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Deliverable D1.1
Requirements, state of the art and base line

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Abstract

This document constitutes deliverable D1.1 of the Arrowhead fPVN project.

WP1 objective is to gather requirements regarding the Common Arrowhead Technology, the Microservices paradigm, the Major fPVN data models and the Automated data model translation. WP1 will further collect and summarize common technology and use-case baselines with respect to the project objectives, to provide a consolidated way of validating and verifying the project advancement and objectives fulfillment.

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1. Introduction

This deliverable reports the results of the preliminary requirements elicitation and of the use cases baseline definition, describing the activities carried on in Task 1.1 and Task 1.2 during the first six months of the project.

In the first part, the deliverable defines the concept of requirement, illustrates the process adopted for the requirements elicitation, reports the set of requirements collected following this process and provides some preliminary considerations.

In the second part, the deliverable describes the methodology that has been followed for the analysis of the baselines and provides the preliminary baseline definition for all the three main building blocks of the projects (horizontal WPs) and for the use cases.

The requirements elicitation and use cases baseline definition will be further extended, refined, and updated, and the new results of these activities will be presented in Deliverable D1.2.

1.1 Overview of WP1 tasks

WP1 is composed of two tasks:

- Task 1.1 Requirements
- Task 1.2 Use case baseline

1.2 Task 1.1 role and objective

Task 1.1 is responsible for the elicitation of the project requirements, involving in principle all the project's partners, with the tasks and use cases leaders generally providing the requirements, and horizontal WP leaders as potential suppliers of the required technologies/solutions. Requirements are specified defining several information about their nature and relationship with the use case and project objectives and include specific information to allow tracking their fulfillment at the end of each project year.

The task has to define a process for the requirements elicitation and fulfillment assessment, which aligns to the project engineering cycles and provides the possibility to update, refine and add new requirements in every cycle. This flexibility is required by the nature of the research activities carried on in the project, by the complexity of the horizontal technologies and use cases and to ensure the continuous alignment with the progress and evolution of the project.

1.3 Task 1.2 role and objective

Task 1.2 is responsible for the definition of the use case technology baselines, a set of snapshots that illustrate the status of the architecture, technologies and solutions adopted in a use case at M0: the baseline is the reference point for the evaluation of project improvements. Initially the baseline was focused only on the use cases, but we decided to define a baseline also for horizontal work packages to keep track of the improvement introduced by the technologies/solutions that will be developed in the project when compared to M0.

Considering the complexity and heterogeneity of the baselines and of their analysis, the task adopts a common methodology for the baseline definition and provides surveys to support the analysis and ensure the collection of uniform and coherent information across the different use cases and horizontal WPs. The surveys guide the WP and use case leader in the analysis of the baseline and represent a good exercise intended to support a detailed assessment of the situation at M0.

Task 1.2 is in charge of analyzing and aggregating the baselines information, creating a report (D1.1, D1.2 and D1.3) that is updated, refined and potentially extended in every engineering cycle of the project. This flexibility provides the partners the time required to acquire the right level of expertise in the horizontal technologies and use cases (which is not always available at the beginning of the project), and ensures a high quality of the baselines analysis, which results in a more valuable validation and evaluation of project results at M36.

2. Requirements elicitation

This chapter describes the concept of requirement and illustrates the process for requirements elicitation. The preliminary requirements defined in this preliminary phase can be found in the Excel file available as annex.

2.1 The nature and role of requirements

The requirements describe the relationships between the actual concrete results developed in the work packages and the project objectives they satisfy. In general, they reflect the demand and supply relationship between the use cases and the horizontal WPs (WP2, WP3 and WP4), but are not limited to it: the request for a requirement defined in a use case can be satisfied by the use case itself. Requirements are not a wish list: identifying a requirement means that there is a need for what the requirement defines, and those that provide the requirement should be ready to help assess and explore the potential results intended to fulfill the requirement.

Requirements are defined in the form of a matrix to get a comprehensive and uniform record of the operational goals at the start of the project. The matrix gives in a compact way an overview of the expected concrete outcomes to record and improve collaboration between WPs. It will also serve as a concrete checklist for achieving the project objects as results are ticked off.

Requirements definition includes data and metadata related to the nature of the requirement, its description and motivation, and also contains information about how the requirements themselves relate to the project organization and to its objectives. Requirements may be defined at different abstraction levels and may relate to small technology details or larger systems and solutions, but they must be limited in number and have to focus on the adoption of the Building Blocks and on the project's objectives. There isn't an absolute limit, but just a soft and reasonable rule to ensure we don't miss the main targets of the projects, avoiding getting lost in an endless list of technical requirements with an excessive granularity.
The definition of requirement requires the specification of the following information:

- **ID**: requirement ID, automatically generated.
- **Submitter name**: the person providing the requirement.
- **Submitter's mail**: the email contact of the person providing the requirement.
- **Originating task**: the task from which this requirement originated.
- **Project building blocks**: the project building blocks related to this requirement, namely
  - Microservices,
  - Major digital models,
  - Automated data translation, Governance,
  - Verification use cases and
  - Training material.
- **Project Objective**: the project objective that is aimed to fulfill this requirement, namely
  - Facilitate 50%+ translations in PVN through automation.
  - SOA-based deployment and autonomous utilization of translators.
  - Update industrial data models.
  - Management methodology for translators' adoption.
  - Sustainable governance for Open-Source.
- **Requirement short description**: simply a very short description of the requirement.
- **Requirement motivation**: an explanation of why the requirement is needed.
- **Expected supplier**: the Task or WP that is expected to fulfill the requirement.
- **Related standards**: the list of relevant standards related to the requirement.
- **Means of assessment (KPI)**: explain how the requirement fulfillment can be assessed.
- **Validating Use Case**: the use case in which the requirement will be validated.
- **Validation Means**: explanation of how the use case will validate the requirement.
- **Y1 Fulfillment (%)**:1st year assessment of the fulfillment of the requirement in percentage.
- **Y1 Evaluation**: explanation of the fulfillment percentage achieved in the 1st year.
- **Y2 Fulfillment (%)**:2nd year assessment of the fulfillment of the requirement in percentage.
- **Y2 Evaluation**: explanation of the fulfillment percentage achieved in the 2nd year.
- **Y3 Fulfillment (%)**:3rd year assessment of the fulfillment of the requirement in percentage.
- **Y3 Evaluation**: explanation of the fulfillment percentage achieved in the 3rd year.

2.2 The elicitation process

To simplify the requirement elicitation process and to make it more efficient, we identified some steps to be followed and we set up a Sharepoint web site providing a form for the definition of the requirement. This approach ensures that the information we collect are uniform and coherent and provides Microsoft Office functionalities to elaborate the collected data and the export in Excel format (see the following figure).

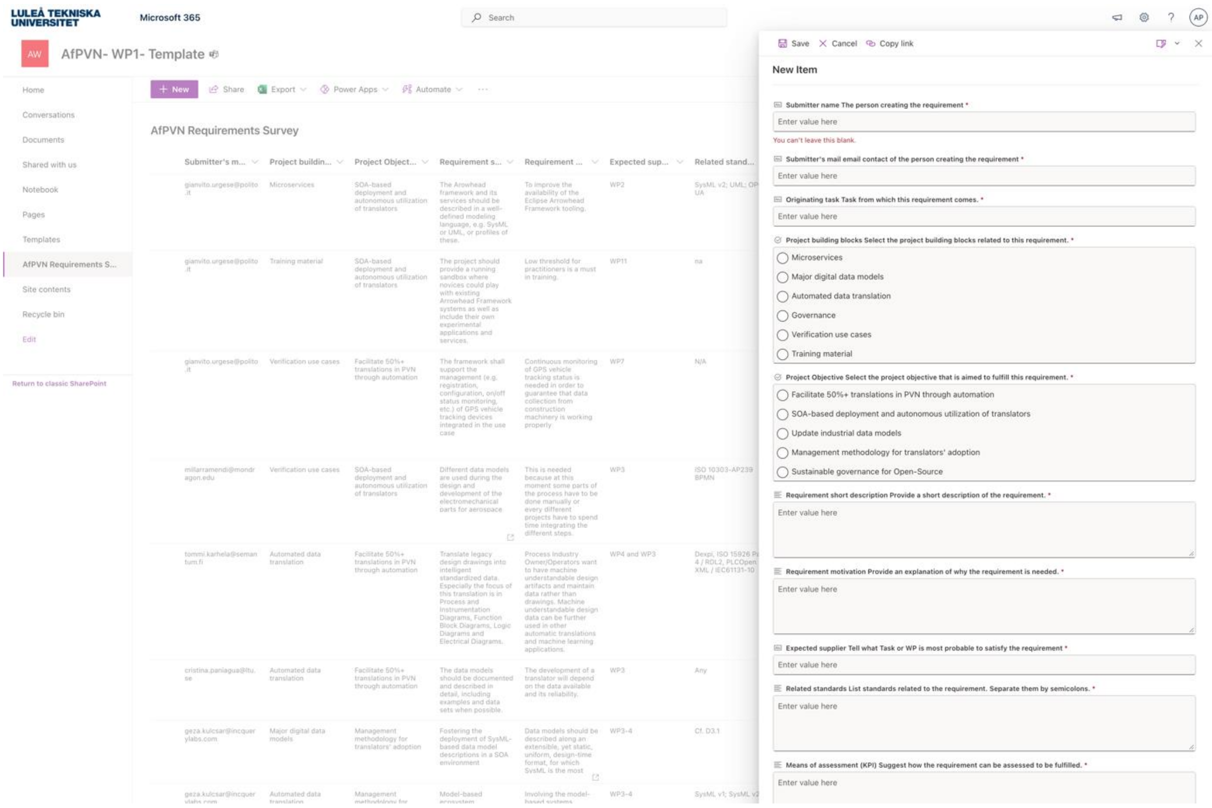

Figure 1 - The Sharepoint web site for requirements elicitation.

The requirements matrix mentioned in the Document of Action is and will be available in the form of an Excel file (see Annex 1).

The link to the Sharepoint web site was sent to the WP leaders of WP2, 3 and 4 and to the use cases leaders, but we also informed all the project's partners because, in principle, all the consortium partners could define requirements. As expected, at the beginning there have been some difficulties in the requirement elicitation, due to the complexity of horizontal technologies and of the use cases, but also as a result of the habit of going into technical details immediately without considering the project objectives as a reference. This problem caused a delay in the elicitation process, but gradually resolved and the first preliminary set of requirements is currently available.

The requirements elicitation process will be cyclical and will allow the project partners to review, refine, update, extend the existing requirements and add new one: this will be a continuous activity during the year, thanks to the Sharepoint web site that allows the online continuous editing of the requirement matrix. On the contrary, at the end of each project year we will evaluate the consolidation of requirements and their level of fulfillment.

2.3 The requirements matrix and its future use and maintenance

Deliverable D1.1 contains the requirements matrix as of end of December 2023 (see Annex 1). This defines a first baseline and starting point for the project, providing a preliminary indication about the expectations for the years to come. As anticipated, the Matrix will be continuously updated to guide and follow at the same time the evolution and progress of the project. We have been through a process of creation and consolidation that will continue in the next months until the end of the first project year with the first fulfillment evaluation. After this step, we will proceed with the continuous "maintenance" of the Matrix repeating the same process until the final requirement consolidation and fulfillment evaluation at M36.

In our first iteration we have ended up with 37 requirements. There are areas that are better covered than others, and in our next iteration of the requirements in a year from now, we intend to cover all areas in an equilibrate way, update and refine the existing requirements, add new ones, and start consolidating existing requirements to better support the fulfillment evaluation.

3. The baselines

This chapter introduces the concept of "baseline", illustrates the methodology used to analyze the building blocks (horizontal technologies) and use cases to define the correspondent baselines, and reports the preliminary results of this analysis.

3.1 The concept of "baseline"

A baseline is a snapshot in time that illustrates the current status (at M0) of a horizontal technology or a use case. It represents a reference point for the evaluation of the improvements introduced by the technologies developed in the project.

For the horizontal technologies the baseline covers the following aspects:

- the state of the art of specific enabling technologies in the domain of the building block;
- the action plan, starting from M0, to reach the WP-specific and project objectives;
- the identification of KPIs and the definition of an evaluation and validation process.

For the use cases the baseline covers the following aspects:

- the architecture of the use case as a sequential list of functional blocks;
- the relation with the project objectives;
- an explanation of how the building blocks will be adopted;
- the description of the engineering process adopted in the use case;
- the analysis of the engineering costs;
- the adopted standards;
- an outlook of the previous aspects beyond the baseline, including an action plan to reach the project objective and a final evaluation process.

The WP leaders of the horizontal work packages are responsible for the definition of the baselines of the building blocks, while the use case leaders are responsible for the use case baseline definition. In order to simplify the baseline definition and to ensure that the analysis produces uniform and coherent information, we have defined two surveys which support and guide WP and use case leaders in this task. The templates of the two surveys are provided as annex to these deliverables (see Annexes 2 and 3).

Conceptually, the surveys have been conceived to align and follow the outline of "project approach and ambitions", as defined in the project proposal (see next figure and figure 1.13 of the DOA). The surveys are living documents that, starting from the first iteration providing the contents for D1.1, will be continuously updated to keep the baseline consistent with the evolution of the project. Periodically we will request an update of the baseline (e.g. new technologies, better understanding of the state of the art, etc.) that will be included in the deliverables according to the project timeline (D1.2 and D1.3).

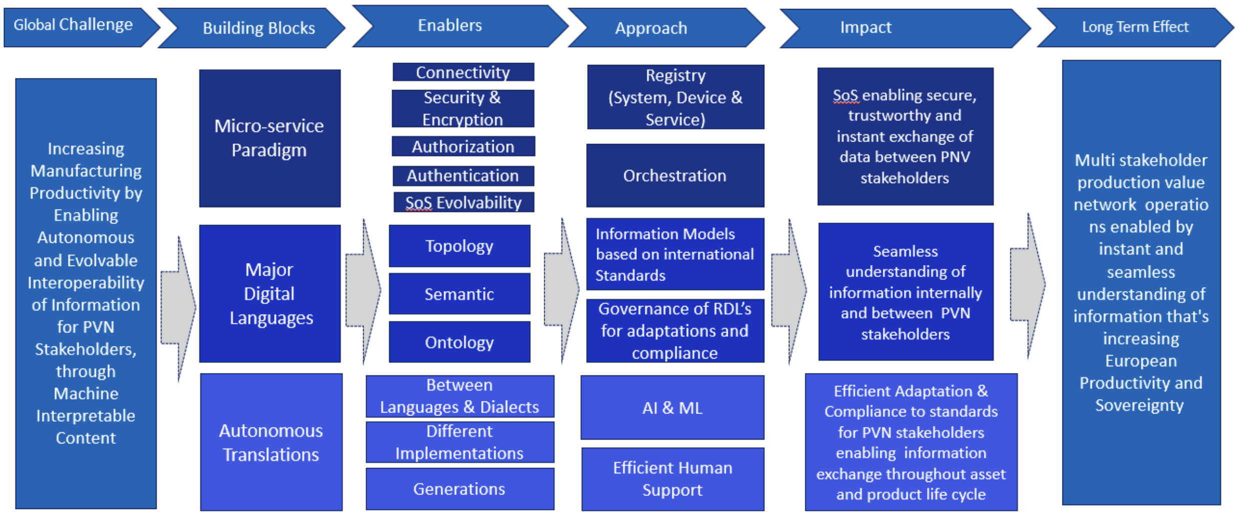

Figure 2 - Approach and Ambition outline in logical steps (from DOA).

3.2 Building blocks baselines

This section reports the preliminary analysis of the baseline of the main building blocks that will be designed and developed in the projects by the horizontal work packages:

- Micro-service paradigm,
- Major digital languages,
- Autonomous translations.

Although in the first engineering cycle the definition of the baselines is in a preliminary stage, focusing mainly on the analysis of the technology and of the state of the art, for the building blocks baselines the information available in this phase are already quite complete, covering in detail all the aspects included in the survey. We can consider these baselines in a stable status, potentially being consolidated already in the next deliverable (D1.2).

3.2.1 Micro-service paradigm

3.2.1.1 Building Baseline summary

The grand challenge in the Microservices area is primarily related to the paradox of stagnating productivity despite rapid digitalization. In Arrowhead fPVN, the maturing and extension of the Eclipse Arrowhead architecture and implementation platform will take place. This enables the design and implementation of flexible automation and digitalization solutions based on runtime orchestration and workflow management. This approach puts Eclipse Arrowhead in a leading position as the open-source IoT and SoS platform opening up the IoT and SoS market for open competition and independent development.

3.2.1.2 Baseline analysis

The current industrial production baseline is an emerging use of micro services to enable flexible, dynamic, and scalable production-automation and digitalization solutions. This emerging use starts from handmade integration between multiple monolithic systems addressing one or several functionalities in the ISA-95 production architecture. The introduction of the microservice technology requires a high degree of interoperability at both communication technology and data level to enable integration of current state of the art with the more flexible microservice-based approach. A shift towards Service Oriented Architectures (SoA) has started to evolve for Industry 4.0 – one widely accepted solution is the Eclipse Arrowhead framework. Nevertheless, further expanding the SoA approach with more focus on the microservice paradigm itself and its technology advancements.

The paradigm shift from legacy monolithic systems and closed/proprietary protocol sets to the microservice approach opens for integrating legacy technology with open microservice technology. Protocol translators or adaptors is the primary approach. Using translators and adaptors the legacy technology communication can be transformed to microservices. A very concrete example thereof is the OPC-UA to Eclipse Arrowhead adapter. Here OPC-UA to microservice interoperability at the communication and orchestration technology level (hardware and protocols) is demonstrated.

The current state for integrating legacy automation technology with the microservice paradigm consists of a number of open-source OT/IT integration frameworks like FiWare, Basyx, Eclipse Arrowhead, LWM2M, OCF, IoTivity, Autosar. None of these frameworks address autonomous support of the underlying issues, such as protocol and data model translation, which are clear technology gap. The comparison indicates that Arrowhead has edge compared to other initiatives regarding Interoperability, Security, Edge computing and Real-time capabilities. Another knowledge and technology gap is autonomous identification of the interoperability mismatch. The ideas of dynamic and autonomous instantiating translators based on needs should be further investigated in the Microservice WP.

For Arrowhead fPVN, the Eclipse Arrowhead framework will be used as the implementation baseline for Arrowhead fPVN advancements beyond SoTA. Protocol and encoding translation uses the novel translation and adaptor technology already released by the Eclipse Arrowhead project. This technology results from the Arrowhead Tools, Productive4.0, Arrowhead and other projects which are fundamental stepping stone knowledge to Arrowhead fPVN. For the baseline the most important available Eclipse Arrowhead core systems are briefly presented in Table 1.2 of the Annex 1, Part B – Grant Agreement.

To enable the, by the 10 use cases forecasted impact, a further maturing of a set of the Eclipse Arrowhead core system has been deemed necessary. Thus maturing a set of Eclipse Arrowhead core systems and related engineering tools and procedures and providing a long term development and maintenance governance structure is important for both short and long term exploitation of the technology.

Thus, the identified knowledge gaps are related to:

- Autonomous detection of non-interoperable properties of protocols and data models
- Autonomous instantiating of necessary translations

- Maturing of and extensions to Eclipse Arrowhead core system and its engineering procedures and tools
- Long term governance support to Eclipse Arrowhead

3.2.1.3 Beyond the baseline

Engineering tools and procedures. The planned advancements are – Refinement and working demonstration of dynamic engineering process required to autonomously engineer and deploy identified translators of protocols and data models, targeting minimum TRL 6. The approach depends on the architectural mechanism of Eclipse Arrowhead regarding dynamic instantiating of system and services. This will require extensions to the various relevant modules of Eclipse Arrowhead core system like ServiceRegistry and Orchestration. This topic also covers various levels of governance of the microservice architecture.

Maturing core systems of Eclipse Arrowhead. The planned advancements are to mature Eclipse Arrowhead core systems. Beside the main core systems will be made available at TRL 8, several supporting core systems, and adapter systems are going to reach TRL 6-8 according to Table 1.2. This widens up the interoperability possibilities for legacy industrial systems and new system components alike, in all targeted application domains. The conceptual extensions as well as the reference implementations for validation and verification are governed through a dedicated road map process execution.

Maturing protocol and encoding interoperability translator and legacy adaptors. The planned advancements are - to reach TRL6-8 according to Table 1.2. The microservice paradigm will furthermore address autonomous identification of non-interoperability and autonomous instantiating of translation systems to resolve the identified non-interoperability. The approach here is based on analysis of data model metadata like e.g. used ontologies.

3.2.1.3.1 Technology action plan

The following actions are planned to be carried out in the Arrowhead-fPVN project to reach the goals in the **Engineering tools and procedures** section:

1. Creation of a cookbook for building Industry5.0-compliant microservice applications.
2. Gathering of architectural and design patterns of microservice based applications and SoS. These patterns should reside in the cookbook.
3. The definition and testing of a process for version and change management of services and systems in the Eclipse Arrowhead framework in some dimension.

The following actions are planned to be carried out in the Arrowhead-fPVN project to reach the goals in the **Maturing core systems of Eclipse Arrowhead** section:

1. Delivery of an Eclipse Arrowhead framework at TRL 7-8, potentially including Open Source and commercial applications.
2. Documentation of interconnection patterns and solutions with other IoT platforms.
3. Implementation of microservices that support interoperability, using automatic translators.
4. Design of means for Autonomous Contracting and Invoicing – to be able to commercialize the domain.
5. Development of third-party access management, in line with contracting and invoicing.

The following actions are planned to be carried out in the Arrowhead-fPVN project to reach the goals in the **Maturing protocol and encoding interoperability translator and legacy adaptors** section:

1. A method or system that detects if non-interoperable interfaces reside in the SoS.
2. Autonomous allocation and assignment of translators when non-interoperable interfaces need to collaborate.
3. Support for security mechanisms in local and global clouds.

3.2.1.3.2 KPIs, Evaluation, and validation process

The Table 1 summarizes the KPIs defined for the autonomous translation evaluation and validation.

Table 1: Micro-service paradigm KPIs

Key Performance Indicators (KPI)			**KPI Fulfilment & Evaluation**		
Name	**KPI Description**	**Means of assessment**	**Year 1**	**Year 2**	**Year 3**
2.1.1	Cookbook presence	Review, approve and use the cookbook			
2.1.2	Number of patterns present in the cookbook.	Counting of implemented /verified patterns			
2.1.3	Governance process	Percentage of WP defined services under version control.			
2.2.1	TRL level of Eclipse Arrowhead framework components.	Assess percentage of components that have reached M36 TRL level.			
2.2.2	Number of reports on interconnection analyses.	<TBD>			
2.2.3	Number of available translators in Eclipse Arrowhead.	Counting			
2.2.4	Existence of a process for Contracting and Invoicing	Review, approval and verification of implementation.			
2.2.5	Existence of access control to components in the Eclipse Arrowhead framework.	Verification of a purchase process.			
2.3.1	Presence of detection of non-interoperability.	Demonstration of function.			
2.3.2	Allocation of translators in the Eclipse Arrowhead framework.	Demonstration of function.			
2.3.3	Translators use IA core systems in Eclipse Arrowhead framework	Demonstration of function.			

3.2.2 Major digital languages

3.2.2.1 Building Baseline summary

The Grand challenge is information interoperability. According to the European Interoperability Framework, there are several levels of interoperability as shown in Figure 3.

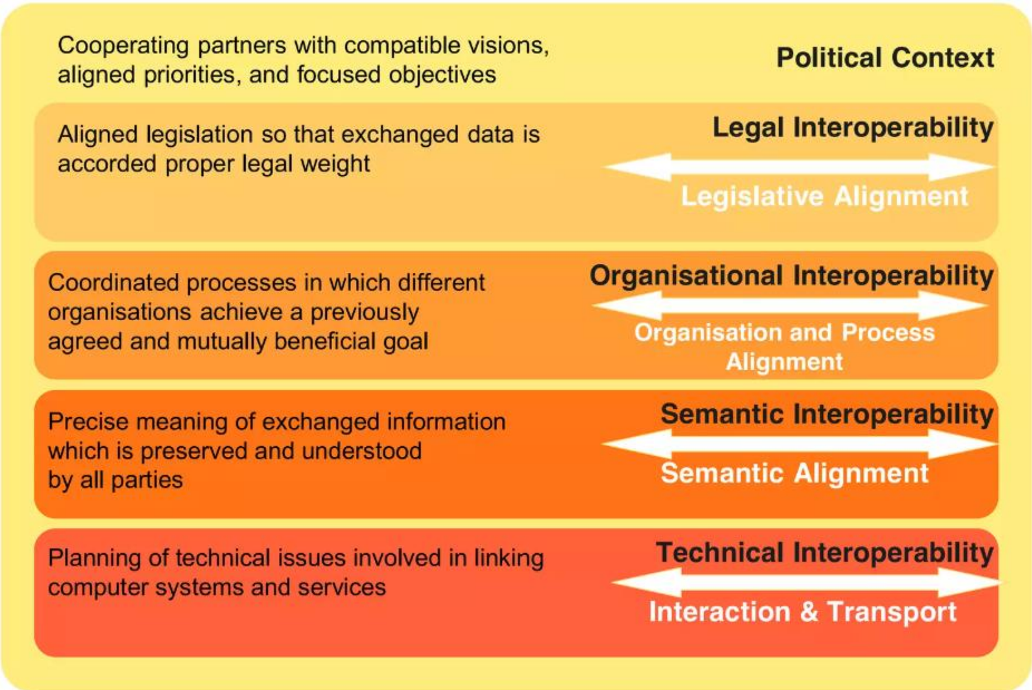

Figure 3: Levels of interoperability described in the European Interoperability Framework

WP3 concentrate its efforts on Semantic Interoperability especially between defined and in real life used international Information Model standards. Some Management standards addressing Organizational Interoperability includes valuable semantics without defining it in a formal way using Information models. The relevant part of these standards needs to be included in a Semantic Alignment effort.
The Grand Challenge on the semantic level is the lack of alignment. Many standards are developed in isolation by a standardization group focusing on a specific part of e.g. a products life cycle and the alignment with other standards with different scopes is poor.

To support the specified use-cases the most important information model standards to align are:

- WP6 (Automotive): ISO 10303 STEP, URDF Robot description, (speech and noise standards)
- WP7 (Aerospace): ISO 10303 STEP, ASD-5000F (In service feedback), 2000M Material Management) and 3000L (Logistic support)
- WP9 (Process Plant): ISO 15926 (Oil & Gas) and related industry standards DEXPI, DEXPI+ and CFIHOS, ISO 10303 STEP, ISO 18101 (Interoperability principles), IEC 61987 (CDD), IEC 611311-3 (PLC), ISO 81346-1 Classification and identification), IEC 61406 (GUIDs), ISO 12006 (Classification framework), ISO 19650 (Life cycle phases), ISO 61499 (Distributed automation) and OPAF (Process automation).

3.2.2.2 Baseline analysis

Most of the main standards in scope of WP6, WP7 and WP9 are based on the ISO 10303 and ISO 15926 modelling paradigm. First generation of these information model standards used the ISO Express language. Later revisions have been using SysML (as a modelling language), XML Schema and RDF Schema. Both the ISO 10303 family and the ISO 19526 family has been applying methods to achieve internal interoperability but the inter standard capability of interoperability between e.g. ISO 10303 and ISO 15926 has been very limited even though the standard has been developed in the same ISO subcommittee.
All standards in scope for the WP6, WP7 and WP9 pilots carry very valuable semantics and the possibilities to achieve good interoperability is considerable from a modelling methods point of view. Other standards with a more management/process/organization standard type mentioned by the WP6, WP7 and WP9 require much more basic modelling, to make the semantics in the standard explicit and non-ambiguous. It would be of interest to create a high-quality ontology out of a management standard like ISO 81346.

3.2.2.3 Beyond the baseline

3.2.2.3.1 Technology action plan

WP3 objectives related to the Major digital languages are:
1. Select major standardized data models relevant to the use cases.
2. Identify the foundational properties of the selected data models.
3. Identify similarities and dissimilarities between the standardized data models.
4. In cooperation with WP4 propose updates to the selected standard which will improve data model translation accuracy.

Objective 1 has been achieved by using a survey to ask WP6, WP7 and WP9 which standards they are planning to use in their use-cases.
Objective 2 and 3 will be achieved by expressing the standards in a semantic language, and performing the analyses and comparisons needed to support the use-cases of WP6, WP7 and WP9. ISO 23726 Industrial Data Ontology (IDO) is proposed as the Upper Ontology.
Objective 4 needs more planning in cooperation with WP4.

3.2.2.3.2 KPIs, Evaluation, and validation process

Table 2 summarizes the KPIs defined for the autonomous translation evaluation and validation.

Table 2: Major digital languages KPIs

Key Performance Indicators (KPI)			**KPI Fulfilment & Evaluation**		
Name	**KPI Description**	**Means of assessment**	**Year 1**	**Year 2**	**Year 3**
3.1	Number of collected and analyzed standards regarding Automotive fPVNs	Inventory (Reports and documents in the Owncloud)	1	2	2
3.2	Number of collected and analyzed standards regarding	Inventory (Reports and documents in the Owncloud)	>1	>2	>3

	Aerospace fPVNs				
3.3	Number of collected and analyzed standards regarding Process Industry fPVNs	Inventory (Reports and documents in the Owncloud)	>4	>5	>5
3.4	Number of collected data model formats regarding use case partners	Inventory (Reports and documents in the Owncloud)	>3	>5	>5
3.5	Number of analyzed data model formats	Inventory (Reports and documents in the Owncloud)	>2	>3	>3
3.6	Number of analyzed communication protocols	Inventory (Reports and documents in the Owncloud)	>2	>3	>3
3.7	Number of analyzed modelling and knowledge representation languages	Inventory (Reports and documents in the Owncloud)	>1	>2	>2
3.8	Number of standard comparisons	Inventory (Reports and documents in the Owncloud)	>1	>2	>3
3.9	Number of found synergies	Inventory (Reports and documents in the Owncloud)	-	>1	>2
3.10	Number of found interoperability problems	Inventory (Reports and documents in the Owncloud)	-	>1	>2

3.2.3 Autonomous translation

3.2.3.1 Building Baseline summary

In order to achieve successful communication, systems require to have a compatible interface and understanding of the data among them. This includes the communication protocol, encoding, encryption, compression, message structure, payload key values, and semantics. Once the data is successfully received, the data needs to be understood to be properly used.
Nevertheless, in some cases, the communication cannot be established due to mismatches between the interfaces or the incompatibility of the data. In this situation, translation techniques can be used to solve the differences between the systems and solve the communication problem. There are several situations where this type of translation is necessary, in some cases as a temporary solution and in others as a permanent solution. Autonomous translation can be used when due to any problem one of the systems stops working and to avoid the pause of the activities, another available system is used instead. The new couple of systems may not have the interfaces designed to work together and translation mechanisms are needed to make it work until the previous system is restored.
Another situation is the new integration of systems that due to their vendor or version are not compatible with the current working systems. In this case, to reduce engineering time the translation mechanism is put in place. In the same way, when an old system is updated changes in the function or interface can affect the compatibility with the others.
Regarding autonomous translation technologies, several grand challenges shape the landscape of this field. Understanding and overcoming these challenges is vital for the successful

development of translation services that can seamlessly bridge the gap between diverse data modelling languages.

One of the primary challenges is achieving a deep semantic understanding of data models across different languages. Each data modelling language often carries its own unique semantics, making it necessary to employ advanced techniques and semantic reasoning to accurately map concepts and relationships between them. Moreover, data models are not limited to textual information; they can encompass a wide range of data types, including diagrams, images, and structured data. Handling and translating this multimodal data is a significant challenge.

Ensuring interoperability of translated models across heterogeneous systems is a crucial challenge. Achieving this often involves the use of standardized data exchange formats and well-defined APIs to enable seamless integration into various platforms.

To address these challenges, three approaches are investigated:

- Ontology-based translation
- AI-based translation
- Model-based translation

3.2.3.2 Baseline analysis

To further analyze the state-of-the-art for specific enabling aspects of autonomous translators this section has been divided into the three main approaches selected for the project.

Ontology-based translation state-of-the-art. Semantic Annotations for Web Services Description Language (SAWSDL) [1] is a W3C recommendation for the semantic annotation of Web Service Descriptions (WSDL) and XML Schema [2]. SAWSDL allows us to include semantic annotations within the schema, enabling the mapping of XML instance documents to ontologies. SAWSDL model references connect XML Schema elements, types, or attribute declarations with named semantic concepts of some semantic model. To increase the expressiveness of model references, not only to ontology concepts but also to properties and individuals, Annotation Paths [3] were proposed. When annotating a schema with Annotation Paths, path expressions are inserted as values for Model Reference attributes. Later, in [4,5], methods to group semantic annotations and to add complement data values were proposed to solve ambiguities and to provide additional data required by the consumers. Additionally, in [5], a tool named TAG-Tool was used to verify XML-based system compatibility as well as to automatically generate translators to support their interaction.

AI-based translation state-of-the-art. Recent advancements in AI- and ML-based methodologies are primarily employed for a range of critical functions. These functions include data analysis, feature extraction, real-time predictive analytics, as well as for addressing security concerns. These security applications encompass threat detection, anomaly detection, and information protection, in addition to classification tasks.

Martin Bauer's [6] work introduced the concept of a virtualized IoT platform, referred to as VirIoT, designed to facilitate information exchange between producers and consumers. This innovation relies on the implementation of a standardized, neutral information model known as NGSI-LD. Furthermore, the paper proposes the integration of Machine Learning methods in the ontology matching process to support developers. The core idea underpinning this solution is the effective utilization of ML algorithms for the automatic extraction and translation of sensor data into a standardized, neutral format. Knowledge infusion techniques were also applied in the matching process.

Neural Machine Translation (NMT) [7] represents a state-of-the-art neural network-based approach for language translation. The training phase leverages dictionaries that are transformed into word pairs following a preprocessing stage. In the realm of NMT, Deep Neural Machine Translation (DNMT) stands out as a variant that operates with multiple neural network layers, distinguishing itself from single-layer NMT models. OpenNMT, on the other hand, is a noteworthy open-source Python framework employed for learning and translating using NMT techniques.
Pasindu et al. [8] contributed to the field by presenting techniques aimed at enhancing the performance of Neural Machine Translation methods in language translation. Their evaluation work utilized the OpenNMT framework, revealing that translating between grammatically similar languages could be notably improved by introducing an intermediary language, such as English, into the translation process.
In addition, continuous learning is a fundamental aspect of autonomous translation technologies. Systems need to adapt and improve continually. Advanced approaches include reinforcement learning techniques, where the system learns from user feedback and interactions, gradually enhancing its translation quality over time.

Model-based translation state-of-the-art. Kleppe et al. [9] provide the following definition of model transformation: **A model transformation** is the automatic generation of a target model from a source model, according to a transformation definition. **A transformation definition** is a set of transformation rules that together describe how a model in the source language can be transformed into a model in the target language. **A transformation rule** is a description of how one or more constructs in the source language can be transformed into one or more constructs in the target language.
This definition is very general, and covers a wide range of activities for which model transformation can be used: automatic code generation, model synthesis, model evolution, model simulation, model execution, model quality improvement (e.g., through model refactoring), **model translation**, model-based testing, model checking, model verification, and many more [10].

In the Arrowhead-fPVN project, we will focus on the model based translation techniques from one data model standard to another.
A model-based translation requires the mastery of a transformation language as well as a sufficient knowledge of the source and the target languages (standards) in which the source and the target models are expressed.
In Model driven Engineering, transformation languages can be classified in three categories according to [11]: The first category represents the declarative transformation languages as Query/View/Transformation language (QVT) [12] and its sublanguage QVT-Relations (QVTr) Triple Graph Grammar (TGG) [13], and the Transformation Nets (TNs) [14].
The second category represents imperative languages such as QVTOperational (QVTo) [15]. While the third category includes hybrid languages such as Atlas Transformation Language (ATL) [16] and Epsilon Transformation Language (ETL) [17].
A Java like transformation languages such as Xtend and Xtend based languages like the VIATRA transformation language [18] are as well used in the model-based translations.

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3.2.3.3 Beyond the baseline

The Table 3 summarize the planned actions regarding each WP4 objective.

Table 3: Planned actions regarding WP4 objectives.

Objective	Actions Planned
Provision of data set for translation development and early assessment of translation quality.	- Survey WP 1 – Questioner about translation and data sets available. - Connection with the use cases available datasets.

	- Analysis of the data structure and synthetic creation of data to avoid confidentiality issues. - Test and validation with real data in demonstrators.
Investigating the capabilities and feasibility of the ontology-based approach	- Analysis of data models, datasets, and use cases. - Identification of translation challenges. - Development of a tool prototype (DITAG) for interoperability verification and translation automatic generation. - Make available in open access the tool prototype. - Validation of the tool prototype. - Demonstration about how to use the tool. - Publication about the tool prototype and results.
Investigating the capabilities and feasibility of an ML/AI-based approach	- Research and analysis of the translation gaps that can be addressed by AI. - Investigation of AI techniques to generate translation at service communication. - Development of open-source tools and solutions based on the investigation. - Validation of the tool prototype in demonstrators. - Publication about approach and results.
Investigating the capabilities and feasibility of a model-based approach	- Select at least 3 different data model standards (most used by use cases) and study the commonality and the differences between the standards. - Study the transformation language (select the most convenient one) - Provide an example of a model-based translation in Papyrus. - Study the idea to make SysML a common Intermediate representation for the translations between those standards. - Implement other model transformations and study the process to automatically generate them. - Publishing the result in conference papers - Developing the POC and package it to be used by the use cases. - Integration of the tool in the Arrowhead framework
In cooperation with WP3, to provide translation microservices based on the above approaches	- Meetings and technical workshops to integrate the translation solutions into Arrowhead microservices. - Analysis of data model structures and usage in conjunction with the WP3 to further application in the translation solutions - Integration and testing of the solutions in the framework.

3.2.3.3.1 Technology action plan

The following points summarize but are not limited to the research activities planned for the autonomous translation of data models:

1) Analysis of the data sets and data models provided by the use cases. This activity includes the identification of the structures and features and the creation of syntactic data for their use in the developments without infringing industrial confidentiality.

2) Study of different data models and standards based on the WP3 work, the analysis will be performed from the translation point of view, including commonalities and differences.
3) Analysis of the translation scenario, technology gaps, and challenges regarding autonomous translation. This includes mismatch identification, description abstraction, translator generation, and testing and validation among others.
4) Investigation of AI and ML techniques to address the gaps and provide new translation solutions.
5) Study of the use of SysML V2 textual language as a common intermediate representation for all translations.
6) The implementation of prototypes based on the investigated approaches using a set of selected languages for at least three data model standards.
7) The Integration of the tool in the Arrowhead framework.
8) Recompilation of the translation solutions and prototypes on an inventory available for the consortia, including technical details and links to the realized code.
9) Writing of scientific publications (conferences and journals) and communication of results to a broader scientific audience.

Implementation

The translation solutions will be implemented into tools, prototypes or/and Arrowhead supporting systems, ensuring their practical usability. These tools and prototypes will serve as tangible applications of our translation approaches, allowing for real-world testing and validation. Our objective is to make these integrated tools and prototypes openly available, promoting their accessibility and encouraging broader utilization within the project.
The solutions will follow the microsystem architecture approach and provide accessible APIs. During the project the tools will be integrated with the Arrowhead framework and adapted to the use cases.

Documentation

In the context of our work package's development, a fundamental aspect of ensuring clarity, consistency, and adherence to best practices is the seamless integration of documentation with the implementation of our translation solutions and prototypes. The documentation will follow the Arrowhead framework documentation structure and mirror the framework's guidelines, ensuring, as much as possible, that every interaction, component, and feature is comprehensively described, with clear references to the relevant parts of the prototypes implementation. This approach not only enhances the usability of our documentation but also facilitates collaboration among team members, stakeholders, and the broader development community. In the case of a resale tool, this should be documented: how to download, how to install, and how to use with an example provided with the tool.
In addition to the documentation, the results will be also presented as scientific publications in conferences and journals.

Demonstrators

In the forthcoming stages of our project, it is imperative to establish a framework for testing and validating the translation solutions within the context of our demonstrators and use cases. To ensure the effectiveness and reliability of these solutions, a comprehensive testing strategy will be employed. This strategy encompasses both functional and performance testing, wherein the translation solutions will be subjected to a variety of scenarios that mimic real-world use

cases. We will assess their accuracy, speed, and scalability under different conditions to validate their practical utility. The demonstrators, which mirror the intended operational environments, will serve as the testing grounds, allowing us to evaluate how well the translation solutions integrate and function within the specific contexts of our use cases. Through these systematic and comprehensive validation procedures, we aim to guarantee that the translation solutions meet the exacting standards required for their successful deployment.
Each task will in addition select at least a use case and integrate the tool to the Arrowhead framework to be used in this use case demonstrator.

Timeline
The following diagram in
Figure 4 summarizes the expected timeline.

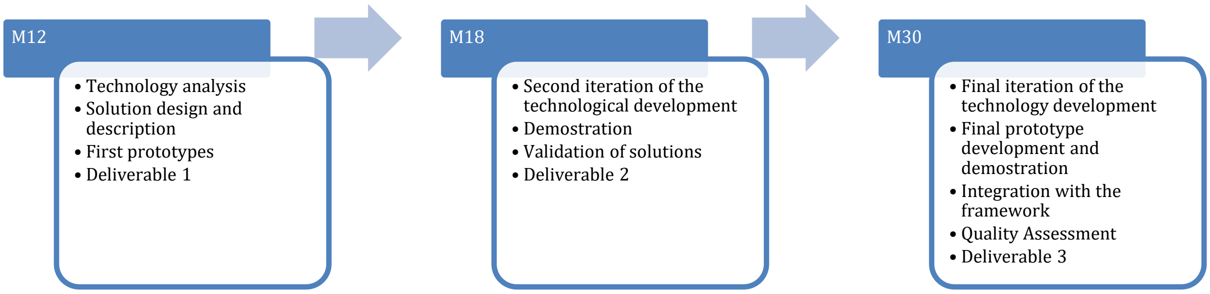


Figure 4: Autonomous translation timeline

3.2.3.3.2 KPIs, Evaluation, and validation process

Table 4 summarizes the KPIs defined for the autonomous translation evaluation and validation. The KPI are explained in more detail after the Table 4.

Table 4: Autonomous translation KPIs

Key Performance Indicators (KPI)			**KPI Fulfilment & Evaluation**		
Name	**KPI Description**	**Means of assessment**	**Year 1**	**Year 2**	**Year 3**
4.1	Number of translation solutions provided during the project	Inventory (File in the Owncloud)	3	4	5
4.2	Range of data-models, standards and protocols translated.	Inventory and demonstrators	>3	>5	>6
4.3	Translation accuracy	Measure the correctness and precision of translations (Metrics)	>60%	>70%	>80%
4.4	Resource utilization on the use cases.	Monitor the utilization of translation resources (translators, tools, and software).	>20%	>40%	>60%
4.5	Number of scientific publications in the work package	Number of register publications.	>4	>6	>7

4.6	Evolution of the prototypes available	Tools and prototype version (version id)	1st version	2nd version	3rd version
4.7	Integration of the solutions on the Eclipse Arrowhead Framework	Number of solutions integrated in the framework	-	>2	>3

KPI description:

- 4.1 - Number of translation solutions provided during the project. Throughout the project, a variety of translation solutions based on different approaches will be offered. An inventory will document these solutions, including details about the translated data model, revised code, and integration with the Arrowhead framework. The inventory file is accessible to the consortia via OwnCloud and will be regularly updated as a progress indicator.
- 4.2 - Range of translated data models, standards, and protocols. Based on the data model analysis conducted during the project, several data models and standards will be used in the translation process. The number of pairs translated will serve as an indicator of the progress of the translation solutions.
- 4.3 - Translation accuracy. Translation accuracy refers to the correctness of the translation solutions. Accuracy can be measured using various metrics, including the percentage of messages translated and the correctness of the translated payload when compared to the ideal solution.
- 4.4 - Resource utilization in use cases. The solutions will be provided to the use cases, and this Key Performance Indicator (KPI) will quantify how useful the translation solutions are for these use cases. It will measure the percentage of solutions and resources used.
- 4.5 - Number of scientific publications in the work package. The solutions will be published to reach a broader scientific community, and the number of publications will be tracked throughout the project.
- 4.6 - Evolution of the available prototypes. The prototypes will evolve during the project's iterations, with new versions being presented each year.
- 4.7 - Integration of the solutions with the Eclipse Arrowhead Framework. In the first year, the tools and solutions will be developed independently of the Arrowhead Framework. For the remainder of the project, the solutions must be integrated into the framework, and the number of integrated solutions will serve as an indicator of progress.

3.3 Use case baselines

This section reports the preliminary results of the baseline analysis for the following use cases:

- 1_6 - Automotive Battery Innovation fPVN
- 1_7 - Interoperable intelligent management of production lines: Towards Model-based Enterprise.
- 1_8 - System-Driven Modularization and Digitalization for Offshore Renewables.
- 1_9 - Pump Station Engineering.
- 2_6 - Humans in the interoperable System.
- 2_7 - Aircraft Health Management System (AHMS) for Trend Monitoring, Predictive Maintenance and Fleet Operations & Maintenance Simulation.

- 2_9 - Digital Twins that enable higher performance by interoperability in pulp mills & carton board mills.
- 3_9 - Interoperability for technical information exchange in process industry.

In this preliminary phase the definition of the baselines presents very different levels of maturity. Use cases 1_6, 1_7 and 2_7 already provided a complete baseline, which can be considered in a stable status. For use cases 1_8, 1_9, 2_6, 2_9 and 3_9 the analysis of the baseline is still ongoing.

The use case survey contains a specific section related to the engineering process and costs: building on the very positive outcomes of the Arrowhead Tools project, we decided to include a section on this topic to consolidate those results and share the acquired knowledgebase for the benefit of the new use cases. In this preliminary phase, although already included in the survey, we decided to skip the part related to the engineering process because it requires specific expertise and training. Starting from the next semester, we will organize a set of conference calls specifically focused on the engineering process and costs, to provide some informational and training material to all the partners of the project and, in particular, allow the use case leaders to include this topic in the use cases baselines.

The baselines definition is a continuous activity, and the associated documents can be considered a living material. We expect a marked improvement during the next year, to proceed towards the finalization during the last year of the project.

3.3.1 Use-case #1.6 – Automotive Battery Innovation fPVN

3.3.1.1 Baseline summary

3.3.1.1.1 General description of the baseline

The UC in T6.1 "Interoperable information along the full life cycle of EV batteries" will develop demonstrators for three exemplary stages of the battery life cycle as shown in the Figure 5:

1. interactions between battery design and test labs,
2. operation phase (use in an electric vehicle, EV) and
3. optimized end-of-life processing.

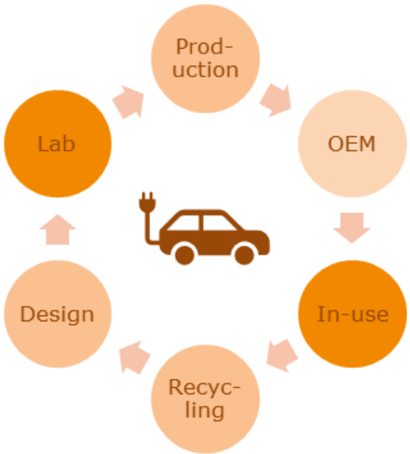


Figure 5: UC-1.6 Full life cycle of EV batteries.

Ad (**1**): Today, data interfaces from R&D to V&V are only partly implemented. The challenge is to use & exploit data from tool chains used in design and testing (usually from multiple vendors) on one side by test factory management systems (TFMS) on the other side. This is to avoid the need for manual transfer or the need for “glue logic coding”, for data like specifications (e.g., capacity, max. current, ...) Especially as this might often need rework upon changes (e.g., updates).

Ad (**2**): During operation, battery data is typically collected by the battery management systems (BMS) in the vehicle. However, this is often a closed & proprietary system, which makes it hard to learn from real-world experience, and aggregate it across vehicles and fleets, to gain deeper understanding about battery performance and aging. Relevant data include battery electrical parameters as time series (current, voltage) and environmental data (e.g., temperature and vibration/acceleration).

Ad (**3**): Fast and efficient evaluation of battery health is important for optimal decisions about when to replace it in the vehicle (ending its “first life”) and where to best use it afterwards (“second life” or recycling). This decision is typically based on measurements (charge/discharge tests), taking time and effort.

This estimation could be significantly improved by using detailed battery information (like type, age, materials used etc.) as well as accessing the conditions during its usage.

3.3.1.1.2 Initial architecture of the use case as a sequential list of functional blocks

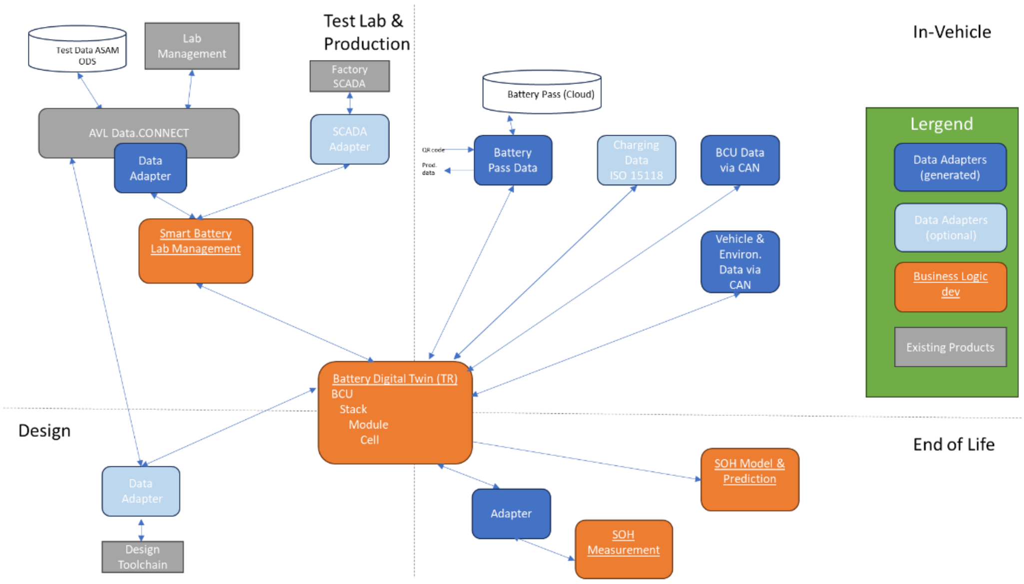


Figure 6: Initial UC-1.6 Architecture

Table 5 lists functional blocks planned for prototypical implementation in the project (see Figure 5)

Table 5: UC-1.6 Functional Blocks planned for prototypical implementation.

Name/Label	Short description
Data Adapter	Access to measurement data (e.g. stored in ASAM ODS compliant systems other);
Battery Pass Adapter	Access to descriptive data of specific EV batteries (Battery Pass[1])
BCU Data via CAN	Data from battery management system (BMS) via battery control unit (BCU)
Vehicle and Environment data	Real-world / in-use phase data collected directly from vehicle sensors via its network (e.g., CAN)
Adapter to the SOH measurement system	exchange data to/from digital twin in order to improve residual value estimation

3.3.1.1.3 Objectives that are linked to the Arrowhead fPVN objective

Table 6: UC-1.6 Arrowhead fPVN objective.

Project Objective	**UC Contribution**
Obj 1 - Facilitate more than 50% of needed translations in realistic production value networks	Shall be prototypically implemented in functional blocks as listed in Table 5

[11] https://data.consilium.europa.eu/doc/document/PE-2-2023-INIT/en/pdf

by autonomous machine-based translation micro-services thus significantly reducing the need for human support.	
Obj 2 - Microservices/SOA enabling of dynamic deployment and autonomous utilization of information translation in PVNs	Will be used to implement and access the functional blocks listed in Table 5
Obj 3 - Update proposals for major digital data model for industrial production between which autonomous and seamless data model understanding is enabled.	Currently n/a
Obj 4 - Digital transformation management methodology for the introduction of seamless and autonomous translation within a PVN	Will be demonstrated for optimized lab management in a battery test lab
Obj 5 - Established a sustainable governance of open-source architecture and implementation platform	Currently n/a

3.3.1.2 Baseline analysis - building blocks & enablers

3.3.1.2.1 Micro-service paradigm

3.3.1.2.1.1 State of the art

Current solutions are either implemented as monolithic applications, or based on general SOA (but not micro-services) like AVL's Data.CONNECT™, see https://www.avl.com/en-at/development-speed-and-methodology/connecting-solutions/data-management-dataconnect

3.3.1.2.1.2 Enablers

Arrowhead's micro-service approach shall allow a modular, yet flexible orchestration of a digital twin of the EV battery, linking together the different silos of the phases Test / In-Use / End-of-Life; a first suggested architecture is depicted in
Figure 5.

3.3.1.2.2 Major digital languages

3.3.1.2.2.1 State of the art

- Test Phase: ASAM-ODS, see https://www.asam.net/standards/detail/ods/
- In-use Phase: currently no generally accepted standard is used; signals are defined on a quite low level e.g. via CANdb, e.g. https://cdn.vector.com/cms/content/products/candb/Docs/CANdb_Manual_EN.pdf
- End-of-Life Phase: currently no generally accepted standard is used.

3.3.1.2.2.2 Enablers

- Test Phase: extend to non-ASAM-ODS-compliant systems by supporting also alternative data models/descriptions.

- In-use Phase: the upcoming Vehicle Signal Specification (VSS) by COVESA is a protocol-agnostic approach for describing vehicle data in a standardized and extensible manner, see https://github.com/COVESA/vehicle_signal_specification
- End-of-Life Phase: future battery pass extensions might extend on the ISO 15118 defining the communication between EV chargers, network and vehicles (still under discussion), see https://www.iso.org/standard/69113.html

3.3.1.2.3 Autonomous translation

3.3.1.2.3.1 State of the art

Typically, only specifically implemented translators exist.

3.3.1.2.3.2 Enablers

This UC shall analyze the potential applicability of autonomous translations for the benefits for all three phases (Test / In-Use / End-of-Life).

3.3.1.2.4 Standardization requirements

Table 7: UC-1.6 Standardization Requirements

Standardisation Requirements		
Categories of Standards	**Baseline**	**Final**
System and Software	Life Cycle Management, REST APIs, ERP/MES, Function Blocks, ISO 25012	Life Cycle Management, REST APIs, ERP/MES, Function Blocks, ISO 25012
Information and Representation	Product data representation and exchange, ASAM-ODS, CANdb,	Product data representation and exchange, ASAM-ODS, CANdb, EU BatteryPass
Semantic and Language	XML, JSON, UML, Ontologies	XML, JSON, UML, SysML, Ontologies, LDP 1.0
Communication	Fieldbus, OPC-UA, MQTT, Internet Protocols: HTTP, TCP/IP, UDP	CAN, MQTT, HTTP/S, UDP
Cybersecurity and Safety	-	ISO 27001 HTTPS, TLS, UNECE Cybersecurity (UN R155 / R156), ISO 26262
Reference Model	RAMI	RAMI, New automotive EE Architecture (SDV)
Domain-Specific	Automotive	Automotive, Factory Control/SCADA IoT, Digital Twin, Integration Life Cycle
Framework Development and Specific Applications for development	.NET	.NET, Eclipse, Python, Docker

3.3.1.2.5 Key Performances Indicators

Table 8: UC-1.6 KPIs

Key Performance Indicators (KPI)			KPI Fulfilment & Evaluation		
Name	**KPI Description**	**Means of assessment**	**Year 1**	**Year 2**	**Year 3**
DI_V	Number of data items from the vehicle (in-use phase) available in EV-Battery-Digital Twin	Count	in-vehicle data items: 2	in-vehicle data items: 5	in-vehicle data items: 6
DI_T	Number of data items from test labs (development phase) available in EV-Battery-Digital Twin	Count	Test labs data items: 0	Test labs data items: 1	Test labs data items: 2
DI_E	Number of data items for determining residual value (end-of-first-life) available in EV-Battery-Digital Twin	Count	Residual value data items:0	Residual value data items: 0	Residual value data items: 3

3.3.1.3 Beyond the baseline

3.3.1.3.1 Use case action plan

As outlined in the DoA, the use case will follow these steps:

- Analyse use case, scenarios, data standards, models and structures, as well as access and security requirements
- Define requirements for the 3 planned demonstrators (see below)
- Develop architecture for a unified digital twin, allowing data exchange and use across phases (based on
- Figure 6)
- Implement prototype of digital twin based on Arrowhead framework
- Implement prototype data transfer for selected data sources
- Integration of developed technologies into three demonstrators described below
- Development of applications for realistic real-world validation and demonstration
- Validation against defined KPIs and project goals

Demonstrator development

- demonstrate an intelligent battery lab-management system. Goal is to optimize the allocation of lab resources (cyclers, channels) to objects (e.g., sample battery cells) by enabling interoperability in the PVN. In the R&D chain, additional information becomes available for consideration like previous experience, design hints, and business objectives. This use-case will optimize the utilization of a battery lab significantly, with the aim of a considerable reduction in cost, throughput time and energy consumption.
- demonstrate in-vehicle/in-use monitoring to support model extraction and validation for improved SoC/SoH calculation

- demonstrate efficient re-purpose/recycle decision support by improved determination of state of health (SoH) of batteries. This will be supported by combining inspection (observing performance in specific test scenarios) with estimation of wear out based on degradation data from the in-use phase (e.g., usage profiles).

3.3.1.3.2 Contribution to project objectives

Table 9: UC-1.6 - Contribution to project objectives

Project Objective	Status at M0	Expected improvement	Planned actions	Status at M12	Status at M24	Status at M36
Obj 1 - Facilitate more than 50% of needed translations in realistic production value networks by autonomous machine-based translation micro-services thus significantly reducing the need for human support.	0%	Focus on in-vehicle data and test lab data	Requirement specification, design, Prototype implementation	0%	25%	50%
Obj 2 - Microservices/SOA enabling of dynamic deployment and autonomous utilization of information translation in PVNs	Not available	Focus on test-lab data	As above	Design spec available	Early prototype	TRL6 prototype
Obj 3 - Update proposals for major digital data model for industrial production between which autonomous and seamless data model understanding is enabled.	n/a	-	-	-	-	-
Obj 4 - Digital transformation management methodology for the introduction of seamless and autonomous translation within a PVN	simple digital solution available	Vision: Smart lab management	Implement optimized allocation of lab resources exploiting data from other phases	Design spec available	Early prototype	TRL6 prototype
Obj 5 - Established a sustainable governance of open-source architecture and implementation platform	n/a	-	-	-	-	-

3.3.1.3.3 KPIs, Evaluation, and validation process

See Table 8.

3.3.2 Use-case #1.7 – Interoperable intelligent management of production lines: Towards Model-based Enterprise

3.3.2.1 Baseline summary

3.3.2.1.1 General description of the baseline

The products related to the use-case, in most cases, are electromechanical products to be produced where in their design, different departments (electronics and mechanics) must work in parallel to reach a single product. The integration and efficient management of all this development up to production is still not fully automated. Once the designs are ready (after the pertinent revisions required also by the aerospace domain regulations), they are launched to the factory and nowadays, both worlds, OT and IT are not completely connected, and it is not evident to keep the traceability of the product. Furthermore, once the product reaches the customer, it is currently not possible to track the operation of these products. Needed is to link the products with the interoperable operational data to improve future designs.
Interoperable intelligent management of production lines in aerospace is a use case that focuses on building automation, flexible, and intelligent production lines for electro-mechanical parts for the aerospace domain.
The products related to the use-case, in most cases, are electromechanical products to be produced where in their design, different departments (electronics and mechanics) must work in parallel to reach a single product. The integration and efficient management of all this development up to production is still not fully automated. Once the designs are ready (after the pertinent revisions required also by the aerospace domain regulations), they are launched to the factory and nowadays, both worlds, OT and IT are not completely connected, and it is not evident to keep the traceability of the product. Furthermore, once the product reaches the customer, it is currently not possible to track the operation of these products. There is a need to link the products with the interoperable operational data to improve future designs.
The goal is to deploy an intelligent method system that can effectively communicate and exchange data between different systems, resulting in a more efficient and error-free production process.
This use case is part of the larger context of intelligent manufacturing, which covers the entire life cycle of a product, from design to maintenance The implementation of interoperable intelligent management of production lines in aerospace requires a collaborative and interdisciplinary approach to system development, as well as the use of advanced tools and techniques such as MBSE.

3.3.2.1.2 Initial architecture of the use case as a sequential list of functional blocks

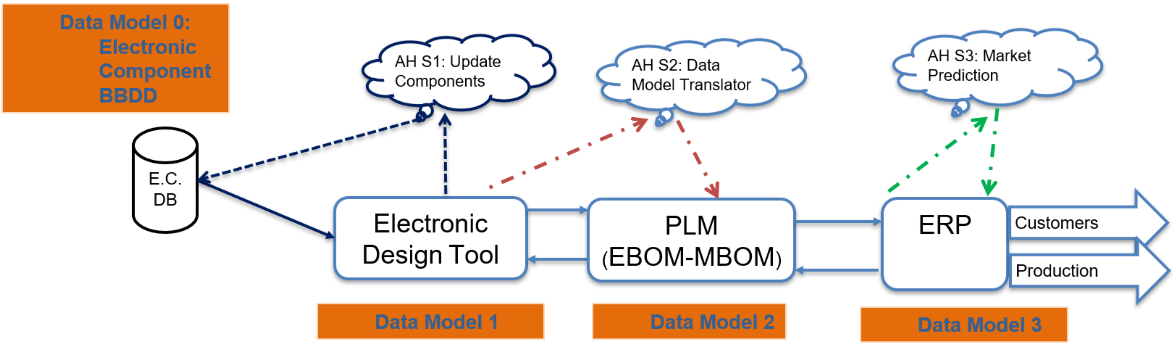


Figure 7: Initial UC-1.7 Architecture

The use case represented in Figure 7 involves several components that need to be interoperable in order to manage the lifecycle of electromechanical products. The architecture of this use case can be broken down into the following components:

- Database: This component stores information about electronic components that will be used by the electronic designer by the electronic designing tool.
- Electronic Design Tool: This tool needs inputs from the database to design electronic components and circuit boards.
- PLM Tool: This tool manages the EBOMs (Engineering Bill of Materials) and generates the MBOM (Manufacturing Bill of Materials). It needs to be interoperable with the electronic design tool to ensure that the MBOM is accurate and up-to-date.
- ERP: This component receives the MBOM from the PLM tool and manages the production, customers, and logistics. It ensures that the right components are ordered and delivered to the right place at the right time.

In order to make it work, during the use case three Arrowhead compliant services will be developed.
On the one hand, there will be a service that will ensure that the information stored in the DDBB is synchronized with the information that is in the PLM. Both these tools are able to update information, but it is not possible to have different information/not synchronized information in both components. Thus, this service is going to be developed since the tools themselves, considering just commercial ones, do not provide this communication and traceability in both directions.
It will be also developed a second service to try how it is possible to translate the different data models that are using the DDBB module and the PLM module.
Lastly, the ambition is to integrate in the process an AI-based service that will help personnel from customer sales when buying the parts. This AI service will be based on historical data of the companies' purchases (delays, quantities bought, providers, ...) to make a market prediction.

3.3.2.1.3 Objectives that are linked to the Arrowhead fPVN objective

Table 10: UC-1.7 Arrowhead fPVN objective

Project Objective	UC Contribution
Obj 1 - Facilitate more than 50% of needed translations in realistic production value networks by autonomous machine-based translation micro-services thus significantly reducing the need for human support.	The use case will need to translate data models in the different steps of the product lifecycle and these translations will be automated by using micro services that can make this work.
Obj 2 - Microservices/SOA enabling of dynamic deployment and autonomous utilization of information translation in PVNs	The different steps of the process will need to publish and consume services that will translate the data models and to do that a microservices oriented solution has been defined.
Obj 3 - Update proposals for major digital data model for industrial production between which autonomous and seamless data model understanding is enabled.	No contributions
Obj 4 - Digital transformation management methodology for the introduction of seamless and autonomous translation within a PVN	The methodology to be used during the product lifecycle will follow the MBSE methodology based on Arrowhead services.
Obj 5 - Established a sustainable governance of open-source architecture and implementation platform	The translation services and intelligent services applied for optimising the sales department decisions will be implemented in the Arrowhead platform.

3.3.2.2 Baseline analysis - building blocks & enablers

3.3.2.2.1 Micro-service paradigm

3.3.2.2.1.1 State of the art

The current solution and methodology are not based on microservices paradigm. The current solution is a close solution and any update require to develop every step according to the new requirements. It is not a flexible and open solution.

3.3.2.2.1.2 Enablers

In order to develop a microservice-oriented solution, the use case will use the core services of the Arrowhead Framework (Registry, Orchestration and Authorization Services)

3.3.2.2.2 Major digital languages

3.3.2.2.2.1 State of the art

The digital languages or data models used in the use case are the ones to represent electromechanical components and the data models that represent EBOMs and MBOMs needed in the PLM and automatic production lines.

3.3.2.2.2.2 Enablers

The ontologies that are able to represent the electromechanical elements to be designed and developed in the production lines will be used.

3.3.2.2.3 Autonomous translation

3.3.2.2.3.1 State of the art

Current status: during the process (starting from design to production and sales), different tools and data models are used. At this moment, the process is semi-automatic but close and specific translators must be developed to automate the process.

3.3.2.2.3.2 Enablers

DITAG tool provided by UNINOVA has been identified to be used as an autonomic translator and in the use case this possibility has been identified as a possible solution to translate different data models that are in the process.

3.3.2.2.4 Standardization requirements

Table 11: UC-1.7 Standardization Requirements

Standardisation Requirements		
Categories of Standards	**Baseline**	**Final**
System and Software	Life Cycle Management, Software life cycle processes, REST APIs, ERP/MES, Function Blocks	Life Cycle Management, MBSE, Software life cycle processes , REST APIs, ERP/MES, Function Blocks
Information and Representation	Product data representation and exchange,	Product data representation and exchange, Framework for object-oriented information exchange Worksite data exchange,
Semantic and Language	XML, JSON,	XML, JSON, SysML, UML,
Communication	Internet Protocols: HTTP, SSH, FTP, TCP/IP, IPSEC, SMTP, UDP	Internet Protocols: HTTP, SSH, FTP, TCP/IP, IPSEC, SMTP, UDP
Cybersecurity and Safety	Authentication,	Authentication, Safety for Electrical/programmable electronics
Reference Model		RAMI, Digital Factory
Domain-Specific	Integration Life Cycle	Integration Life Cycle,
Framework Development and Specific Applications for development	SQL Server, Java	JAVA, Eclipse, Python, Haddoop, Spark, SQL Server, SQLLite

3.3.2.2.5 Key Performances Indicators

Table 12: UC-1.7 KPIs

Key Performance Indicators (KPI)			KPI Fulfilment & Evaluation		
Name	**KPI Description**	**Means of assessment**	**Year 1**	**Year 2**	**Year 3**
Interoperable	Automatization of the lifecycle workflow	Number of steps automatized: data models translated automatically	20%	70%	100%
Market Prediction	Electronic Components market prediction service	Intelligent service able to predict market of electronic components deployed	10%	60%	100%
SOA Model	Service Oriented Architecture	The use case will be deployed in a SOA architecture	10%	40%	100%

3.3.2.3 Beyond the baseline

3.3.2.3.1 Use case action plan

In this use-case the aim is to work on three aspects that is believed that will improve the productivity of the electromechanical products:

- Prepare the PLM system so that electronic and mechanical designs are automatically integrated, thus generating manufacturing orders automatically and intelligently in a more efficient way.
- Automate the planning and management of plant production through intelligent agents based on customer characteristics/requirements and the status of the designs (electronic and mechanical).
- Enable a system to have interoperable and up to date product information in operation so that this information can be used to improve future designs increasing efficiency and in addition also improving the carbon footprint achieving better sustainability results

The specific requirements and the plan that have been defined for the use case in order to achieve the aforementioned topics are the following:
Design phase: M0-M9

- Analyse the data models used during the different steps of the MBSE methodology deployed in the use case
- Define the transformations that are needed in each step of the MBSE methodology deployed in the use case.
- Analyse the market information of the Electronic Components in order to develop an intelligent algorithm to predict the most cost-effective components when buying the components for each project.

Development phase: M9-M30

- Develop the automatic translator able to solve the interoperability issues when linking the different tools.

- Develop an intelligent algorithm that enables the market prediction of electronic components.

Deployment phase: M26-M32:
- Deploy the translator in the use case.
- Deploy the intelligent algorithm that will be linked to the MBSE methodology to help making decisions for the sales department.

Validation phase: M32-M36:
- Validate the automatic integration of the PVN in the use case.
- Validate the intelligent algorithm that will be linked to the MBSE methodology to help making decisions to the sales department.

3.3.2.3.2 Contribution to project objectives

Table 13: UC-1.7 - Contribution to project objectives

Project Objective	Status at M0	Expected improvement	Planned actions	Status at M12	Status at M24	Status at M36
Obj 1 - Facilitate more than 50% of needed translations in realistic production value networks by autonomous machine-based translation micro-services thus significantly reducing the need for human support.	**Not automatic translation**	**Automatize process by using automatic translators**	Develop or use services/tools able to translate data models such as DITAG	Translators Tools/Services defined	Translators Developed	Translators Integrated in the use case
Obj 2 - Microservices/SOA enabling of dynamic deployment and autonomous utilization of information translation in PVNs	**No SOA architecture**	**More flexible solution that will enable the evolution of the solutions or integration of new stakeholders in an easy way**	Every step, any translation/integration or communication with other tools/frameworks will be done by services	Architecture and Services defined	First services developed	All services developed and integrated. A SOA solution available
Obj 3 - Update proposals for major digital data model for industrial production between which autonomous and seamless data model understanding is enabled.	**No contributions**					
Obj 4 - Digital transformation management methodology for the introduction of seamless and autonomous translation within a PVN	**No autonomous methodology in operation**	**Define and launch a MBSE methodology for electromechanical components in aerospace**	The product workflow and lifecycle will be traceable automatically	First steps of the process implemented	More than two steps/actors of the process integrated using the MBSE methodology	MBSE methodology launched in the company
Obj 5 - Established a sustainable governance of open-source architecture and implementation platform	**No open source solution/platform**	**Use of open source and flexible solution to automatize the electromechanical components for aerospace**	Arrowhead based solution will be developed and deployed in validation	First service implemented using the Arrowhead framework and its core services	Eclipse Arrowhead platform based solutions development for new	All the development finished using the Arrowhead Eclipse tooling from

					services (following the Model Based translators using Papyrus)	the design to deployment.

3.3.2.3.3 Use case and engineering costs

Requirements: 3 PMs
Functional Design: 7 PMs
Procurement & Engineering: 20 PMs
Deployment & Commissioning: 10 PMs
Operation & Management: 10 PMs
Maintenance, Decommissioning & Recycling: 5 PMs
Evolution: 5 PMs
Training & Education: 5 PMs

3.3.2.3.4 Micro-service paradigm

3.3.2.3.4.1 Approach

This use case will use the Arrowhead framework to implement the micro-service paradigm. To do that, the core services of the Arrowhead platform will be used (registry, authorization, orchestration) and service providers such as data model translators, or market predictors will be developed. In order to link all the development process of the electro-mechanical components, consumers of those services will also be developed and deployed in the use case.

3.3.2.3.4.2 Impact

The main impact of having implemented this approach, will be the automatic integration of the different steps of the process and the capability to have the traceability of the products. Instant exchange of data between the PNV stakeholders will be also enabled.

3.3.2.3.4.3 Long-term effect

As a long-term event, the use of micro-services paradigm will provide a more flexible approach to the lifecycle of the products enabling the incorporation of new stakeholders or the evolution of new products or processes.

3.3.2.3.5 Major digital languages

3.3.2.3.5.1 Approach

The digital languages to be used will be SysML to model the lifecycle of the products and the processes involved in and also data models that define the electronic components that will be integrated into the electromechanical components/products for the aerospace industry.

3.3.2.3.5.2 Impact

The impact of adopting digital languages will be that the development of the solution will be automatized because the tooling that enables the development of the services and the logics to integrate the different stakeholders will allow first to design/model the lifecycle model and then generate automatically the skeleton of all the services that will link the different steps of the process automatically.

3.3.2.3.5.3 Long-term effect

The long term effect will be that any evolution or new services that will be integrated into the process can be developed and deployed with less development effort.

3.3.2.3.6 Autonomous translation

3.3.2.3.6.1 Approach

The use case needs to translate the data models to be used in the different steps of the life cycle of the electromechanical products. To do that the use case intends to use automatic translators and to start this work, the idea is to use the DITAG tool developed by UNINOVA.

3.3.2.3.6.2 Impact

The use of this type of technology will enable the efficient adaptation and compliance to standards and automatic information ex throughout assets and product life cycle.

3.3.2.3.6.3 Long-term effect

As long term effect, we expect to have a more standardized and automatized PVN in the development of electromechanical components. This will impact also in having less defects in the process because of the automatization (human errors and delays in the process will be avoided)

3.3.2.3.6.4 Other aspects

The data models that will be used in the use case will be the ones that represent the electronic components and EBOMs and MBOMs of the production assets.

3.3.2.3.7 KPIs, Evaluation, and validation process

A validation and verification plan is strategic to be used for testing a product, service, or system to ensure that it meets the requirements and specifications and that it satisfies its intended purpose. Based on the development plan defined in the previous sections, the validation and verification plan of this use case can be broken down into three phases: initial validation, mid-term validation, and final validation.
The initial validation phase, which occurs at M15, involves testing the first version of the services in a lab environment. This phase is critical to ensure that the services are functioning as intended and to identify any issues that need to be addressed before moving on to the next phase.

The mid-term validation phase, which occurs at M27, involves testing the second version of the services in a lab environment and integrating at least one service and proving it by using a consumer in a real environment. This phase is important to ensure that the services are working together seamlessly and that they are meeting the needs of the consumer.
The final validation phase, which occurs at M33, involves conducting a final demo to ensure that the services are fully functional and meeting all of the requirements and specifications. This phase is critical to ensure that the services are ready for production and can be used by customers and logistics.
In summary, this will be the plan for the use case:

- Initial validation (M15)
    - First version of the services in lab environment
- Mid-term validation (M27)
    - Second version of the services in lab environment
    - At least one service integrated and proved by using a consumer in real environment
- Final validation (M33)
    - Final Demo.

3.3.3 Use-case #1.8 – System-Driven Modularization and Digitalization for Offshore Renewables

3.3.3.1 Baseline summary

The technology base line for our use case is a diverse landscape of 3D CAD systems, proprietary and in-house engineering databases and discipline tools such as process simulators and equipment design tools. Spreadsheets are widely used for exchange, integration, consolidation, and reporting of data.

The analysis of this baseline is still ongoing.

3.3.4 Use-case #1.9 – Pump Station Engineering

3.3.4.1 Baseline summary

The technology base line for UC T9.1 Pump Station Engineering is that the procurement process and engineering of a new pump station is based on sets of PDF documents with requirements and Excel files with technical data, that are exchanged between the site owner and an engineering company.
These documents are then interpreted by engineers that use various engineering tools to produce new documents. These new documents are used for procurement and construction of the equipment to be delivered. Once the new equipment is installed, the engineering data and other documents are converted into human-readable formats (usually PDF and Excel), and delivered to the site owner, where they are once more entered into the engineering platforms used by the site owner.

The analysis of this baseline is still ongoing.

3.3.5 Use-case #2.6 – Humans in the interoperable System

3.3.5.1 Baseline summary

Industry is not just machines! The future of production lies in the efficient and effective collaboration between humans and machines. However, to facilitate a smooth holistic interoperability, we must optimize the interaction between humans and machines. The challenges to be addressed and overcome are three-fold. First, we need to adjust the processes to the workers' needs, thereby creating a more intuitive, less error-prone or stressful and overall quicker way of collaborative human-robot interaction. Second, automation pressure is high in the European car manufacturing industry. At the same time, there is diversity due to different car manufacturers focusing on collaborative industrial robots in different production areas, such as logistics, assembly, quality inspection, dispensing. This requires a different, and a differently intensive human-robot interaction (HMI); it also require different repertoires of commands and feedback signals within the interaction (both in terms of vocabulary size and complexity). Third, workers of European car manufacturers form international teams. Many languages are involved. Sound and voice interfaces have to cope with this degree of accents, languages, etc. – and, moreover, need to be prepared to noisy environments.

The analysis of this baseline is still ongoing.

3.3.5.1.1 Initial architecture of the use case as a sequential list of functional blocks

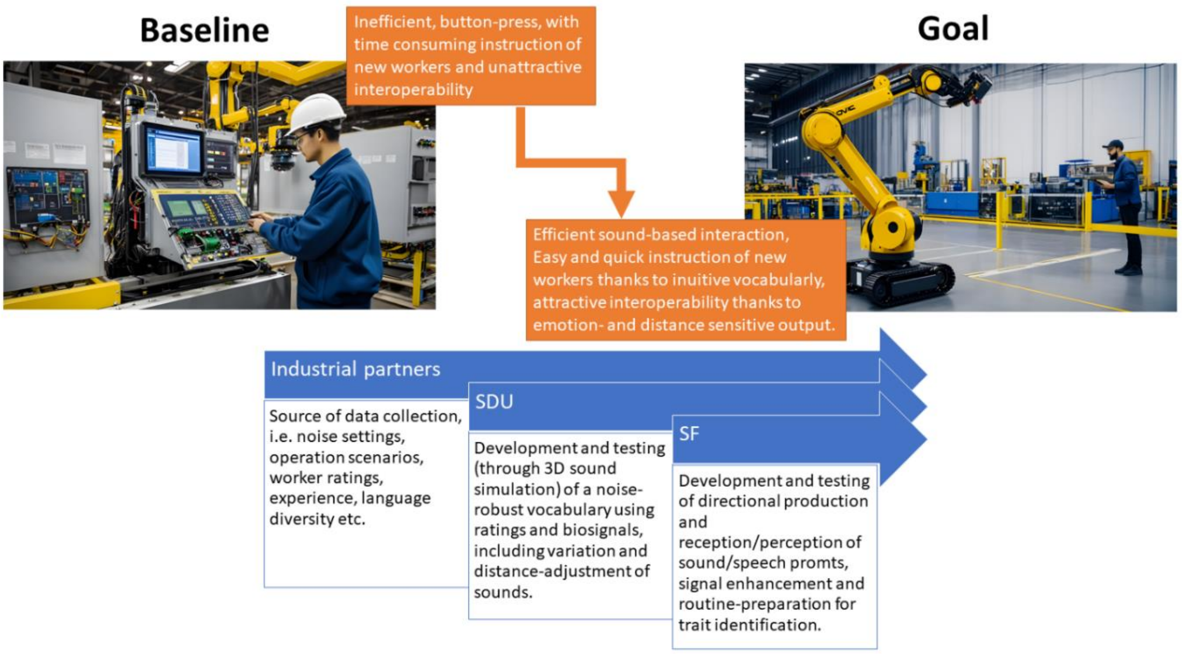


Figure 8 - Use case architecture.

3.3.5.1.2 Objectives that are linked to the Arrowhead fPVN objective

Table 14: UC-2.6 Arrowhead fPVN objective

Project Objective	UC Contribution
Obj 1 - Facilitate more than 50% of needed translations in realistic production value networks by autonomous machine-based translation micro-services thus significantly reducing the need for human support.	**(1) A more intuitive interoperability "vocabulary" makes Human-Robot-Interaction more acceptable and attractive both for employers and employees (workers) and, moreover, accessible to age groups who have not been in touch with robots (i.e. elderly workers).** **(2) A more noise-robust interoperability "vocabulary" can help make robots applications run in tough environmental settings where places are noisy and a distance between human worker and robot is hard to avoid (i.e. no button press is possible).**
Obj 2 - Microservices/SOA enabling of dynamic deployment and autonomous utilization of information translation in PVNs	
Obj 3 - Update proposals for major digital data model for industrial production between which autonomous and seamless data model understanding is enabled.	
Obj 4 - Digital transformation management methodology for the introduction of seamless and autonomous translation within a PVN	
Obj 5 - Established a sustainable governance of open-source architecture and implementation platform	

3.3.6 Use-case #2.7 – Aircraft Health Management System (AHMS) for Trend Monitoring, Predictive Maintenance and Fleet Operations & Maintenance Simulation

3.3.6.1 Baseline summary

3.3.6.1.1 General description of the baseline

Current embedded hardware platforms are not capable to deliver the required processing power to manage the amount of data generated by the aircraft. Digital twin technologies have to be used to design aircraft and their required support, enabling assessment of alternatives through simulations.

Since these activities comprehend all the life cycle phases of an aircraft, there are several involved stakeholders: Customers, Industry and Suppliers. Some proof of concepts of Aircraft

Health Management System (AHMS) have been developed to test the possible benefits in terms of data processing, maintenance procedures optimization and effort reduction.

A potential improvement of the actual AHMS, powered by Digital Twins, high performance embedded computers and interoperability between the three stakeholders is envisaged to offer new services aimed at increasing aircraft availability.

3.3.6.1.2 Initial architecture of the use case as a sequential list of functional blocks

The AHMS is aimed at gathering, collecting, and analysing data concerning aircraft fleet maintenance.

The overall system consists of different modules, located both on-board and on-ground, providing data and HW / SW framework, whose objective is to collect and correlate all data in order to support AHMS users.

A first prototype has been developed through the Cyber Physical Systems For Europe Project (CPS4EU), as depicted in the figure below:

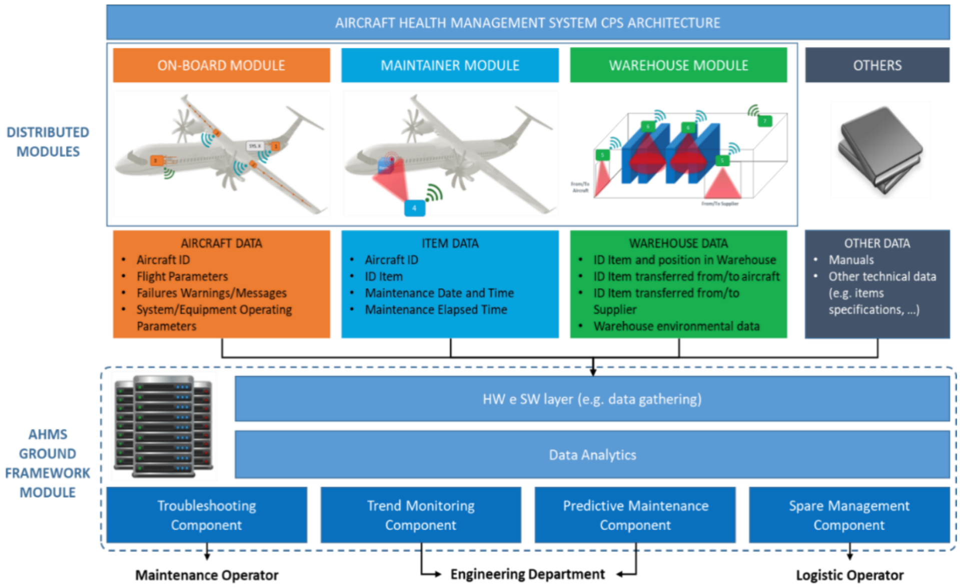


Figure 9 - The use case architecture.

Data coming from aircraft belong to two main categories: failures (i.e. events having a possible impact on aircraft availability) and performances (to be used to monitor aircraft systems health status). The first has to be fixed as soon as possible, the latter has to be used to anticipate future possible failures.

Regarding warehouse data, they are related to equipment/components removed from the aircraft to be repaired (at Customer or Supplier premises) and equipment/components available as spare in the warehouse.

Other data (e.g. maintenance data, manuals) are obtained from other sources/external systems that this framework is supposed to be connected with.

AHMS Ground Framework (GF) is a module on ground where the above data are collected and analysed to:

- monitor aircraft performance
- support the decisions of several operators concerning the troubleshooting of failures, the setting of maintenance actions and the spare parts supply.

The output are several digital services, two of which already fully developed during the CPS4EU project:

- **Troubleshooting Component**: This area gives Maintenance Operator decision support on troubleshooting operations, optimizing duration and tools/facilities availability
- **Spare Management Component**: This section permits, through a series of indicators with predictive features, to optimize spare quantification in order to maximize fleet availability, reducing Aircraft On Ground events due to missing parts.

3.3.6.1.3 Objectives that are linked to the Arrowhead fPVN objective

Table 15: UC-2.7 Arrowhead fPVN objective

Project Objective	UC Contribution
Obj 1 - Facilitate more than 50% of needed translations in realistic production value networks by autonomous machine-based translation micro-services thus significantly reducing the need for human support.	The proposed solution is intended to iIncrease interoperability in translating and exchanging data from the three different sources using S5000F. The subset of S5000F relevant for this use case will be fully translated.
Obj 2 - Microservices/SOA enabling of dynamic deployment and autonomous utilization of information translation in PVNs	The AHMS Services should follow a SOA modular architecture and adopt the Eclipse Arrowhead framework as a service bus to manage the services offered and consumed by the various components of the AHMS architecture.
Obj 3 - Update proposals for major digital data model for industrial production between which autonomous and seamless data model understanding is enabled.	Data shall be exchanged basing on S5000F and S-SERIES data model
Obj 4 - Digital transformation management methodology for the introduction of seamless and autonomous translation within a PVN	The Orchestration module of AHMS allows the automation of repeated data processing operations, encapsulated in workflows, that transform source data, move data between multiple sources and sinks, load the processed data into an analytical data store, or push the results straight to a report or dashboard.
Obj 5 - Established a sustainable governance of open-source architecture and implementation platform	Currently n/a

3.3.6.2 Baseline analysis - building blocks & enablers

3.3.6.2.1 Micro-service paradigm

3.3.6.2.1.1 State of the art

We are not aware of SOA platforms adopted for predictive maintenance and digital twins for the vertical domain of this use case.
The Eclipse Arrowhead framework, a microservice based architecture, represents the current state of the art and will be used together with the S5000F standard to reach interoperability inside and between fPVNs. The framework will provide exchange of information through the routing of messages and data to the base modules that contribute to the development of the AHMS. A High-Performance Embedded Computer will be used to process a simulated data stream.

3.3.6.2.1.2 Enablers

The core services of the Eclipse Arrowhead framework represent the state of the art to enable and improve the interoperability between the AHMS systems, adopting a SOA paradigm and micro-service architecture.

3.3.6.2.2 Major digital languages

3.3.6.2.2.1 State of the art

At the moment no standard is adopted for exchanging data between aircraft and its maintenance and supply chain and the ground storage and processing architecture.
The data generated by the aircraft have been defined during the aircraft design phase for engineering and maintenance purposes and are based on custom Company data models.
Same method adopted for maintenance and supply chain data, designed for logistic and contractual purposes.

The transfer of data from the aircraft to the ground architecture for digital services is done manually and on demand, based on Customer requests for specific in-service technical issues.

3.3.6.2.2.2 Enablers

Two main enablers are related to digital languages, that for us are represented by a standardized models for data exchange/sharing, the S-SERIES standard, a common denominator for a set of specifications associated to different integrated logistics support aspects including aeronautics, and the translators developed in WP4 and intended to convert proprietary data format into S-SERIES standard.

3.3.6.2.3 Autonomous translation

3.3.6.2.3.1 State of the art

As anticipated, currently the transfer of data from the aircraft to the ground architecture for digital services is done manually and on demand, based on customer requests for specific in-service technical issues.

The conversion from the aircraft data to information that can be used for digital services does not follow a specific standard, therefore has to be re-assessed each time a new type of aircraft is added to the fleet or if a customer wants to share only a subset of data. Same for maintenance and supply chain data, which can change depending on the Customers software tools (e.g., info-logistic tools, SAP, …).
The validation of the data received is done only after its reception, and there are no business rules, valid values or orchestration of the information.

3.3.6.2.3.2 Enablers

The translators developed in WP4 are the enablers, allowing to automatically convert custom data format into a standard (the S-SERIES), and thus improving interoperability, simplifying system integration, improving efficiency quality of service, etc.

3.3.6.2.4 Standardization requirements

Table 16: UC-1.6 Standardization Requirements

Standardisation Requirements		
Categories of Standards	**Baseline**	**Final**
System and Software	Microsoft Azure, PowerBI, Parquet	Microsoft Azure, PowerBI (to be confirmed), Parquet
Information and Representation	No standards adopted	S-SERIES, with particular focus on S5000F
Semantic and Language	XML, JSON, RDF, SQL, Python, UML, HTML/CSS3	XML, JSON, RDF, SQL, Python, UML, HTML/CSS3
Communication	MQTT, WIFI, ARINC Internet Protocols: HTTP, FTP, SSH, SFTP, TCP/IP, IPSEC, SMTP, UDP	MQTT, WIFI, ARINC Internet Protocols: HTTP, FTP, SSH, SFTP, TCP/IP, IPSEC, SMTP, UDP
Cybersecurity and Safety	IEC 62443, ISO 27001, Dir. 94/9 ISO/IEC 80079-34, ISO/IEC 20000-1:2011, ISO 22301:2012 Societal security - Business continuity management systems, ISO/IEC 27001:2013 information security management	IEC 62443, ISO 27001, Dir. 94/9 ISO/IEC 80079-34, ISO/IEC 20000-1:2011, ISO 22301:2012 Societal security - Business continuity management systems, ISO/IEC 27001:2013 information security management
Reference Model	RAMI (IEC 62890), IEC 81346	RAMI (IEC 62890), IEC 81346
Domain-Specific		S-SERIES, with particular focus on S5000F
Framework Development and Specific Applications for development	JAVA, Javascript, .NET, Python, Jupiter	JAVA, Javascript, .NET, Python, Jupiter

3.3.6.2.5 Key Performances Indicators

Table 17: UC-2.7 KPIs

Key Performance Indicators (KPI)			**KPI Fulfilment & Evaluation**		
Name	**KPI Description**	**Means of assessment**	**Year 1**	**Year 2**	**Year 3**
Data exchange capability	1. Data continuously collected during flight 2. Data collected after aircraft landing 3. Data collected from simulated flights [Time required to retrieve, process and share data between the AHMS subsystems - M0: 1-20 hours - M36: ?]	1. exchange between flying aircraft and ground station will be simulated only, therefore will be tested the capability of a ground system to handle telemetries and exchange them with the AHMS 2. post flight data will be provided as input. Will be tested the capability of the Consumer Service to exchange them with AHMS GF 3. simulation results will be provided as input. Will be tested the capability of the Consumer Service to exchange them with AHMS GF.			
Data exchange model in accordance with S5000F	Compliance between data exchanged through S5000F message and defined business rules [Y/N - M0: no - M36: ?]	the compliance of the exchange data with a defined set business rules will be verified			
Data integrity	Compliance between data exchanged through S5000F message and raw data [Y/N - M0: no - M36: ?]	the data exchanged through S5000F messages will be tested with respect to raw data			
Orchestration of the 3 service providers and 1 service consumer	Adoption of SOA oriented solution [Y/N - M0: no - M36: ?]	The architecture of the adopted solution must be based by design on the SOA paradigm and microservice architecture			

3.3.6.3 Beyond the baseline

3.3.6.3.1 Use case action plan

The use-case will address the development of an interoperable AHMS to support the aircraft life cycle, in particular the Customer Support and Engineering processes. There are three different scenarios:

- Real-time Data collection and transfer to AHMS via satellite. Note: the whole scenario will be simulated only in terms of data collection and data transfer.
- Collected data will be used for the needs of customer support, engineering, and maintenance.
- Data models will be used to understand the impact on operations and logistics.
- The overall use-case has schematized in figure 1 that mainly consists of three macro-areas:
- Cohesive suite for physical and digital systems.
- Component function interrelationships for advanced analysis.
- Diagnostic highways for users of the AHMS.

In the next figure, the systems, the capabilities and the fPVN are interconnected, and the data exchange is interoperable. Some components had been partly developed in CPS4EU project. Three types of data generation/utilization will be considered:

- Real-time flight data, produced by the aircraft (simulated only).
- Post flight data, acquired when the aircraft is on the ground after landing (stored during the flight).
- Simulated flight scenarios, based on aircraft mission planning.

The results of the use-case will be used by industry to improve the design and logistic support of aircraft, and by the customer to increase the flight-ready aircraft availability through interoperable maintenance and operations planning activities during and post flights.

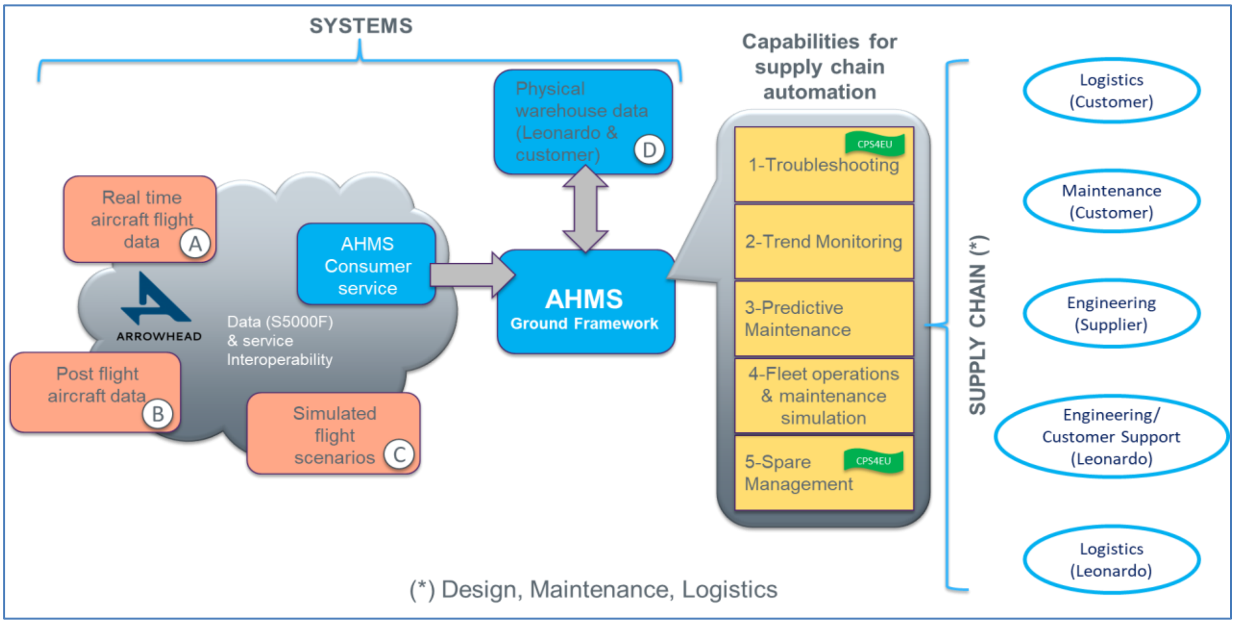


Figure 10 - The Arrowhead local cloud, the interconnected systems, and their capabilities.

In the overall context of the S-Series Specification (an international standard not exclusively used in the Aerospace domain) the use-case will leverage the S5000F (International specification for in-service data feedback). The scope of the S5000F is to handle information from in-service operation of a product, in this case an aircraft system. However, the specification can be used for data exchange at any moment of the life cycle of the aircraft. The S5000F is focusing on the information exchange, therefore the system used for originating and receiving the data will be unaffected by the specification. S3000L (International procedure specification for Logistic Support Analysis) and S2000M (International Specification for material management) will also be used as a reference for the Integrated Logistic Support processes involved in the use-case scenario. The use-case will start at TRL4 and end at TRL6.

3.3.6.3.2 Contribution to project objectives

Table 18: UC-2.7 - Contribution to project objectives

Project Objective	Status at M0	Expected improvement	Planned actions	Status at M12	Status at M24	Status at M36
Obj 1 - Facilitate more than 50% of needed translations in realistic production value networks by autonomous machine-based translation micro-services thus significantly reducing the need for human support.	Automatic translation not available.	The subset of S5000F relevant for this use case will be fully translated.	Integrate into the AHMS an automatic translator from WP4.			
Obj 2 - Microservices/SOA enabling of dynamic deployment and autonomous utilization of information translation in PVNs	Solution based simply on a modular system of systems	AHMS will be based on the SOA paradigm and microservice architecture	Adoption of Eclipse Arrowhead Framework			
Obj 3 - Update proposals for major digital data model for industrial production between which autonomous and seamless data model understanding is enabled.	No standard adopted	Data shall be exchanged based on S5000F and S-SERIES data model. We don't plan to update the standard.	Adoption of S5000F			
Obj 4 - Digital transformation management methodology for the introduction of seamless and autonomous translation within a PVN	Low level of automation, mainly based on a human operator.	The Orchestration module of AHMS allows the automation of repeated data processing operations, encapsulated in workflows, that transform source data, move data between multiple sources and sinks, load the processed data into an analytical data store, or push the results straight to a	Development of an orchestration module for the automation of maintenance process operations.			

		report or dashboard.				
Obj 5 - Establish a sustainable governance of open-source architecture and implementation platform	Currently N.A.					

3.3.6.3.3 Micro-service paradigm

3.3.6.3.3.1 Approach

In this use case the approach to adopt a Service Oriented Architecture is based on the Eclipse Arrowhead Framework.

3.3.6.3.3.2 Impact

The impact generated form the adoption of a Service Oriented Architecture includes:

- Modularity, allowing to easily customize the solution for the customer
- Seamless update/substitution of services without impacting on the architecture
- Possibility to customize the services portfolio depending on customer needs
- Improved scalability of the entire solution
- Security improvement based on the adoption of the Arrowhead local cloud

3.3.6.3.3.3 Long-term effect

The effects of the adoption of a Service Oriented Architecture includes:

- Evolvability of the solution, which will be open
- Increased interoperability among the stakeholders involved in the value chain
- Near real-time information sharing between the stakeholders involved in the value chain, with an impact on costs, efficiency, quality of offered service, and fleet availability.

3.3.6.3.4 Major digital languages

3.3.6.3.4.1 Approach

S5000F provides a data model that allows the exchange of in-service feedback. It can be tailored to the specific use case and progressively expanded.

The approach will be the following:

- The use cases (within AHMS Use Case) that will require exchange of in-service data, will be identified
- Business rules about the data exchange will be defined for the selected use cases
- A data mapping between the raw data and the S5000F will be performed
- An XML that identifies the exchange message will be tailored starting from the specification
- An export capability that generates the XML data to be transmitted will be developed
- An import capability that allows to import the XML data received will be developed.

If necessary, additional elements taken from the S-SERIES model (S3000L, S2000M…) will be taken into account.

3.3.6.3.4.2 Impact

The selected use cases within AHMS Use Case selected for the mapping versus S5000F are actual industrial examples that are used to improve Customers support services, product, and supply chain design.

Using this standard enables aircraft post-delivery analysis and in-service optimization that have impacts both on aircraft availability and life cycle costs.

Since the standard is tool agnostic, it can be integrated within the AHMS architecture without designing new or modifying legacy databases to export and import information. A translator should be necessary.

3.3.6.3.4.3 Long-term effect

Compliance with the standard allows the adoption of a common model for exchanging information between Customers, Industry and Suppliers. That information, validated through business rules, can be used to analyze performance, and calculate KPI.

Moreover, whenever a new product (a new aircraft equipment) or a new Customer enters the network, the common model can be used in order to integrate their information with a minimum effort within the AHMS architecture.

3.3.6.3.5 Autonomous translation

3.3.6.3.5.1 Approach

The autonomous translators will allow to automate the following step of the aircraft maintenance process and related logistics:

- A data mapping between the raw data and the S5000F will be performed
- An XML that identifies the exchange message will be tailored starting from the specification
- An export capability that generates the XML data to be transmitted will be developed
- An import capability that allows to import the XML data received will be developed

Currently this process requires a human operator and will be fully automated with the proposed solution.

3.3.6.3.5.2 Impact

A solution based on autonomous translators will significantly boost the interoperability of the AHMS and will bring the company to the state of art in terms of data exchange standards, enabling future commercial opportunities.

3.3.6.3.5.3 Long-term effect

With the proposed solution we can integrate potentially any kind of aircraft used by different customers, significantly extending the potential share of the market accessible to the company.

3.3.6.3.6 KPIs, Evaluation, and validation process

In accordance with D7.1 section 2.2.7, a high-level plan for validation and verification for scenarios of input data feeding has been defined.

In general, several elements have to be verified:

- Data exchange capability
- Data exchange model in accordance with S5000F
- Data integrity
- Orchestration of the 3 service providers and 1 service consumer

Actual data will be provided for testing. The aim is to determine if within the AHMS platform (Consumer service + GF) the data are correctly exchanged and stored for the successive analyses.

In detail, for data exchange capability:

- Data continuously collected during flight: exchange between flying aircraft and ground station will be simulated only, therefore will be tested the capability of a ground system to handle telemetries and exchange them with the AHMS
- Data collected after aircraft landing: post flight data will be provided as input. Will be tested the capability of the Consumer Service to exchange them with AHMS GF
- Data collected from simulated flights: simulation results will be provided as input. Will be tested the capability of the Consumer Service to exchange them with AHMS GF.

For data exchange model in accordance with S5000F, the compliance of the exchange data with a defined set business rules will be verified.

For data integrity, the data exchanged through S5000F messages will be tested with respect to raw data.

3.3.7 Use-case #2.9 – Digital Twins that enable higher performance by interoperability in pulp mills & carton board mills

3.3.7.1 Baseline summary

The following baseline for this use case has been identified:

- Incompatible data and ontologies in different system making data integration hard and costly.
- Today the situation is vendor lock-in with tech suppliers. Very hard to mix and match between vendors and use best of breed technology. Very costly also over time.
- Operation is today performed with high dependency of a few individuals and much customization.
- The need for long term resilience and risk management is hard to meet.

- Pragmatic solutions are used with lack of traceability in software and data deliverables with liability risks as results.

The analysis of this baseline is still ongoing.

3.3.8 Use-case #3.9 – Interoperability for technical information exchange in process industry

3.3.8.1 Baseline summary

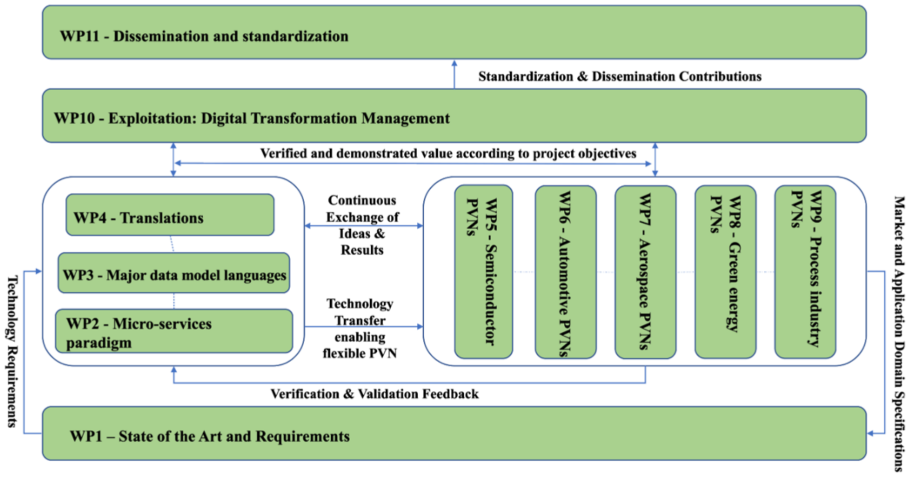
Interoperability for technical information exchange in process industry, information is currently shared between companies manually based on point-to-point and case-by-case specifications. Technical solutions and standards for interoperable digital information exchange are not available. Emerging technology from DEXPI is available only for a small part of this, e.g., P&I diagrams.
Another important emerging technology is ISO15926, based on Semantic Web technologies, that can act as a glue to integrate different data and concepts throughout the lifecycle. The challenge with applying ISO15926 is that it does not yet cover all necessary application domains, such as pulp & paper or processing in general. Also, a lot of attributes and properties, defined in other standards, are needed but not yet included.
Mappings to different systems and between different standard data models are proprietary and implemented manually, and often developed case by case. OPC UA is a de facto standard in process automation integration but despite its extensive information modeling features it primarily provides solutions for runtime systems integration and not for the whole lifecycle including engineering, operation and maintenance needs.
Information cannot be aggregated from multiple sources for many operation and maintenance purposes or process analytics. In such integrations, implementations are based on manually setting up connections to necessary proprietary systems and defining how information is to be used and integrated case-by-case.

The analysis of this baseline is still ongoing.

4. Collaboration with other technical WPs

WP1 is linked and influences all the horizontal WPs and the use cases, with an impact on the entire project, both in terms of the requirements and specifications of the technologies that the project will develop and for the evaluation and validation of the project results. The following Pert diagrams illustrate the relations with the other WPs.

WP1 forces us to brainstorm about the use case architecture, adopted technologies and solutions, about the reuse of the horizontal technologies in different use cases, about the advantages obtained by their adoption and how they contribute to project objectives, looking forward beyond the baseline with an action plan and a validation/verification process. The surveys play an important role to this regard, providing a concrete support for all the aspects of the brainstorming and mitigating the complexity and heterogeneity of the use cases, and the complexity of the horizontal technologies.



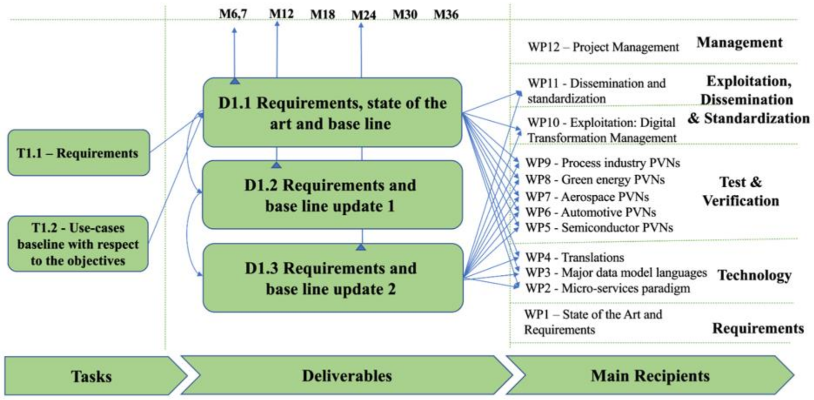


Figure 11 - Project and WP level Pert diagrams

5. Conclusions

This deliverable presented the results of the requirements elicitation and of the baselines definition. The methodologies adopted to carry on these two tasks have been described and we reported the preliminary results of both tasks.

The requirement elicitation allowed to identify 37 requirements focused on project objectives, with a preliminary coverage of several areas. The process of elicitation has been difficult because it intended to identify focused requirements, not use case specific ones which in general are easier to define being inspired by concreteness of the final application. Already from the second semester of the project we expect to improve and to clarify the existing requirements as well as to identify additional ones: the results of this second phase will be reported in D1.2.

A preliminary version of the baselines, including both horizontal technologies and use cases, has been defined. These preliminary baselines are characterized by different levels of maturity and details and will be further extended, refined, updated and consolidated in the next project engineering cycles. The preliminary results reflect the complexity of the horizontal technologies (the building blocks) that will be adopted to satisfy the needs of heterogeneous use cases, based on different technologies, different engineering processes, different objectives, where the partners familiarity with the technologies and use cases will also progressively grow during the project. The results of the analysis for the building blocks and for some of the use cases, although being preliminary, provide already a good overview of the state of the art solutions at M0 and the proposed approach and solutions to meet the project objectives at M36. The baseline analysis is a continuous task and more consolidated results, specifically for the use cases, will be available in deliverable D1.2.

6. Annex

1. Requirements Matrix: external file “AfPVN WP1 - Requirements Matrix.v1.0.xlsx”
2. Template of the Building block baseline survey: external file “AfPVN WP1 Survey.WP2.3.4 Survey Template.docx”
3. Template of the use case baseline survey: external file “AfPVN WP1 Survey.Use Case Survey Template.docx”

7. Revision history

7.1 Contributing and reviewing partners

Contributions	Reviews	Participants	Representing partner
TOC definition and first version		Elisa Londero, Gianvito Urgese, Massimo Vecchio	ETH, Polito, FBK
Deliverable contents		Elisa Londero, Gianvito Urgese, Massimo Vecchio	ETH, Polito, FBK
Deliverable contents		WP2, WP3, WP4 leaders	
Deliverable contents		Use cases leaders	

7.2 Amendments

No.	Date	Version	Subject of Amendments	Author
1	13/12/2023	0.1	Document structure and intro	Elisa Londero
2	19/12/2023	0.2	Requirements section	Elisa Londero, Gianvito Urgese
3	19/12/2023	0.5	Use cases baselines	Elisa Londero, Gianvito Urgese
4	19/11/2023	0.8	Building blocks baselines	Elisa Londero, Gianvito Urgese
5	19/11/2023	1.0	Final revision	Elisa Londero, Gianvito Urgese, Massimo Vecchio

7.3 Quality assurance

No	Date	Version	Approved by
1	18.01.2024	1.0	Jerker Delsign