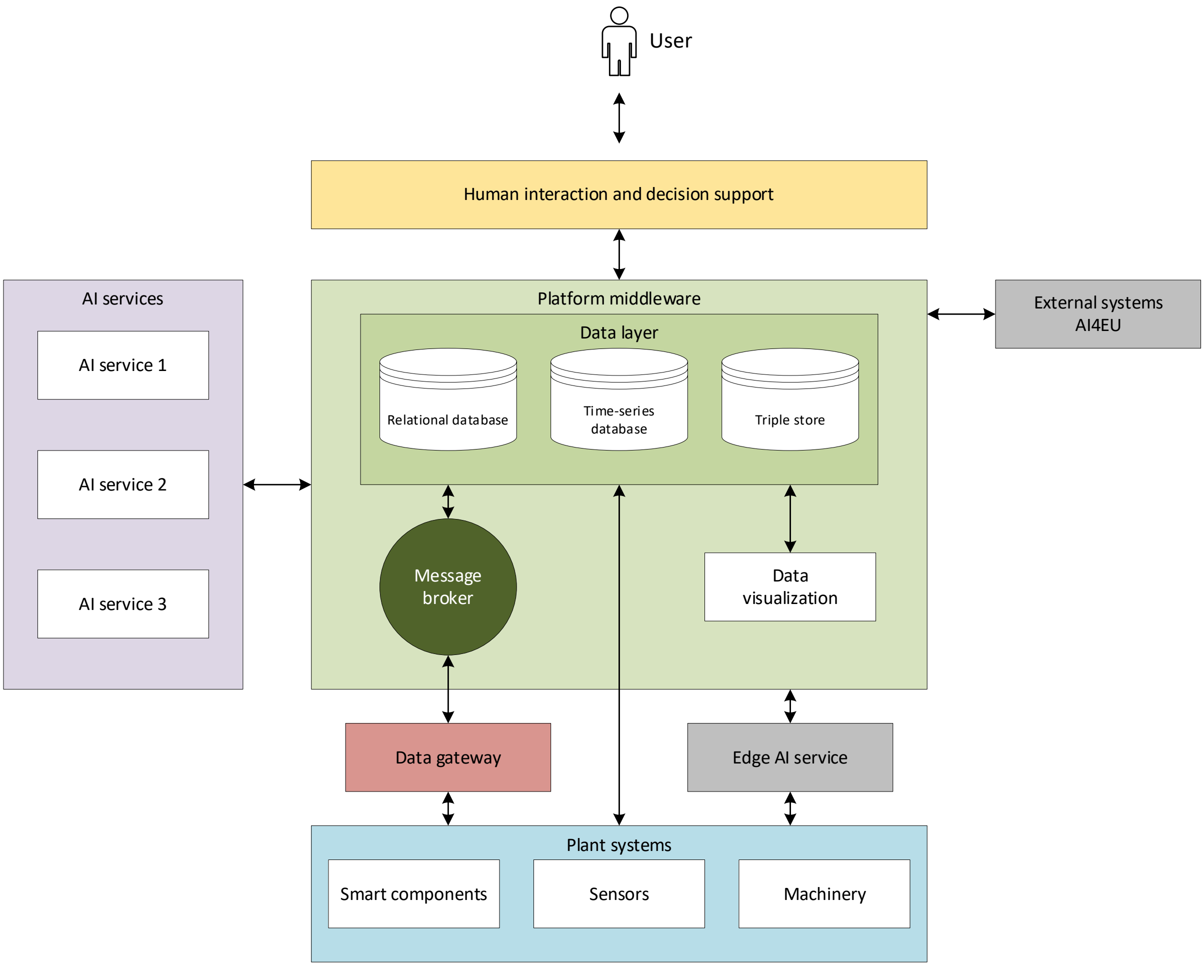

Figure 7: AI-PROFICIENT platform - general overview

4.1 Platform Middleware

The middleware is responsible for the integration of the plant systems, AI services and human interaction and decision support. Besides, it enables the acquisition, storage and retrieval of the collected data as well as visualization for the development purposes. As we can see in Figure 7, middleware consists of the following components:

- Message broker
- Data layer
- Data visualization

4.1.1 Message broker

Message broker aims to support the publish/subscribe message exchange. The most probable candidate is MQTT protocol, which is commonly used in IoT environment. It supports any type of payload (text, binary) which shall be defined by the system designer. By relying on the publish/subscribe pattern, the sending (Publisher) and receiving (Subscriber) parties are decoupled which brings many benefits:

- Implementation of the publisher and subscriber parties independently from each other.
- It is not necessary that Publishers and Subscribers are aware of each other.
- One Publisher could send messages to many different Subscribers.
- One Subscriber could receive messages from many different Publishers.

The aforementioned benefits make MQTT a good fit for a number of communication scenarios, such as constrained devices found in Internet of Things (IoT) deployments, where network bandwidth and computational capabilities are often limited.

Publish/subscribe pattern employed by MQTT protocol can be seen as an alternative to client/server architecture where a client communicates directly with the server. More specifically, in publish/subscribe model, the publishers and subscribers are completely decoupled, and they do not communicate directly. Instead, the messaging broker is a component that handles the communication between them (e.g. Mosquitto MQTT broker that can be used in AI-PROFICIENT platform middleware). The aim of messaging broker is to filter messages received by different publishers and send them to the subscribers. By adopting this approach, publishers and subscribers only need to know how to connect to messaging broker and they are not required to be connected at the same time. Furthermore, most of the MQTT client software libraries employ call-back functions and therefore other tasks do not need to be blocked while publishing or waiting for a message.

MQTT protocol employs a subject-based message filtering method. More specifically, each MQTT message has a defined topic (subject), which is then used by the broker to relay the message only to the client that has been previously subscribed to that topic. The MQTT message topic is composed of one or more topic levels where each of them is separated by a forward slash (e.g. plant1/machine1/sensor2/temperature). It is important to note that a client is not required to create the specific topic before publishing and subscribing to it. The topic is automatically accepted by the broker without the need to perform initialization of the topic.

4.1.2 Data layer

Data layer consist of multiple databases/file storages aimed at storing the data collected from the plants, results of AI services, user inputs, etc. To accommodate different data types, a combination of different database technologies is envisioned:

- Relational database will store the data that can be represented by using relational models. Open source, well maintained solutions (e.g. MySQL, MariaDB, etc.) will be considered for the implementation. Nevertheless, if there is a need to use proprietary databases available at the plants, these will be used as well.

- Time-series database is used as the data storage for large amounts of time stamped data, including IoT sensor data, DevOps monitoring, application metrics, and real-time analytics. This type of database is optimized to allow ingestion of large amount of measurements as well as their querying and basic processing and aggregation. Open-source solutions, such as InfluxDB will be considered.
- Triple-store represent the storage systems which are optimized for hosting triples of data. These, usually, support SPARQL endpoint which allows querying of data by using SPARQL queries. Triple stores can be used to store topology of the plants, different machineries and relations between them. Virtuoso and Fuseki are potential candidates for the platform deployment. Nevertheless, before deciding which of them is the most suitable for AI-PROFICIENT platform, more detailed analysis will be performed in the corresponding task.

4.1.3 Data visualization for development

For the purpose of platform development, especially for AI-services, there is a need to have a user-friendly visualization tool that can be used to inspect the data collected by the platform. Although there exist different visualization tools that can be used, Grafana seems to be suitable for this task. It is open source, allows user authentication and authorization mechanisms, and enable integration with different data sources (e.g. MySQL, InfluxDB, HTTP endpoints, etc.).

4.2 Plant systems

In this section, the aim is to outline the legacy and newly deployed devices in the plants, which will enable the collection of data to be used as an input to AI services. Firstly, we will consider the legacy equipment in order to reuse, for the project's purposes, the data already collected for the plant's regular operation. Later, we will present more details regarding the equipment which will be installed during the project in order to complement the already available data as it is required by the use cases and provided in D1.4.

4.2.1 Legacy infrastructure

All the plants that participate in AI-PROFICIENT project already have a number of sensors and smart components that collect the data for the purpose of plant operation monitoring and control. The data provided by these equipment will be used as an input to AI services. Therefore, it is crucial to decide how these systems will be integrated as a part of AI-PROFICIENT platform, especially having in mind the security protocols and constraints imposed by the plants. Within the plant systems, depending on the Use Case, Edge AI will be deployed. In addition, the data gateway aimed at translating the proprietary protocols into the common one used by the platform will be implemented. In the sequel, we present the initial analysis of possible integration.

4.2.1.1 Continental

Due to high security barriers in Continental, the group cannot provide a direct access to the different databases at the plant of Sarreguemines. Nevertheless, there exists a solution proposed by Continental, which has already been used with other external partners. The actual system is defined in the following Automatism Pyramid, as shown in Figure 8.

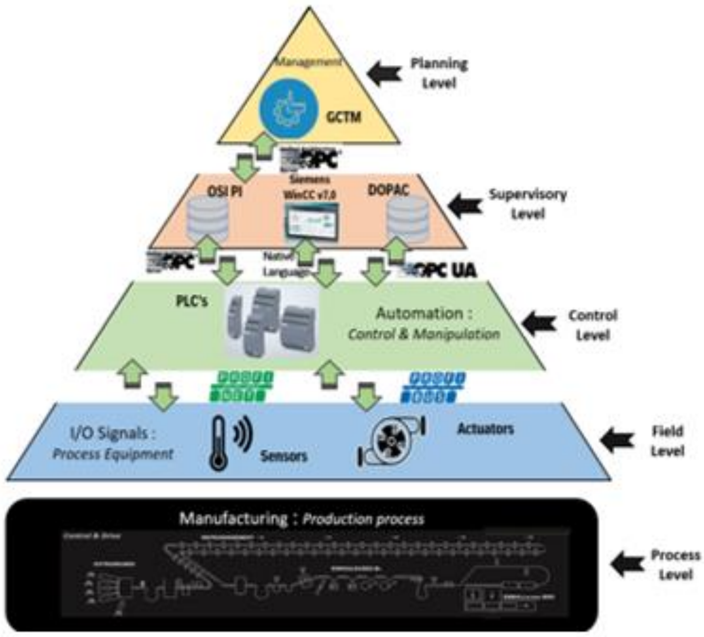

Figure 8: Automatism Pyramid of the plant of Sarreguemines,

This figure describes the different levels of data transfer and the infrastructure from the machine to the Management of the plant. Besides, it also provides an overview of the existing systems (e.g., Database, HMI, PLC's) and the communication protocols.

For the AI-PROFICIENT platform, Continental proposes a single solution which consist of a Virtual machine (VM) located at the plant in Sarreguemines. The proposition is showed in Figure 9 below.

To access to the AI-Platform all the partners will be provided with an individual VPN access account. They will have to fulfil a form and send it to Continental so that they can provide them credentials. An NDA (Non-Disclosure Agreement) for Business Partner Access has to be signed by each of the member that need an access to the platform. This system will host the entire AI-Services that will be developed for the Combiline during the project. The needed data will be available from a dedicated database which will be synchronized with the needed systems on the plant. Currently, at Continental plant, most of the time databases are relational databases.

In order to interact with the operators on the Combiline, Continental employs Siemens HMI. This kind of interfaces can be used to give direct information to the operators on the machine in order to assist them with the production process.

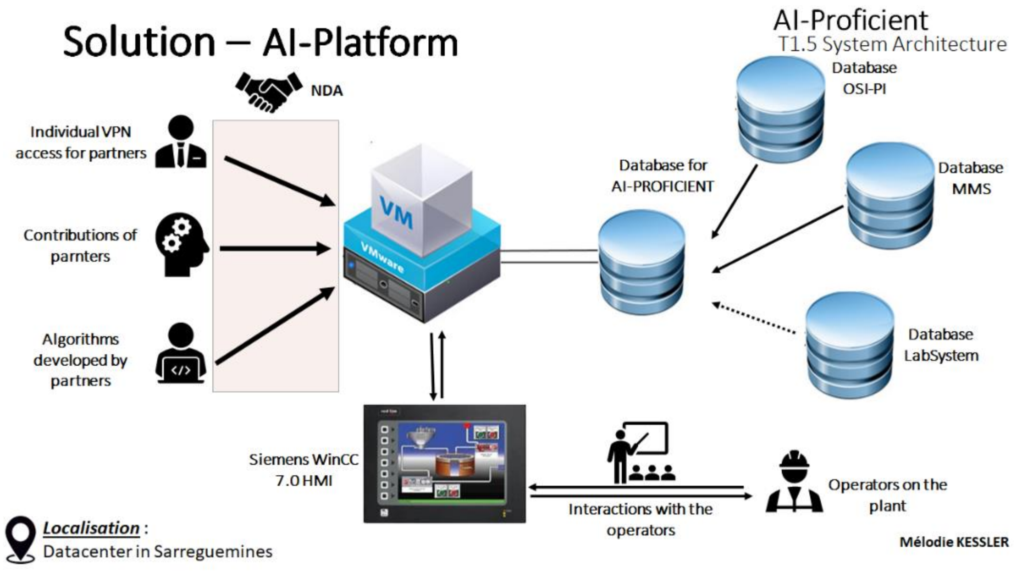

Figure 9: Proposed solution to give access to the data from Continental plant to the project partners

Since all the developed algorithms and models will be hosted on this VM, the system specifications will be adapted to the partner's needs. More details on the platform implementation with respect to the hardware and software architecture will be provided in the corresponding tasks of the project.

4.2.1.2 INEOS Cologne

Due to strict security policy at the plant, a direct access cannot be provided to an external party. In Figure 10, an overview of the INEOS Cologne plant system is presented:

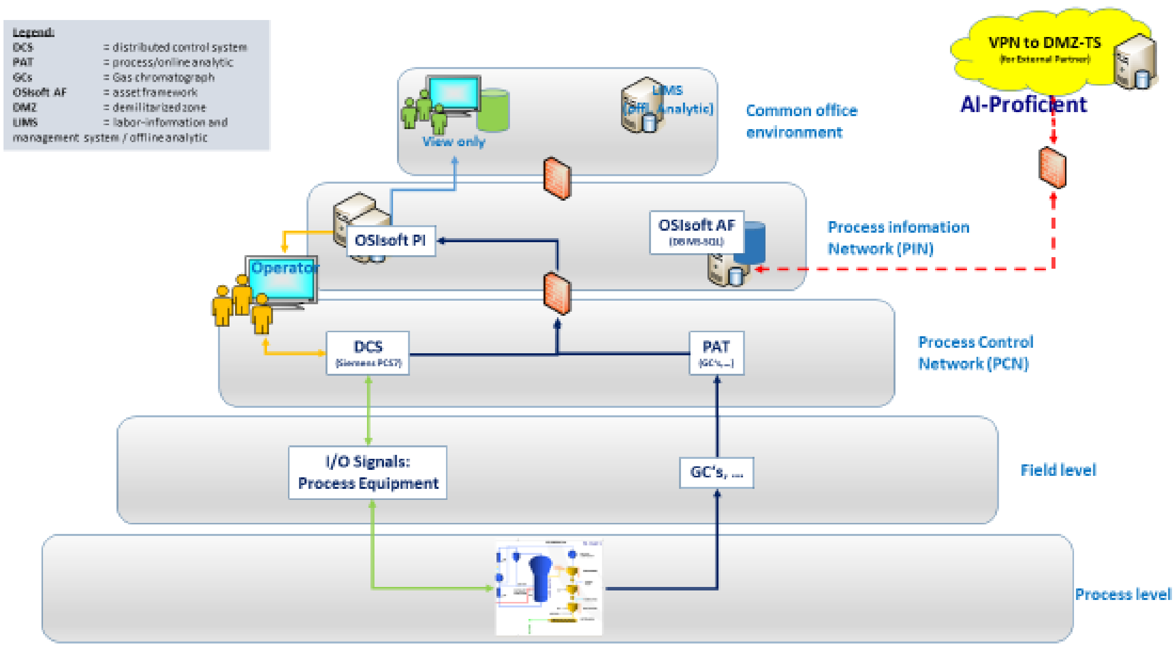

Figure 10: INEOS Cologne plant system

In order to integrate with the AI-PROFICIENT platform an access will be provided via a terminal server (see yellow cloud in Figure 10) that is placed in the demilitarized zone (DMZ). The access will be enabled via the VPN access on the terminal server. Credential access will be provided upon INEOS approval. The necessary authorizations for the OSIsoft systems will be checked and implemented by the INEOS distributed control system (DCS) department. The required AI software components can be installed and set up on the terminal server by IT administrators.

Access to the OSIsoft Asset Framework (AF) and relevant database will be set up by the DCS team and will be documented. All process data required and released for the project can be read in this way and further used in the AI environment. The writing access to the process-related systems of INEOS Cologne will not be allowed. OSisoft AF already offers many possibilities for the use of algorithms by e.g. analysis and interfaces for developed programs. Besides, there is also a Microsoft MS-SQL database that can be used by both AF and external systems. All process data from the DCS, data from offline LIMS (labour-information and -management-system) and online analytics are read in, archived and made available for AF by OSIsoft and can be used for e.g. algorithms. In addition, more data not stored in the database can be made available via various, automated, file transfer options.

4.2.1.3 INEOS Geel

In Figure 11, the plant system of INEOS Geel is presented. Information provided in Section 4.2.1.2 is also relevant for the INEOS Geel use cases, although the system architecture is slightly different for the two different Geel use cases.

For the Use case 1 - reactor stability, Figure 11 presents the existing plant system:

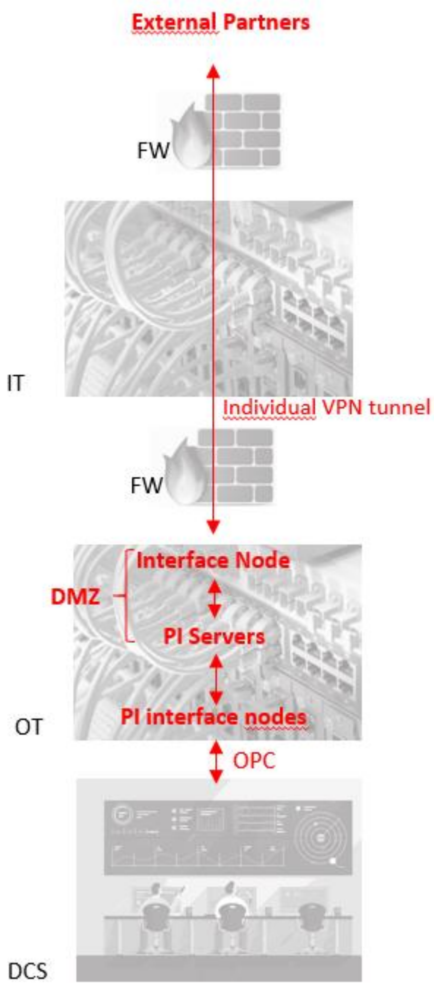

Figure 11: INEOS Geel plant system - Use case 1

For the Use case 2 - image recognition, the above schematic is complemented by additional relevant systems.

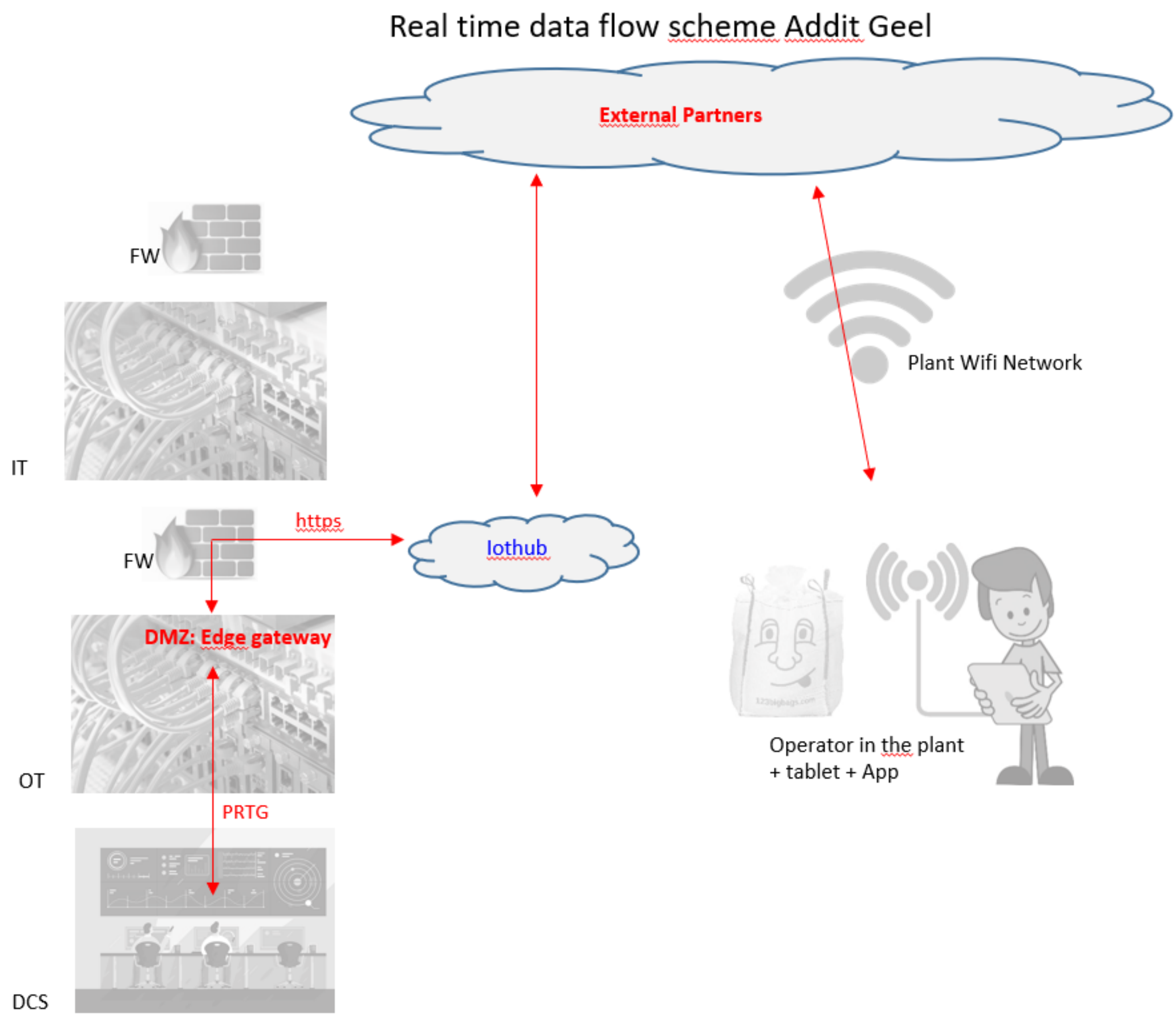

Figure 12: INEOS Geel plant system

DCS : Distributed Control System - This is the “level 2” network with all equipment that is used to control the plant (controllers – workstations for operators – Servers – History database)

OT : Operational Technology Networks : This is also called the “Level 3” network. At Ineos Geel this networks consists out of more layers; The plant has a sublevel 3.0 which is connected to level 2 (“DCS”) via a set of routers. This level 3 is connected to the “**DMZ**” (DeMilitarized Zone or the 3.5 level) via a Firewall (**FW**). Via the Firewall this DMZ layer is connected to the **IT** network (Office) or communication to external connections here is also possible.

Overall it is not allowed to have data transfer which passes more than 1 level in this network architecture. If process data needs to be transferred from the plant to an external party (or vice versa), it needs to pass via a separate node on each level.

For Ineos Geel Use Case 1, plant data (level 2) is gathered via an Interface Node (level 3) to the **PI** (Plant Information) server (level 3.5 : DMZ). From this server in the DMZ zone, access is possible from the office network. An external party can gain access via a VPN to the Ineos IT network.

For Ineos Geel Use Case 2 an extra server on DMZ level (**Edge Gateway**) will be installed to transfer data to / from cloud-based applications from external parties in real time via an iothub. The **Plant Wi-Fi** network is also situated on level 3.5 and connected to the Firewall. The communication from tablets to external parties will be accomplished via this Wi-Fi network.

4.2.2 Newly deployed devices

In order to acquire important information for the use cases, partners need to provide the necessary new devices in collaboration of the industrial partners, For INEOS use cases, all the information can be collected from already deployed devices and no new devices are expected to be deployed. For Continental use cases, some new devices have to be deployed in the collaboration of INOS, as it will be described in the sequel

4.2.2.1 New vision systems

4.2.2.1.1 CONTINENTAL UC 7 Tread alignment

A vision cell will be constructed for the measurement of the position of the treads on the trolley cart and on the transfer belts. This will consist of:

1. One MS Windows 10 PC type computer (vision computer) to control the system, perform the image processing, implement the measurements and any needed AI edge processing. This will satisfy the minimum performance requirements defined by INOS and in accordance with the CONTINENTAL factory standards.
2. Two laser triangulation sensors and a high-resolution camera will be installed on the moving lift cantilevered protrusion that offloads the treads on the individual leafs of the trolley in such a manner that the sensor to leaf standoff is invariant between leafs.
3. One high resolution camera will be installed on top of the roller belt feeding the cell and before the variable angle loading ramp.
4. One (possibly two based on test results) high resolution cameras will be installed on top of the variable angle loading ramp. This will be mechanically mounted so that the angle of the camera to the belt plane is perpendicular.
5. One camera will be installed on top of the vertical lift (before the cantilevered protrusion) and will lift up with the lift so that the camera standoff remains constant.
6. LED illumination will be installed for all cameras (laser triangulation sensors are by definition self-illuminating), triggered by the cameras.
7. A Gigabit Ethernet switch will be used to interconnect the cameras and laser triangulation sensors to the PC. All cameras and sensors have a GigE network interface.
8. Photocells or point distance sensors will be installed to trigger the image sensors. These digital output devices will be connected to the cell/line PLC which will provide trigger signals to the vision computer via the real time network standard of the factory. If such is not available or for policy reasons cannot be made, a digital IO system will be interfaced via an EtherCAT or Profinet or ASNet interface to the PC itself, but the approach is not preferred.

As the cameras on the moving elements (variable inclination belt drive and lift) are moving with these elements, the field of view remains constantly on the area of interest. The lenses and sensor stand-off distances are selected to maximize the effective field of view, i.e. camera pixels are not being unused by having the sensor image outside the element of interest. Therefore, the operator station is always outside the camera field of view and no indirect surveillance is possible at the workers' nominal station. Furthermore, the cameras are not continuously turned on, but are triggered by photocells when the tire tread moves through the belt system and thus there is no indirect surveillance even when an operator performs an action on the stopped machine.

4.2.2.1.2 CONTINENTAL UC 5 Tread blade wear

A vision cell will be constructed for the measurement of the position of the treads on the trolley cart and on the transfer belts. This will consist of:

1. One MS Windows 10 PC type computer (vision computer) to control the system, perform the image processing, implement the measurements and any needed AI edge processing. This will satisfy the minimum performance requirements defined by INOS and in accordance to the CONTINENTAL factory standards. This computer must be equipped with an NVIDIA GPU to support on the edge AI DNN inference.
2. One high resolution camera will be installed at a location past (but near) the cutting station that has been identified by CONTI where the tread momentarily stops.
3. LED illumination will be installed triggered by the camera. The cell/line PLC will provide trigger signals to the vision computer via the real time network standard of the factory.

4.3 Integration with external systems – AI4EU

The European AI on Demand Platform (AI4EU) brings together the AI community while promoting European values. The platform is a facilitator of knowledge transfer from research to business application. The platform can facilitate the development of AI models in the context of the AI-PROFICIENT project by supporting the build, sharing and deployment of the AI assets.

The AI4EU platform will be integrated as a Platform-as-a-service layer to the AI-PROFICIENT platform, as it is depicted in figure 7. The AI4EU platform is based on the Acumos project and an instance will be installed on the AI-PROFICIENT infrastructure. Acumos AI is a platform and open-source framework that makes it easy to build, share, and deploy AI apps. Acumos standardizes the infrastructure stack and components required to run an out-of-the-box general AI environment. The Acumos platform is using a Kubernetes Cluster and Docker containers to run AI Resources, on compute resources served by the infrastructure layer.

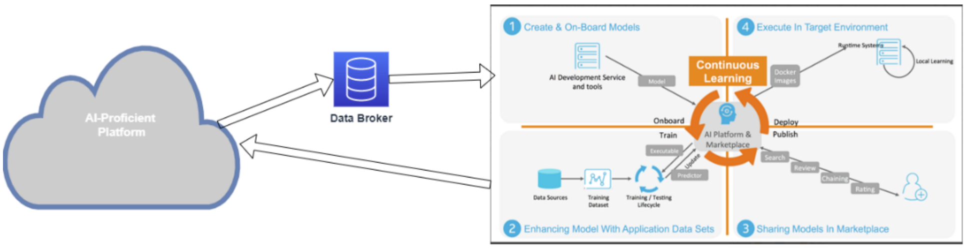

Figure 13: AI4EU integration workflows with AI-PROFICIENT

Interoperability and platform openness is supported through APIs. Specifically,

- **Single Sign On API**: this API allows to share identity between different systems or platform. This API is bidirectional, which means that AI4EU users can be authenticated through the platform SSO and share this ID to access other systems or platforms.
- **On-Boarding API**: this API aims at validating the right format of AI resources that will be used in the Experiments Design Studio component (i.e. containerization).

The Acumos platform enables the use of a wide range of tools and technologies in the development of machine learning models including support for both open sourced and proprietary toolkits. The AI-PROFICIENT developers can on-board models developed in Java 8 or 9, Python>=3.6, <3.7, R>=3.4.4 and sourced from toolkits such as Scikit, TensorFlow, H2O, and R. Consuming APIs of external systems such as cloud service environments, including Azure, OpenStack, and private Kubernetes clouds, the AI4EU platform will support the deployment of the AI-PROFICIENT AI models. For example, the Portal-Marketplace component initiates model deployment in the Azure cloud execution environment by using APIS exposed by the Azure Client.

Moreover, the Runtime Orchestrator component (also called Model connector) will be used to orchestrate between the different models in a composite AI/ML solution. This way, the AI-PROFICIENT developers will benefit from using a workspace for composing AI/ML pipelines composed of more than one AI models, if there is such need. The resulting composite solutions can be converted and exported as micro services, or they can be directly deployed as such on the supported target deployment infrastructures.

Data broker components can support data ingestions from the AI-PROFICIENT platform to the AI4EU instance so that the training of the AI models can take place. This way, the datasets can be loaded on the AI4EU stack and be then consumed by the AI models to be developed.

4.4 AI services

A high-level overview of the services which will be developed within AI-PROFICIENT platform is provided in this section. For each service the following information is provided:

- Service ID
- Service input and dependency on other services
- Service output
- High level service description

The services listed below will be developed in different tasks of WP2, WP3 and WP4, where more details regarding their implementation will be provided.

The services described in the following subsections are aimed at supporting the functionalities that AI-PROFICIENT project will deliver. These aforementioned functionalities have been defined in D1.4 with the summary provided in Table 2 of the present deliverable. The link between the functionalities and the services is made thanks to the suffix of the functionality (column ID of Table 2) added at the end of the service ID.

4.4.1 Diagnostic and anomaly detection service

Service ID	S_DIA
Service input and dependency on other services:	This service is developed taking as a basis the IIoT sensor installation and the acquisition & pre-processing steps carried out by the acquisition and pre-processing service. It will contribute to various of the UCs in which a diagnosis and anomaly identification of the assets is required on the edge, such as the following UCs: CONTI2, CONTI3, CONTI7, CONTI10. In each of the UCs slight variations will occur regarding the input signals used, as not all the UCs are related to the same sensors, however, the output will be common in all the UCs.
Service output:	This service provides an indicator or KPI that reflects the degree of anomaly of the asset currently and, in case certain threshold is surpassed, additional information regarding the faults that might be occurring will be provided.
High level service description:	The aim of this service is to check the assets are operating under normal conditions. When anomalies are detected, these anomalies will be diagnosed identifying the faults that have caused that anomalous behaviour. For that purpose, this service employs the data provided by the sensors installed on the asset.

4.4.2 Health state evaluation service

Service ID	S_HEA
Service input and dependency on other services:	The service should be implemented at the edge and requires at least as input from the system: • Component's characteristics (e.g., physical model about component behaviour) • Component's sensors It will also require some input from other services: • Self-diagnostics output if the service is available • Stopped line self-test output if the service is available
Service output:	The purpose of the service is to provide an estimation of the health state of the component. The health state will be delivered as a time series of single aggregated value, representing the global health of the component.
High level service description:	Two alternative ways will be investigated in order to provide alternative solution allowing to adapt to several use cases. The first deals with Choquet integral, an aggregation operator based on fuzzy measures. The second will consider one class deep neural nets, which will detect excessive deviations from the normal or expected behaviour of the system.

4.4.3 Component prognostics service

Service ID	S_PRO
Service input and dependency on other services:	The purpose of the service is to provide an estimation of the Remaining Useful Life (RUL) of the component. Depending on the use cases and component, the service may also provide the Health state future trajectory of the component.
Service output:	The service should be implemented at the edge and requires at least as input from the system: • Component's sensors • Data from the supervision • Production planning It will also require some input from other services: • Self-diagnostics output if the service is available • Health state evaluation if the service is available

High level service description:	Degradation based prognostics is based on a degradation model of the degradation modes of the equipment. The degradation models are mainly built based on historical data and may consider age, usage and measurement of the equipment. Such a model is then updated depending on available current measurements. The degradation model makes projections over the future in order to predict the remaining useful life of the item in consideration. Such a model includes AI-based techniques but also more conventional approaches such a stochastic processes, trend, and time series models. They may deliver not only the RUL but also the degradation trajectory. RUL prediction prognostics provides only the RUL of the component. Such a model has already been investigated in the project on public dataset [25]. The proposed deep neural networks used for this purpose exploit automatic representation learning to discover weak and complex correlations between sensors that may not be easily captured by domain experts and thus potentially increase portability of the prediction model to other configurations and environments.

4.4.4 Hybrid models of production processes and digital twins service

Service ID	S_HYB
Service input and dependency on other services:	Service input consists of process data and user experience. Process online data including but not limited to flow rates, compositions, temperatures, physical measures and pressures is required. In addition, laboratory data is needed. User experience of process operation, effects of process conditions and raw materials is also used as input. The service is linked to several other services. Inputs it may get from component level data acquisition and pre-processing (T2.2). Several services will utilize results that are based on the digital twin either directly or indirectly via another service. Both predictive AI analytics for production quality assurance (T3.2) and generative optimization (T3.4) will be able to directly utilize results of the service.
Service output:	The developed hybrid models will provide the information on how the manipulated process variables and disturbances affect process outputs. Digital twins will be fast adaptive versions of hybrid models that provide the same information on-line while they continuously improve the match of the model to reality.
High level service description:	Hybrid models, and digital twins based on the hybrid models, will be constructed by combining first principles modelling of the production processes with data driven modelling and human feedback. Depending on the use case, different model combinations will be developed. For first principles modelling, state of the art modelling tools will be exploited (such as ChemSheet for equilibrium chemistry and OpenFOAM for CFD). For Ineos UC1 the chosen solution approach is a hybrid model that combines first principles modelling, data driven modelling and human feedback. For Conti UC2 the solution will be based on integration of a feedback system with a data-based model. In case of INEOS UC3, the approach will be chosen after data

	analysis is carried out and the part of the process that causes rheology drift is identified. Depending on the modelling requirements, simplified linear/nonlinear/one-dimensional forms will be considered and developed to achieve the required computational speed of a digital twin. For this purpose, any physical models will be hybridized using ML techniques that will exploit and combine the operation data from the process (enabled by WP2), and human feedback whenever feasible (WP4), with modelling results.

4.4.5 Predictive Production quality assurance service

Service ID	S_PRE
Service input and dependency on other services:	This service requires the processed sensor reading produced in by the pre-processing service together with the KPIs produced by the diagnostic and anomaly detection service. The computation of quality and its forthcoming development could be involved in the UCs CONTI5; CONTI7; CONTI10; INEOS1; INEOS3.
Service output:	The aim of this service is to produce process quality indicators (KPIs) that reflect the goodness of the manufacturing process and predict how these indicators will evolve in the near future. This way, it allows operators to carry out maintenance actions that will prevent the loss of quality when it is foreseen, that is the possible evolution of those KPIs.
High level service description:	This service is aimed at watching over the quality of the production. As such, it needs to verify the assets are in good health conditions, and also, check that the various quality related measurements taken during the process are also under tolerances. Based on the recent readings, it will also provide estimations of how quality will evolve in the future to foresee possible losses of quality and act accordingly before quality drops.

4.4.6 Root-cause identification service

Service ID	S_ROO
Service input and dependency on other services:	The objective of this service is to identify which indicators or factors, at the sub-process and use case level, are the ones that most affect the final quality of the final part. Those indicators or factors that influence the global quality indicators at the end of the entire production process. The service requires historical data pre-processing and testing sensitivity of signals in low quality, those associated with product characteristics out of desired range.
Service output:	The service will identify the relationship between different established quality indicators (e.g., length, weight, profile thickness ...) and the process variables and breakdowns. The service will identify which parameters are the cause of poor quality at the level of the production process. It will return what are the

	most likely causes and indicators of a defining quality at the end of all stages or the thread production process.
High level service description:	The main aim of this service is to relate the intermediate indicators extracted from each of the sub-processes with the final quality of the product. Different quality indicators are affected by different variables of the process, machine settings, breakdowns and determined decisions of the operators. The service will identify some of those parameters that cause poor quality at the end of the production process. The service will identify which factors are reflected in the quality of the product. From this identification, it is possible to determine and specify the most relevant and stable indicators/factors to evaluate and analyse the behaviour of the process. The indicators offer a way of future evaluating the status of the process and based on the prediction of trends, also its future evolution.

4.4.7 Early anomaly detection service

Service ID	S_EAR
Service input and dependency on other services:	The objective of this service is to detect the absence of normality, related to failures in the process or poor quality, as soon as possible in order to carry out corrective actions. The service requires previous identification or relevant and stable factors/indicators directly related to the final quality of the product or of the process.
Service output:	The service will provide the normality index (N index) for the process, the upper and lower limits of the index and its future trend.
High level service description:	The objective of this service is to group the relevant and stable indicators provided by the 'Root cause identification service' service into a single health index, called H-index, to generate early alerts based on it that will allow decision-making by on the part of the user / operator of the system.

4.4.8 Opportunistic maintenance decision-making service

Service ID	S_OPP
Service input and dependency on other services:	The service should be implemented at the cloud and require at least as input: • Logistic support information such as maintenance team/skill, spare parts, etc • List of maintenance actions and related costs • Production planning and constraints It will also require some input from other services: • Health state evaluation if the service is available • Component prognostics if the service is available

	• Digital Twin if the service is available
Service output:	Maintenance decision consists in planning maintenance actions, for each component, at the right time in a dynamic way, i.e. which can be adapted/updated in presence of short term information such as a new maintenance opportunity, new information related to the components/system health state, logistic support or new impacting event available. Hence, the purpose of the service is to provide an optimal scheduling of the maintenance action to be performed on a line or system. The output of the service will be for a list of maintenance actions and date to be performed for each component/group of components. The estimation of system health state (predictive reliability or RUL) before and after maintenance execution will be also provided.
High level service description:	AI-based proactive maintenance approaches are emphasized. Two main steps are considered: • Step1 – Prognostics of health state at system level: The aim is to develop AI-based approaches allowing to predict the health state of the system considering only the prognostic results at component level (e.g., RUL of components), but also the dependence relationships between components under specific context associated to the systems missions/functions. To support this objective, several dependencies in terms of kinds of interactions between components (e.g., structural/functional, stochastic, informational dependence) should be first modelled and formulated. This helps to quantify the impact of one component/group of components on the health state of other components. Secondly, AI-based approaches (e.g., recurrent neural network) will be investigated to predict the health state at the system level from the prognostic results at component level and the formalized dependencies between components. The prognostics results of health stat will be used for predictive maintenance decision-making at the second step. • Step 2 – Development of AI-based maintenance decision-making models[1]: The proposed models will be built on a set of appropriate decision rules and advanced AI algorithms (e.g. reinforcement learning) which allow to learn the most relevant decision rules to deal with the current condition of the system and its environment from observed data, the estimated health state at both components and system level. In that way, the proposed AI-based decision models should enable not only providing optimal maintenance planning considering both the requirements associated with the maintained system and its support one (e.g. spare parts, maintenance skill) but also to be able to update efficiently the maintenance planning in a dynamic context (e.g. structure changes on main or support system, occurrence of new maintenance opportunities).

[1] Van-Thai Nguyen, Phuc Do, Alexandre Voisin and Benoit Iung. Reinforcement learning for maintenance decision-making of multi-state component systems with imperfect maintenance. The31st European Safety and Reliability Conference | 19-23 September 2021, Angers, France

4.4.9 Generative holistic optimization service

Service ID	S_GEN
Service input and dependency on other services:	The service proper operation (in real-time) requires live streaming of shop floor data. In other words, information about the necessary and sufficient subset of machine settings and readings from certain sensors, have to be fed into the optimization engine, where concrete input signals depend on the considered use case. In that sense, the application of generative optimization has been envisioned within CONTI10, INEOS1 and INEOS3 Use cases. When it comes to dependency on other services, even though it could be a standalone service, proper coupling with certain services developed within a concrete Use case, could be beneficial. For the sake of giving the example of the service possible dependencies, CONTI10 will surely include optimization-side exploitation of anomaly detection module output, while INEOS1 and INEOS3 use cases will possibly (depending on the results of early data analysis, which is ongoing activity) bring cascading of digital twin/predictive process model and optimization service. The idea is to have the outcome of the feedback system (the operator's evaluation of provided decision support - recommendations) as the input, as well, in order to deploy human feedback mechanisms and boost the performances of the service.
Service output:	The optimization service will provide information about the detected causes of production quality deviations and suggestions regarding retuning of control parameters (if the issue is controllable). Concrete recommendations (set of control parameters, settings) depend on the considered use case. Giving the example of CONTI10, those settings could be different set-points of temperatures, speeds, positions of dancers, etc.
High level service description:	The Generative holistic optimization service aims to bring an engine with multifunctional properties, where root cause identification and decision support components stand out. Such that, the service comprises a multi-alternative recommendation system, providing the operator with suggestions regarding the optimal settings of parameters (at least crucial, detected ones) in order to solve the issue and to go step forward, preventing the production of out-of-range products from occurring. It will combine different AI techniques and multi-objective or single-objective optimization methods based on evolutionary algorithms. The approach will differ depending on the availability of the process model or digital twin. In absence of it, surrogate modelling will be applied, resulting in surrogate-assisted optimization.

4.4.10 Future scenario based Lifelong self-learning system service

Service ID	S_LSL
Service input and dependency on other services:	This service heavily relies on the output of other services; hence, a clear definition of inputs/outputs is complex. However, the following are the minimum inputs required that have been identified so far: • Diagnostic and anomaly detection if the service is available • Health state evaluation if the service is available • Predictive Production quality assurance if the service is available • Root-cause identification if the service is available • Early anomaly detection if the service is available • Maintenance decision if the service is available • Generative holistic optimization if the service is available • Feedback/improvements from the users when WP4 services are made available
Service output:	The purpose of the service is to provide a decision making system that combines the optimization information coming from other AI-PROFICIENT services (developed at WP2 and WP3) with the human feedback mechanisms (developed at WP4).
High level service description:	This service integrates the AI information/data and the maintenance decisions by gathering the outputs of the modelling services developed at WP2 and WP3, then, it enriches that data with the feedback services developed in WP4 to produce a decision that reflects also the operators feedback on the different AI models. This will enable taking prescriptive actions based on a close collaboration with the end-users. In addition, this service has the capability of being continuously improved over time, based on the feedback of the operators.

4.4.11 Human feedback service

Service ID	S_HUM
Service input and dependency on other services:	This service might be present in use cases that contain AI systems making predictions/estimations/suggestions etc. Such as in UCs CONTI2, CONTI3, CONTI5; CONTI10, INEOS1, INEOS2 and INEOS3. As the aim of this service is to improve the AI services that are already installed, this service strongly relies on the existence of said services. As an example, that could be the case of Diagnostic and anomaly detection services, which provides diagnostic information and anomaly KPI; and the Predictive Production quality assurance service, that provides quality KPIs and future projections of these KPIs. Additionally, in order to capture human feedback, it will be necessary to provide operators/managers with interfaces, which could be different depending on the UC. AI-PROFICIENT develops ways of human-machine interaction, such as the human-machine interface for data visualization service

	and the extended reality and conversational interface service that will be employed to transfer the feedback information. This service requires channels to ease the integration of the feedback mechanisms in the production line.
Service output:	This service will be in charge of adapting the feedback of the users to data records that can be used to re-train the algorithms/models or the creation of the new algorithms/models that will be carried out in algorithmic service. Hence, the final output of this service is data.
High level service description:	As project contributors reviewing and adapting the AI system predictions, operators and/or maintenance managers will face scenarios were the suggestions/predictions made by the AI are wrong. This service is in charge of detecting the most viable means to receive the feedback of the operators and to use that feedback in the tuning of the AI systems, so that they can improve over the time.

4.4.12 Explainable and transparent decision making service

Service ID	S_ETD
Service input and dependency on other services:	Explainable and transparent decision-making services will be present in three Use cases – CONTI5, CONTI10 and INEOS3. Depending on a particular Use case, inputs will vary. Nevertheless, they will involve various relevant process parameters (e.g., extruder pressure, speed, temperatures, etc.). Additionally, these services will potentially use outputs of other services, such as generative holistic optimization service.
Service output:	The output of the Explainable and transparent decision-making services will differ depending on the use case and XAI approach. However, it is likely that it will provide the cause of some detected problem or deviation and some type of explanation for that reasoning for the operator.
High level service description:	Explainable and transparent decision-making models will cover wide range of different techniques, depending on a use case and its application. It is envisioned that three approaches will be present – semantic technologies, interpretable models (e.g., Bayesian networks) and techniques for unwrapping the black-box models (e.g., DeepLIFT).

4.5 HMI specification

The Human Machine Interface (HMI) layer is responsible for creating an intuitive, human friendly interface to the knowledge that this gathered in the AI-PROFICIENT platform. The interface has to be interactive so that AI-services and human operators can collaborate to achieve a more safe, precise and efficient manufacturing process.

For this a wide range of HMI interfaces will be explored: mobile apps for smartphones and tablets, web apps, but also HMI innovations such as mixed reality smart glasses. This technology has come a long way in the last few years, and it expected they are soon lightweight and sturdy enough to be used on factory floors (e.g. ATEX Certified). They allow hands-free operation and immediate visual feedback for coordination and quality control.

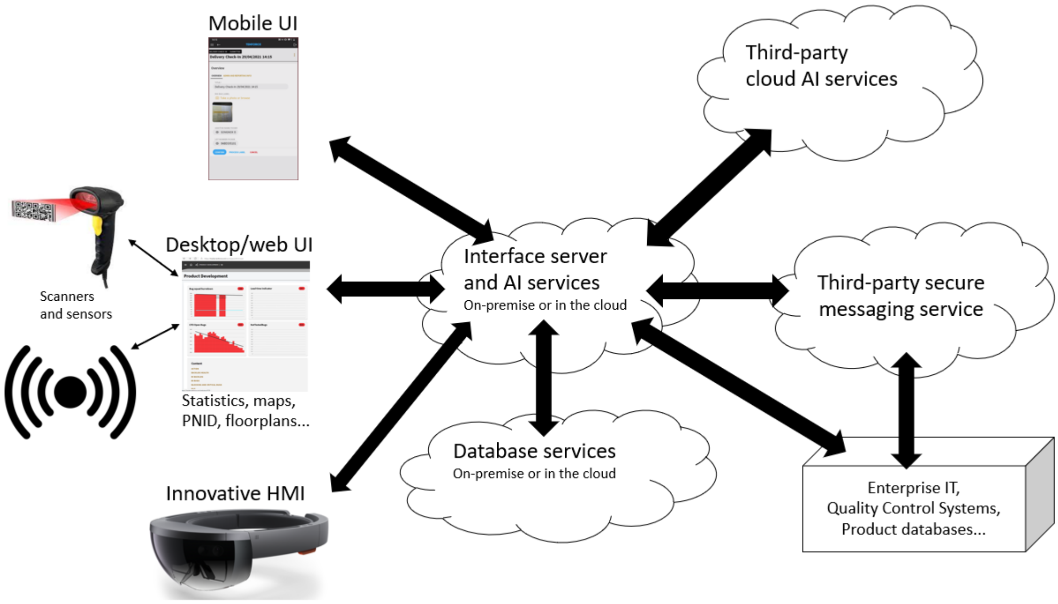

Figure 14: HMI specification

To explore the interactive parts connection must be made with a decision support system, responsible for translating the AI service findings into concrete understandable actions for the operator. Those actions will directly or indirectly (through the effects on the manufacturing process) provide feedback to the AI services. In order to focus on the learnings of creating such advanced HMI interfaces, the decision support system of one partner, TF, has been contributed to AI-PROFICIENT as basis to connect the interfaces to. This avoids reimplementation efforts for creating a partner neutral decision support system with basic UI interface features. Some preliminary experiments have already been conducted to explore the possibilities in the context of the use-cases.

We first focussed on mobile app on a ATEX certified tablet to use for the INEOS Geel use case 2, but it turns out that for the use-case we will focus on the desktop/web application to do the first developments and scenario scoping. There are many information interfaces that make more sense on a desktop computer such as overviews of tabular data, dashboards with statistics, maps, PNIDs, floorplans, and integration with more complex EHSQ (Environmental, Health, Safety, and Quality) requirements. When required, a desktop computer can be outfitted with sensor and scanner hardware. Indeed, in the first place a tablet was considered because it contains a camera required to scan the labels on the big bags in this use-case. But it was considered impractical because of its weight.

The AI-PROFICIENT platform consists of a server backed with databases, a mobile app for both smartphones and tablets, and a web app. The platform easily integrates with third-party services and existing enterprise IT systems of our customers. If a use case partner has high-security requirements, they can run the AI-PROFICIENT system on-premises or run in the cloud and communicate with their own systems through secure third-party messaging services. This way, operators can securely use the software while AI-PROFICIENT provider has access to the software to provide support, fix bugs, and add features.

The AI-PROFICIENT project allowed the consortium members to gain expertise in integrating AI services in the system and in the workflow of operators using the mobile app. We both use AI systems that run on the same VM as the AI-PROFICIENT platform and AI services that run in the cloud, allowing us to make use of their vast computational power. All processing happens in real-time. We have streamlined the data flow in the system so that the operator never has to wait more than a few seconds after pushing a button on the tablet.

Though the developers focused on the mobile app for the INEOS Geel use case 2, TF primarily operated with a desktop/web application for developments and scenario scoping purposes using conventional interfaces such as laptop or a tablet terminal. It provides all the same functionality. There are many services that TF can readily offer that make more sense on a desktop computer such as overviews of tabular data, dashboards with statistics, maps, PNIDs, floorplans, and integration with more complex EHSQ (Environmental, Health, Safety, and Quality) software packages such as work permit management. In specialized cases, a desktop computer can be outfitted with sensor and scanner hardware. This could eventually replace the tablet again so that the operator does not have to lug a heavy tablet around just for its camera.

Lastly, TF is preparing for HMI innovations such as mixed reality smart glasses. This technology has come a long way in the last few years, and soon it will be lightweight and sturdy enough to be used on factory floors (e.g., ATEX Certified). They will allow hands-free operation and immediate visual feedback for coordination and quality control. The Human Feedback service can adapt a natural HMI communication mentioned above in Section 4.4.11.

4.6 Ethics

In this section, the recommendations provided by the ethics team, based on the review of the previous version of this deliverable, are listed along with the corrective actions taken by the content contributors (see Table 6).

Table 6: Ethics team recommendations and corrective actions

Recommendation by Ethics team	Action taken by document contributor
1.5-1) *Recommend to clarify more specifically, in Section 3, in what senses the AI-PROFICIENT platform architecture may be used by contemporaneous or future projects, i.e. what unique design methods or designs can AI-PROFICIENT platform architecture contribute to future projects?* This will help in coming to view the project as a process, to the benefit of the humans involved.	The AI-PROFICIENT platform per se does not include unique design methods. Instead, it is based on the common platform architectures using in industrial environment. The main value of the project is in the AI services which are implemented as a part of the platform which enables the data collection, processing and visualization.
1.5-2) *Recommend that you specify, also Section 3, where the platform is designed to evolve, so as to be useful for future projects (i.e. what modules or components or relationships, including human).* The platform should be designed to evolve. Describing its potential evolution complements the variability of the human as process and helps conceptualize the latter.	The platform is built in modular manner. In this context it means that e.g. the data layer can be extended by using additional database technologies. In addition, by using common messaging format for communication among different system components, new components can be included in the future by using translation of their proprietary messaging format into the standard one to be defined later in Task 5.1.
1.5-3) *Recommend that you explicitly categorize the platform into <u>stable</u>, <u>variable-stable</u>, and <u>variable components</u> (and include the various operator and process engineer contributions in terms of physical action and knowledge or experience in these categories)*. This will help view the operators and process engineers in	The platform presented in this document encompasses different system components aimed at supporting the AI services which represent the main value of the project. The platform design itself is more focused on the technical capabilities following the requirements of the AI services in terms of data access and service deployment. The operators interact with the services via human-machine interfaces. Their

terms of flexible processes rather than mere components.	involvement will be described in a more detailed manner during the actual design and deployment of these interfaces.
1.5-4) Re: Section 4.2.1 Legacy Infrastructure *Recommend that you locate and specify any legacy infrastructure which may overlap with new AI-PROFICIENT platform architecture so as to force operators or process engineers to do double work, either in physical or cognitive actions, and then make design choices to avoid such situations (see V. Govaere presentation, July 1st, 2021, Ethics Channel). Otherwise develop a training timeline and formally make quantitative allowances for operator/engineer engagement with the platform wherever such overlaps occur.*	For Continental, the data that are going to be provided for the AI-PROFICIENT data base will come from already existing databases. They are going to be transferred to the new database. Because of security concerns, it is not possible to do otherwise. For INEOS, there will not be any overlap between the AI-PROFICIENT platform and legacy infrastructure.
1.5-5) Re: Section 4.2.1.1 Solution – AI-Platform Figure 3 *Recommend that the human symbols in Figure 3 be replaced with symbols more representative of human participation in the project, or, if impossible, be clarified with text.* It is unclear what the four human symbols on the left represent, but the project is a human community, and the partners are - ultimately – human, so we should try make the effort to view ourselves, and present ourselves (the Deliverable 1.5 is public) in human terms.	Continental changed the symbols to upgrade the figure and represent more the human.
1.5-6) Re: Section 4.2.2.1 New Vision Systems *Recommend that you check and detail whether any of the new cameras have the operator in their field of vision (particularly the top-down camera located over the variable inclination belt/variable angle loading ramp for UC7), i.e. whether there is indirect surveillance of the operator's station, so that the camera does not record details but simply that the operator is there or not. If yes, then modify the camera angle to avoid this, or if that is impossible then formally clarify to the operator the extent of this indirect surveillance.*	Based on the CAD layout and the selection of optics for the camera and sensor field of views, we do not have the operator's workstation inside the camera field of view.
1.5-7) Re: Section 4.4.8 Generative Holistic Optimization – "the operator's evaluation of provided decision support" *Recommend that you design the interface for the operator's input here from the viewpoint "the operator is solving the problem with the help of the AI as a tool," giving the operator the fullest*	Regarding the multi-alternative nature of the optimization outcome, the current point of view implies offering several combinations of parameter values for execution. The concrete number of options will be decided in later phases of development. The decision will be based on data analysis results and, surely, based on the operators 'and process engineers' experience

opportunity in the input interface to use their reasoning and experience (including experience built during this stage itself) and to 'try things,' at the trial stage, to improve the system. *Input from the operator on the initial design of the feedback interface should be sought here also. Ask the operators and process engineers "what kind of interface would make you interested in solving this problem?"* This is one of several areas where you can acknowledge and include the human agency of the operator as process and bring value into the operator/process engineer experience. Re: High Level Service Description "a multi-alternative recommendation system" *Recommend that you estimate quantitatively what kind of range of options you expect for the operator here*.	and requirements. Additionally, this number will be reasonable (not to overload operators) and parameters will be those considered as crucial for solving or preventing the issue. Those options won't be compulsory for selection. Namely, the operator will have the last word in decision-making, and he/she will be offered "dismiss recommendations" functionality and an extra selector for leaving her / his conclusion, by selecting among some common issues, which will be listed. Finally, this is the current point of view. Surely, it will diverge more or less when the task gets started and will mature through workshops with process engineers, operators, and the ethics team (planned to be organized in the months of task activity).
1.5-8) Re: Section 4.4.10 – High Level Service Description "As consumers and supervisors" *Recommend you replace "As consumers and supervisors of the AI system predictions with "As project contributors reviewing and adapting the AI system predictions."* The original terms have passive and external connotations, i.e. the human is merely receiving or overseeing the solution. Instead, view the human as the integral part of the solution.	Replaced as suggested by the Ethics team.
1.5-9) Re: Section 4.4.11 Explainable and Transparent Decision Making – "some type of explanation" *Recommend that you specify <u>who</u> this explanation is for in each of the relevant UCs, and then <u>what type of explanation</u> will be therefore required, including the reasoning behind <u>why</u> it will be required*.	Recommendations that will be provided through the various XAI services will be intended for operators, so this information has been added in Section 4.4.11. Since numerous XAI services will be developed as a part of AI-PROFICIENT, the explanations will vary depending on the particular use case. Additionally, since XAI will be interacting with other analytical services, more clear specification of the XAI outputs will require more precise specification of the other analytical services. Since the development of these services has not started yet, this information is not available. Therefore, we propose that after prototype version of each XAI service is developed, consultations with ethics team and operators are organized, so that outputs are aligned with the ethical guidelines and operators' needs.

In addition, we provide the categorization of human roles and their variability with the platform in Table 7.

These roles can be as follows:

- stable – e.g. the operator has to press the same button over and over again every day (in relation to some other unchanging part of the platform architecture). The role is not likely to change in future platform uses.
- variable-stable – e.g. the operator has a few choices to choose from choosing between AI recommendations, but the kinds of choices might change if they are related to elements of the platform that could change somewhat. So the role may change in future uses of the platform.
- variable – e.g. the operator has great freedom to choose between the AI recommendations, and to try things according to their experience (they can be creative and unpredictable and be a real part of solving the UC problems using the AI as a tool), or to ignore the AI completely at times as well. These kinds of choices are in relation to other parts of the platform which may be modified to solve the UC problems of our project or in future very different uses of the platform. Under the variable category the human role is likely to change.

Table 7: Human roles categorization

Person	Role	Variability
Extruder Machine Operator	Set up the machinery for extrusion, evaluate input from the system	in stage Variable/Stable in stage 2: Variable
Extruder Machine Operator	Provide feedback to the learning system	Variable
Extruder Maintenance Manager	Provide feedback to the learning system	Variable
Extrusion Line Operator	Phase 1: no impact	Stable
Extrusion Line Operator	Phase 2: An Alarm will be displayed in case the output parameters of the line are not desirable And a prediction of the future condition of the output will be displayed	Variable
Extrusion Line Operator	An alert is raised when a bad cut is detected, the operator decides independently to request a maintenance technician	Stable
Continental Expert With Knowledge	Improve the recommender system.	Variable

Maintenance Technician	The technician currently already logs the action of blade replacement, this should be extended with several parameters that will allow the training of better systems	Variable/Stable
Maintenance Manager	The system will predict when blades will wear out, the manager needs to schedule maintenance	Variable/Stable
Combiline Operator	An alert warns the operator that a physical action needs to be taken.	Stable
Combiline Personnel	There will be a prediction (value=1?) that there will be an alert in the future	Variable/Stable
Operator (conti uc 10)	unclear	unclear
Quality Manager (conti uc 10)	unclear	unclear
Reactor Operator	The prediction tool will provide the operator with the next best-to-do steps to improve the reactor stability, the operator choose to ignore if they feel the AI is mistaken	Variable
Feeder Operator	The tool will, try to, recognize the additives being added to the feeder and provide the operator with an approval in case the additives are compatible with the recipe that was selected	Variable/Stable
PE Installation Operator	The prediction system will provide suggestions for the parameters for the entire next batch (so no updating along the way as with other uc's). The operator chooses which suggestions to apply and which suggestions to ignore.	Variable

5 Conclusions

The aim of this report is to summarize the work performed within Task 1.5 regarding the AI-PROFICIENT system architecture design. This document has taken as the input work performed in Tasks 1.3 and Task 1.4, which has been summarized in Deliverable D1.3 and D1.4 The pilot demonstration scenarios and project requirements defined therein served as a basis for the AI-PROFICIENT platform design. Recommendations provided by the Ethics team have been considered during the platform design and implemented where appropriate.

First, the state-of-the-art review has been provided, which is focused on relevant standard architectures, EU projects and commercial products available. Based on this information and the project requirements the platform architecture has been designed. The document provides an overview of the platform middleware, and possible technological solutions to be used to implement it. Then, it presents the integration with the plant systems, where the focus was on the current data security constraints in the plant and the possible ways to overcome them. Next, we provide the possible approach to integrate with AI4EU, its algorithms and data sets. Then, the high-level specification of AI services, in terms of the input and output data, information processing is presented. Next, human interaction and decision support is explained. Finally, the list of recommendations provided by the ethics team and the actions taken by the project members is provided.

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7 Acknowledgements

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 957391.