InValue

"Industrial Enterprise Asset Value Enablers"

WP5 Leader: SIRRIS, Belgium

Partner Contributions: Sirris, Barco, Facort, Hisarlar, …

[D08] D5.2: Final InValue Reference Architecture

Deadline: December 2017

Table of contents

1 Introduction

This document presents the InValue Reference Architecture as defined and refined at the end of the ITEA3 InValue project. This reference architecture has been created by combining architecture concepts from the state of the art in the Internet of Things, Big Data and the Cloud. It has been iteratively refined by interaction with the industrial use cases in the InValue project consortium.

At the basis of the InValue reference architecture lies the combination of concepts from the Internet of Things (IoT), Big Data and the Cloud. The proposed architecture provides the remote management of digitally enabled (industrial) assets as well as industrial and engineering data sets such as CAD models and 3D point clouds.

The InValue reference architecture offers on premise management of these assets as well as in the cloud. It can be instantiated and tailored indefinitely.

2 Main Concepts

The InValue Reference Architecture consists of five layers, 2 distributed across the enterprise and 3 in the cloud, as shown in Figure 1.

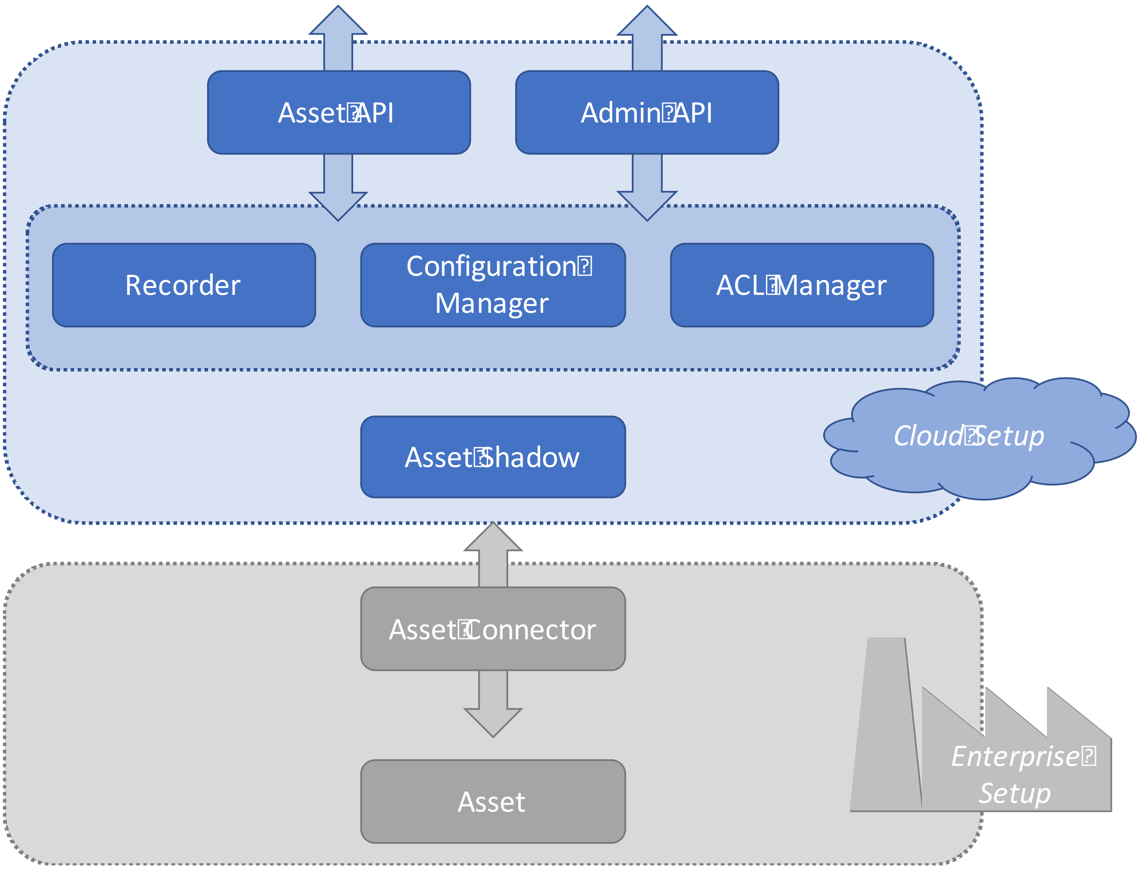

Figure 1. High-Level InValue Architecture

Two architectural layers are defined at the enterprise setup (on-premise):

- At the lowest architecture layer are represented the InValue **Assets** that must be managed and used. Example assets are production machinery, deployed end products but also 3D CAD models and 3D metrology data.
- To make the asset available in the Cloud, the InValue architecture provides an **Asset Connector** layer: it is responsible for giving assets a digital face toward the upper architectural layers and provides the necessary interfaces to interact with the connected asset.

The following architectural layers are defined in the cloud:

- The **Asset Shadow** provides a shadow proxy of the Asset in the Cloud. This allows separating the actual asset from the Cloud, which is beneficial when off-loading asset-related computations to the Cloud. In addition, the Asset Shadow can help Cloud-hosted applications to bridge the permanent connectivity assumption in case this connection is unreliable, without breaking the asset-related functional logic (up to a reasonable level of functionality).
- The **ACL Manager** provides and manages access control to the InValue platform and its components through managed access control lists. The ACL Manager provides an API and primitives to configure, provision, update and query the access control lists in a systematic way.

- The **Configuration Manager** controls the Asset Shadow configuration and their set-up with respect to Asset Connectors, as well as the configuration of the ACL Provider.
- The **Recorder** enables recording and storing data originating from Assets, and provides an interface to query this data.
- The **Asset API** provides access to Assets through a well-defined web interface.
- The **Admin API** provides access to the Configuration Manager.

3 Detailed Description

3.1 Asset

Assets are existing live or offline data sources (sensors, data sets etc.) as well as actuators, or their combination, capable of outputting data synchronously or asynchronously and accepting commands to perform actions in their environment.

Assets can be autonomous or human-operated. Assets have a unique identity.

3.2 Asset Connector

Enables connection of different assets to the platform and exchange of data. There are two types of asset connector: automated asset connector, used with machine data sources and manual asset connector, used with data sources prepared by humans.

The Asset Connector implements the necessary connectivity and security logic to expose the asset to the Asset Shadow. The Asset Connector communicates with the Asset Shadow through mutually authenticated and confidential channel.

Functions:

- establish connection to Asset Shadow
- prove identity of the Asset to the Asset Shadow
- check identity of the connection middleware
- establish confidential communication channel with the Asset Shadow
- accept commands via the communication channel and act upon Assets accordingly
- transfer Asset data to the Asset Shadow synchronously and asynchronously
- filter Asset data as appropriate and requested via commands from the Asset Shadow

3.3 Asset Shadow

Serves as a proxy to the Asset Connector. When the underlying asset is online, the Asset Shadow is updated with the data coming from an asset. When the underlying asset is offline, the Asset Shadow implements appropriate behaviour to represent the underlying asset to the Asset API.

Access to asset shadows is controlled by the ACL Manager.

Functions:

- accept connection from Asset Connector
- prove identity of the Connection Middleware to Asset Connector
- check identity of the Asset Connector
- establish confidential communication with Asset Connector
- send commands via the communication channel to Asset Connector
- prepare and return Asset data according to requests made through Asset API
- configure data filtering on Asset Connector

3.4 Recorder

Implements a database service capable of performing data requests that involve recording of data originating from one or more Assets.

Functions:

- Accept application requests via Asset API to start recording data. A request specifies the Assets from which to record data, the particular data channel to record, recording frequency, recording start trigger, recording end trigger (or continuous recording) and optionally a filter to be performed on data.

Upon receiving a request to record, the Recorder issues a request to the Asset Shadow which starts the data transfer from the Asset according to specified recording parameters.

Similar requests from the Asset API reuse data from recording jobs already running.

Functions:

- Accept data queries on the data stored in the database.

Recorded data are objects subject to ACL check upon access

3.5 ACL Manager

Implements and maintains the access control list, defining access to different components based on the concept of users and roles. It is consulted upon each access request on Asset Shadows and the Configuration manager.

Functions:

- Maintain the access control list defining accessible objects and roles with rights to access objects
- Accept authenticated and authorized requests through the Admin API to update the ACL
- Allow or deny requests to perform an operation on the Configuration Manager and the Asset Shadow

3.6 Asset API

Provides access to assets through a well-defined web interface. Uses the ACL Provider to allow or deny a particular type of access to Asset Shadows.

Functions:

- Expose Asset data and asset control to client applications
- Provide confidential and authenticated access
- Collaborate with the ACL Manager to control access
- Provide access to necessary data filtering and processing functions

3.7 Configuration Manager

Administrative component used to control the Asset Shadow configuration and their set-up with respect to Asset Connectors, as well as the configuration of the ACL Provider.

Functions:

- Used through the Admin API to configure the components of Connection Middleware

- Creates/removes/manages Asset Connectors
- Creates/removes/manages user roles and users with the ACL manager

3.8 Admin API

Provides access to the Configuration Manager.

Functions:

- Expose system administration functions of the Configuration Manager to the administration front-end
- Provide confidential and authenticated access

4 Example Implementation

4.1 Amazon Web Services IoT

AWS[1] IoT is a platform that enables connecting devices to AWS Services and other devices, secure data and interactions, process and act upon device data, and enable applications to interact with devices, even when they are offline.

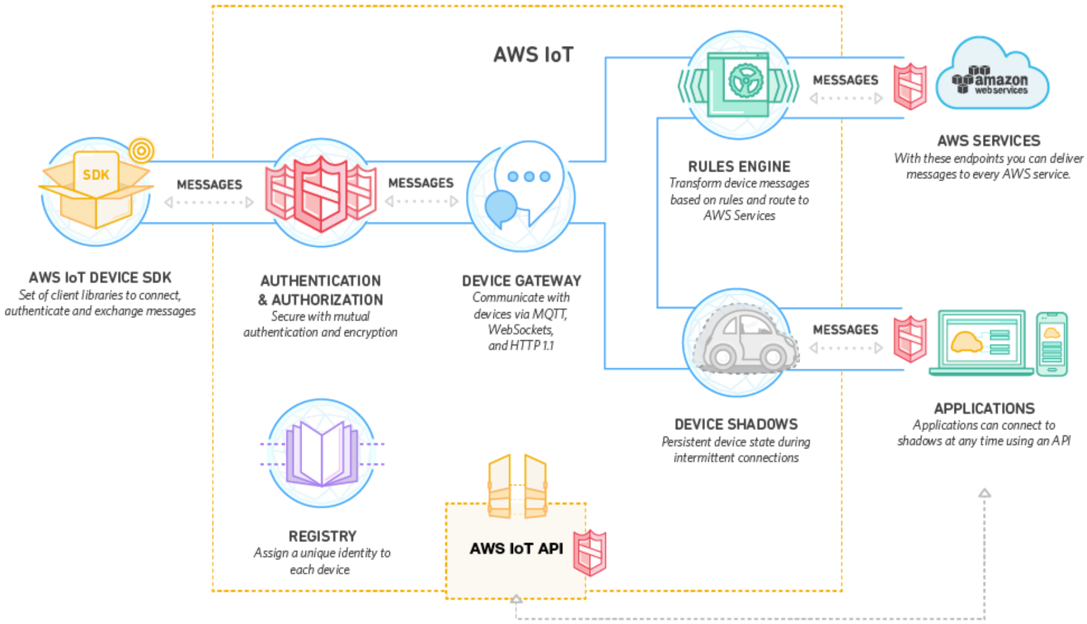

Figure 2. Amazon AWS IoT architecture (source: Amazon)[2]

[1] AWS: Amazon Web Services

[2] The Amazon AWS IoT platform: how it works: https://aws.amazon.com/iot-platform/how-it-works/

5 Platform Implementation in the InValue Consortium

5.1 Belgian Demonstrator

The Digital Cinema (DC) branch of Barco's Entertainment division has an install base of over 50.000 DC projectors worldwide. Per DC projector a few hundred parameters are continuously logged depending on the exact model of the projector. The DC projectors correspond to the **Assets** in the High-Level InValue architecture (see Figure 1).

The monitored parameters in a DC projector are exposed to the outside world via SNMP[3]. A DC projector can signal via the SNMP trap mechanism to a monitoring agent the arrival of new data or the occurrence of important events. These SNMP messages are transported over the communication link of AXEDA Connect[4] product to a centralized information storage in Barco. This AXEDA connect communication link corresponds to the **Asset Connector** in the INVALUE architecture.

An information storage framework was developed, and its supporting infrastructure erected at the Barco premises. The central element in this information storage framework is a so called "stone" – an optimized python structure. Through it, current and cached historic parameters values can be easily retrieved. These stones correspond in a certain way to the **Asset Shadow** component in the INVALUE architecture.

Next to the information that is retrieved via the mechanism described above, data obtained from other systems or channels might also contain valuable information (i.e. issue tracking system; sales system …). This is shown in Figure 3.

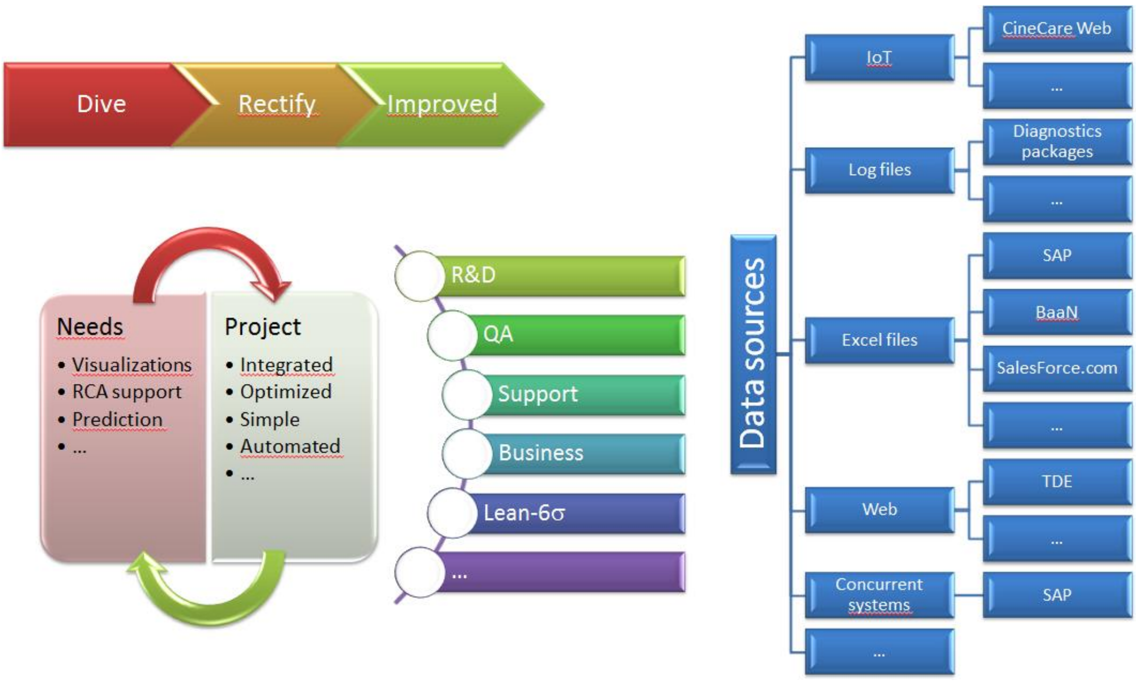

Figure 3.

[3] SNMP: Simple Network Management Protocol; an Internet-standard protocol for collecting and organizing information about managed devices on IP networks and for modifying that information to change device behaviour

[4] AXEDA Connect: IoT Connectivity Middleware from PTC; https://www.ptc.com/en/axeda

An extensive framework based on open source tools has been developed to provide a unified access to all these information sources and to be able to formulate and proving hypothesis on the data. This framework is depicted in Figure 4. This comprises the **Asset API** building block from the High Level InValue architecture.

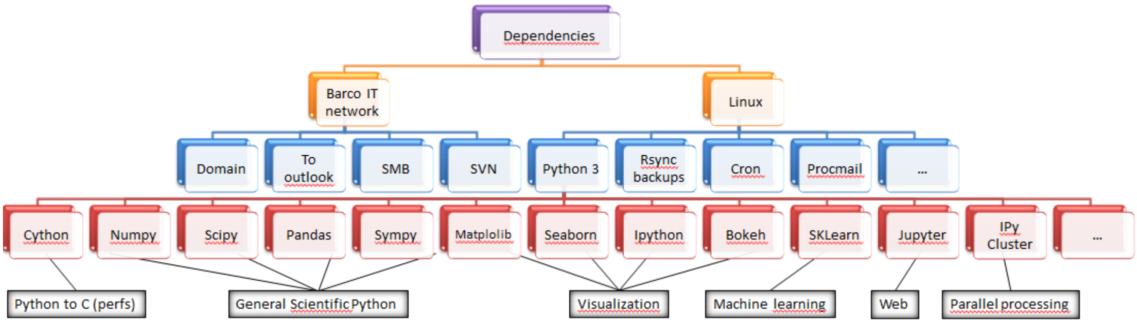

Figure 4.

5.2 Portuguese Demonstrator

The Portuguese use cases for the InValue project will be applied on Facort, a metallurgical company specializing in precision parts for the Automotive industry. Two types of common machines in this industry (Machining Centre and CNC Turning Centre) will be monitored due to their high impact in production challenges and product quality.

In the Portuguese use case, the platform is composed by 3 main layers, as can be seen in Figure 5:

- **Data acquisition**
- **Data processing (Big Data Management & Big Data Processing)**
- **Information Delivery**

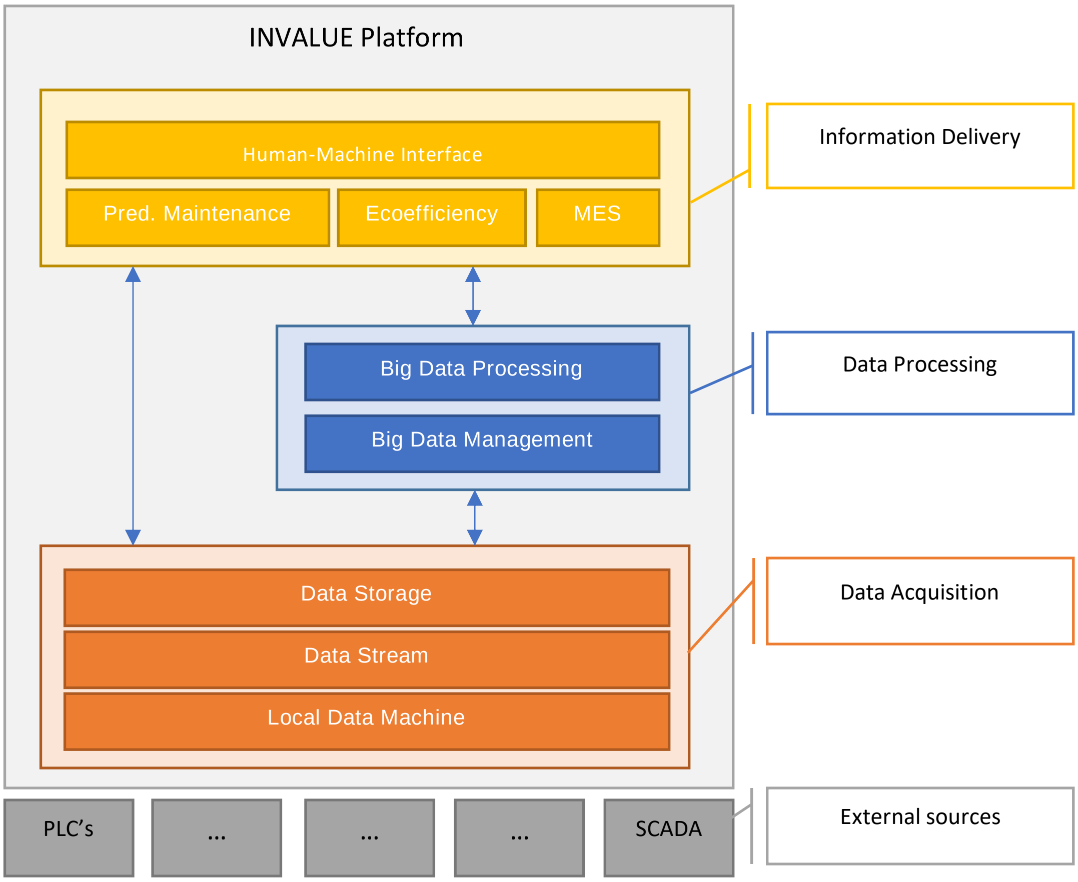

Figure 5. The Portuguese Use-Case InValue Platform

The monitored machines correspond to the **Assets** on the High-Level InValue architecture and are targets of different data acquisition approaches. The data is collected by the Data Acquisition layer, being supplied by the machines themselves – made available through a BUS with a described protocol and gathered by a gateway – and by sensors. The sensors collect information of interest that is not provided by the machines, compensating for possible differences between new and legacy models while also providing new variables that are monitored by neither. This corpus of information includes, but is not limited to:

- Noise and Vibrations;
- Spindle Load and Pressures;
- Job info, including: number of cycles, Operator ID, etc.;
- Emulsion Levels;
- Lubricant Levels;
- Energy Consumption;
- Movements done.

The acquired data is published through a gateway implementing a Publish/Subscribe communication pattern, using Apache Kafka. This message manager corresponds to the **Asset Connector** of the InValue High-Level architecture. A central server consumes all the data published by the Data Acquisition layer and writes it in a database, keeping the current and historical data of each machine. These machine representations therefore roughly correspond to the **Asset Shadow** components in the InValue High-Level Architecture.

The Data Processing layer is responsible for pre-processing the data and employing Machine Learning and Data Mining techniques in order to identify potentially failing components, diagnose past failures and propose corrective measures; these actions will reduce machine downtime, number of failures and increase product quality through reducing potential damage to goods. The results of these processes are stored in the central server database.

The access to the central database is provided by a framework-based API, corresponding to the **Asset API** block from the High-Level InValue architecture.

The Information Delivery Layer shows data concerning the machines' statuses, both historical and in real-time, along with notifications and alerts related to potential maintenance activities. Additionally, it allows for the definition of both user and roles and to establish access levels to this information, corresponding to the **ACL Manager** of the High-Level InValue architecture.

Therefore, even though not all elements of the High-Level InValue architecture are directly mappable to the Portuguese use-case, the ones that can be mapped would do so as described in Figure 6:

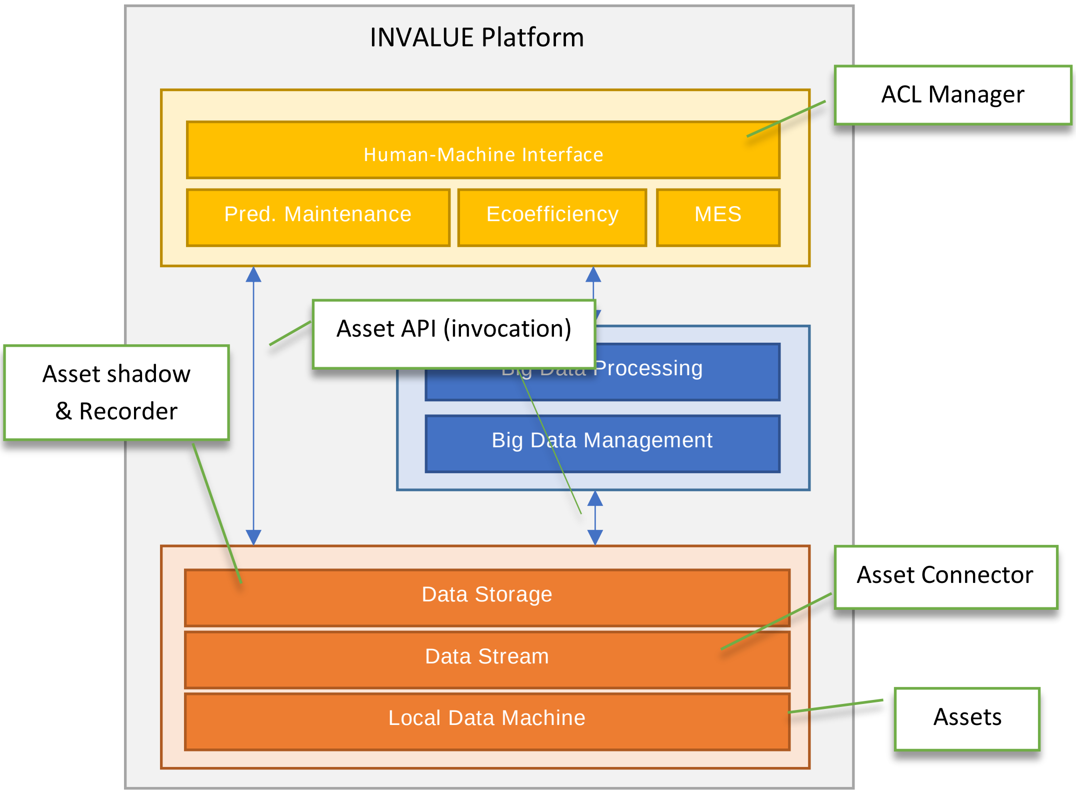

Figure 6. Portuguese and High-Level InValue Architecture mapping

5.3 Spanish Demonstrator

The Spanish use case is focused on the camshaft manufacturing process in terms of improving the quality control. It covers specific technology demands coming from diverse type of end-users, mainly automotive, naval and agriculture sectors. EPC has decided to integrate a virtual metrology solution in order to optimize its quality control system enhancing the capacity to adapt itself quickly and effectively.

The following scheme shows the architecture implementation within the InValue project for the Spanish consortium:

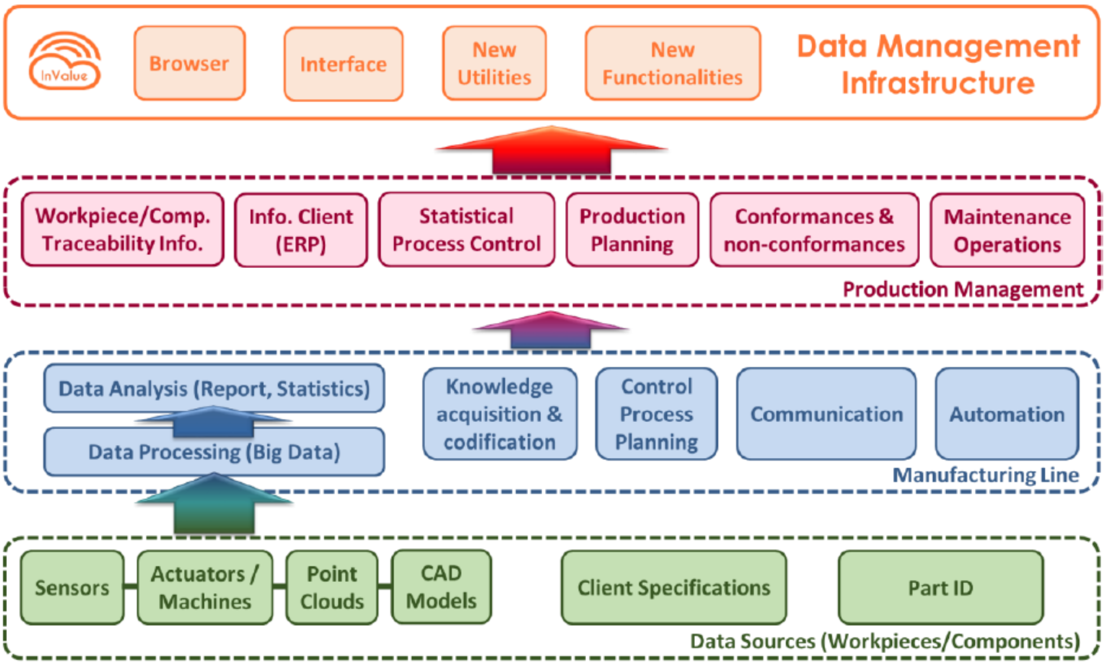

Figure 7.

This diagram stands for the platform architecture implemented in the Spanish Use Case, which does not take into account the sub-divisions of the Manufacturing Line and Production Management levels in the same way the InValue architecture does. Hence, Manufacturing Line block and Production Management in a certain way stand for the Asset Connector + Asset Shadow in the InValue architecture.

The definition of the architecture's implementation has been done according to the previous diagram, which represents better the structure followed by the Spanish consortium in order to design the architecture and interaction between components.

Data sources or Assets:

The information is generated in the first level of the architecture, from different sources: sensors, actuators and point-clouds, whose information is obtained in-line; and client specifications, CAD models and part IDs, which are generated before the process (off-line). The parts involved in the process are the following:

- Sensors: The sensors used for the workflow defined for the InValue project are, mainly, the ones that control the tempering process. Hence, the information coming from those sensors will include: temperature, temperature variations, humidity, time, etc.
- Actuators/Machines: Manufacturing a camshaft requires the usage of different machines. The information provided by those machines will be used for traceability purposes.
- Point clouds: The information captured by the optical scanner, which should be equipped in a Coordinates Measuring Machine (CMM), will be an aggregate of points that represent the surfaces of the analysed part. Those point clouds will be later compared to the original CAD model in order to obtain the deviations, so they have to be stored and shared properly in order to allow posterior analyses.
- CAD Models: The 3D models of the parts serve as a reference to compare the theoretical dimensions or geometries with the real ones, which can be obtained

from the point-cloud. The CAD models are necessary both for manufacturing and quality control of the parts

- Client specifications: Clients might require some concrete specifications to be followed, which have to be taken into account for the manufacturing process. Alongside the CAD model, client specifications must be inputs for the manufacturing process.
- Part ID: Every manufactured part has an own ID, usually composed by a part number (the codification that EPC gives to an element/design, which is not individual) and the serial number or lot number. Depending on the traceability needed for a part, it is given a lot number (multiple parts are produced, in batches, and are given the same lot number and makes no distinction between the different parts) or, if higher traceability is needed, a serial number is given (a unique number that only refers to a concrete part, usually with its own Manufacturing Order).

Manufacturing Line – MES

The next element on our internal architecture is in charge of analysing the data obtained from the lower level, processing it, and generating useful information to be used by the manufacturer. The connected systems provide reliable and specific information about the manufacturing process, the parts and their quality, etc. in order to be used to prevent deviations, correct or enhance current manufacturing processes and, finally, provide a high traceability of the manufactured elements. This level could be divided in:

- Data Analysis (Report, Statistics): M3 Software, with its new functionalities, is in charge of providing the reports and statistical analysis regarding the dimensional quality of the parts. The data obtained from the point-clouds is compared to the CAD model, extracting the geometries and dimensions, previously specified by the user, and giving the results of the measurements. Moreover, this tool analyses the results and provides statistics about concrete geometries, or dimensions, in order to control a specific characteristic.
- Control Process Planning: In order to manufacture a part, it is necessary to plan the manufacturing process. At this level of the architecture, it is needed to design the different phases, processes and machines that should be used in order to manufacture the part. With the information from the lower level, this process planning can be controlled, and might be further enhanced if reliable data is available.
- Communication: Necessary to connect the different systems that act in EPC's manufacturing environment, the communication between systems must be trustworthy, reliable and fast, in order to track the process in real-time.

Production Management – ERP:

The next level of the architecture, Production Management, is in charge of controlling the knowledge and valuable information that has been generated by the previous level, in order to manage the production in the best way. The new items introduced by InValue give a better overview of the manufacturing process to EPC, as traceability is enhanced at all levels and the whole manufacturing process is controlled.

- Workpiece/Component Traceability Information: All the collected data from the lower levels, the manufacturing order, the process information, the dimensional report of the part, etc. is put together in the ERP system, which should be capable of storing this data and relating it to a concrete part. The control of such high number of parameters allows EPC to have the information available at the same place, so it can be used for investigations, analysis, etc. Moreover, the possibility of having the point-cloud stored allows EPC to analyse a concrete camshaft even if it has left the plant or if it has been already assembled.

- Statistical Process Control: The reports and statistical analyses generated by M3 provide valuable information in order to control the process of the manufacturing part by analysing the dimensional/geometrical defects on the parts, possible deviations, etc. The statistical control provides a tool that can be used to enhance the process, to analyse where is it failing, or to make decisions regarding the different phases of the process.
- Production Planning: Alongside the Statistical Process Control and Maintenance Operations, if some defects are found it is possible to re-plan the production according to the quality of the manufactured parts. Moreover, maintenance operations can be planned if any defect that can be directly related to a machine/tool.
- Conformances & non-conformances: The metrological analysis provided by M3 and the metrological system installed in EPC's manufacturing line will allow the early detection of non-conformances. Moreover, the system also provides EPC with the possibility of further analysis once the part has left the plant, enhancing traceability of the produced parts. This allows EPC to determine whether the parts are conformant or non-conformant in a precise way and allows them to stop non-conformant parts to leave the plant.
- Maintenance Operations: The statistical analyses and reports allow EPC to better plan maintenance tasks on the machines or tooling that is being used. From statistical analyses, non-conformances can be correlated to tool wear and, consequently, allows to create preventive maintenance tasks in order to avoid them.

Data Management Infrastructure:

The highest level of the InValue architecture is thought to provide data management, through different utilities and functionalities.

- Browser
- Interface
- New Utilities
- New Functionalities

5.4 Turkish Demonstrator

Turkish implementation will be in the production line of an Automotive Manufacturing company HISARLAR Agricultural Machinery Factory settled in Eskisehir / Turkey. Manufacturing devices will be covered with additional sensors and also existing metrics and sensor data on devices will be collected by DTTs[5] and will sent to the site gateway. After mapping and optimising data on the gateway data will be sent to the InValue Cloud platform over a secure connection. InValue platform is going to visualise and run data analytics on this raw data and generate business related reports, notifications etc.

The architecture will contain into two main parts (Figure 8):

[5] A DTT (Data Transfer Terminal) provides data collection flexibility and is configured depending on the device(s) it has been attached to.

- ICP : the collection of business and data related block
- IES : the collection of data acquisition & collection parts.

Figure 8.

The data connection flow is described in Figure 9.

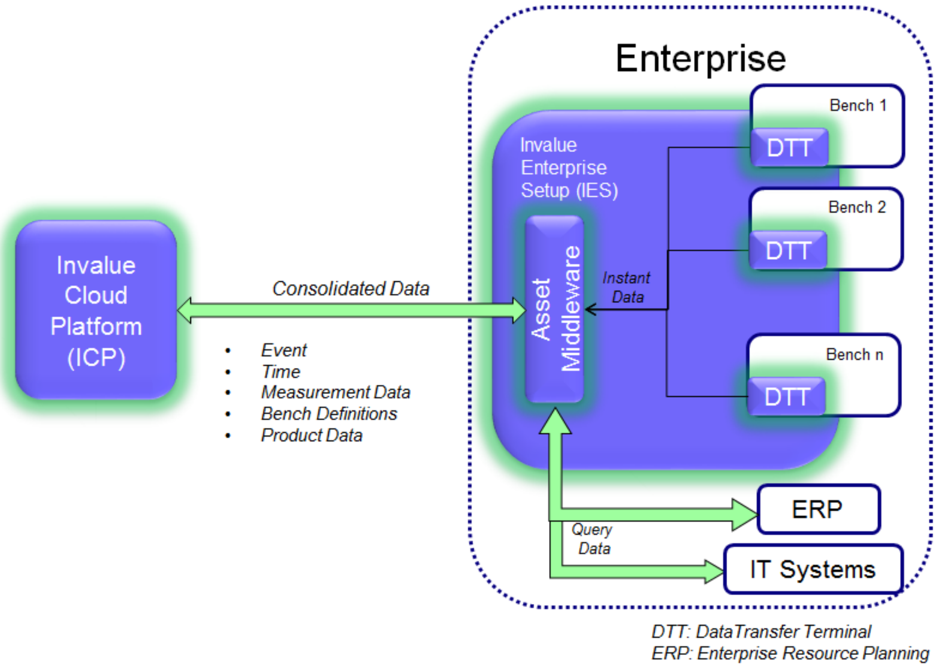

Figure 9.

In cooperation with other members of the consortium, Turkey use case and implementation is mostly covering the initial architectural design blocks. Turkish consortium contribution to architectural blocks listed below.

- Domain-specific Applications
  - Business Functionalities
  - Process Automation
  - Planning

- Generic Application Support Components
  - Data Analysis
  - Report Generation
  - Visualization
- Storage and Processing Middleware
  - Data Ingest
  - Storage
  - Execution
- Asset Middleware
  - Data Acquisition
  - Access Control
  - Connection Security
- Assets
  - DTTs
  - Sensors
- Administration
  - Access Control
  - User Management
  - Platform Management
  - Asset Management