VerSatilE plug-and-play platform enabling remote pREdictive mainteNAnce

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		OCULAVIS GmbH
		SynArea Consultants S.r.l.
		DELL EMC
		Laboratory for Manufacturing Systems & Automation
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Summary:

The design of the SERENA cloud-based platform for remote diagnostics will be presented in this document to drive the work in all the implementation tasks of WP5, but in strict collaboration with the parallel work in WP2-3-4 to be validated in WP6, following the requirements defined in WP1.

Contents

List of Abbreviations

AI	Artificial Intelligence
AR	Augmented Reality
CAD	Computer-Aided Design
CEN	European Committee for Standardisation
CSP	Cloud Service Provide
CWA	CEN Workshop Agreement
DNS-SD	DNS Service Discovery
ERP	Enterprise Resource Planning
HDFS	Hadoop Distributed File System
HMI	Human Machine Interface
HTTP	HyperText Transfer Protocol
ICT	Information and Communications Technology
JEE	Java Platform, Enterprise Edition
JSON-LD	JavaScript Object Notation for Linked Data
KPI	Key Performance Indicator
NTP	Network Time Protocol
ODBC	Open DataBase Connectivity
OEM	Original Equipment Manufacturer
PLC	Programmable Logic Controller
RDF	Resource Description Framework
REST	Representational State Transfer
SaaS	Software as a Service
SME	Small and Medium Sized Enterprise
SPARQL	SPARQL Protocol and RDF Query Language
SQL	Structured Query Language
STEP	STandard for the Exchange of Product model data
ToC	Table of Contents
TRL	Technology Readiness Level
UUID	Universally Unique IDentifier
VR	Virtual Reality

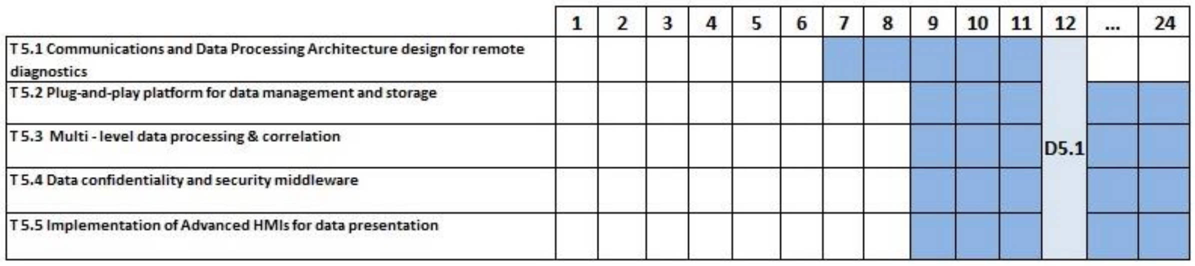
List of Figures

Executive Summary

The purpose of this document is describing the design of WP5 developments. The current deliverable (i.e. *D5.1 – Design of cloud-based platform for remote diagnostics*) aims to report on the actual results of several tasks, namely (see Figure 1):

- T5.1 Communications and Data Processing Architecture design for remote diagnostics which starts at M7 and ends at M12
- T5.2 Plug-and-play platform for data management and storage
- T5.3 Multi-level data processing & correlation
- T5.4 Data confidentiality and security middleware
- T5.5 Implementation of Advanced HMIs for data presentation which start at M9 and end at M24

The user's requirements collected in WP1 for the cloud-based platform for remote diagnostics will be used for defining the SERENA cloud-based solutions for predictive maintenance but considering also the requirements related to the remote factory condition monitoring, AI condition-based maintenance and planning and AR based tools for remote assistance and operator support. The overreaching solution will be able to support predictive diagnostics and data analytics in a remote cloud and proposing corrective actions and guidance for maintenance activities within the factory.



	1	2	3	4	5	6	7	8	9	10	11	12	...	24
T 5.1 Communications and Data Processing Architecture design for remote diagnostics							🟦	🟦	🟦	🟦	🟦			
T 5.2 Plug-and-play platform for data management and storage									🟦	🟦	🟦		🟦	🟦
T 5.3 Multi - level data processing & correlation									🟦	🟦	🟦	D5.1	🟦	🟦
T 5.4 Data confidentiality and security middleware									🟦	🟦	🟦		🟦	🟦
T 5.5 Implementation of Advanced HMIs for data presentation									🟦	🟦	🟦		🟦	🟦

Figure 1 D5.1 and contributing tasks

To this end the main input of such activities is *D1.1 – Report on Use-case definition, evaluation metrics and End-Users requirements*, another project deliverable integrating and reporting the outcomes of all tasks in WP1 whose objectives are: a comprehensive description of the targeted use-cases from the end-users (WHEMEA, KONE, TRIMEK, VDLWEW); extract user requirements and evaluation criteria in terms of performance, usability and relevant KPIs; define the roadmap towards achieving industrial TRL for each targeted technology; have a precise description of the end users requirements in terms of remote factory condition monitoring, AI condition based maintenance and planning, AR based tools for remote assistance and operator support, cloud-based platform for remote diagnostics.

Moreover, D5.1 has been written taking in consideration the approaches followed in the following deliverables due at M12 as well:

- *D2.1 - Design of versatile framework for factory condition monitoring*: this deliverable describes the design of HW and SW solutions for versatile remote factory monitoring;
- *D3.1 - Design of versatile maintenance and planning*: this deliverable describes the design of WP3 approach in terms of improving existing solutions for predictive maintenance as well as planning of maintenance solutions;
- *D4.1 - Design of AR-based remote diagnostics platform and interfaces*: this deliverable describes the design of WP4 overall approach in terms of development and adaptation of Augmented Reality (AR) based technologies for providing step-by-step assistance to the maintenance technicians and sensor-based information about the status of the machinery and overall equipment within the factory;
- *D6.1 - Test beds design & adaption*: this deliverable focuses on the design and integration of the test beds regarding the white goods, metrological engineering, and elevators production industrial

pilot cases (WHEMEA, TRIMEK and KONE), as well as the pre-demonstration case of steel parts production industry (VDLWEW). To this aim, the SERENA architecture will be tailored to allow use case owners to implement their testbeds in accordance with their specific requirements and constraints.

The methodology followed to complete deliverable D5.1 included:

- Table of Contents (ToC) and document scope: once the ToC was agreed among the partners, a detailed template including a description of the required information along with examples was circulated to guide the section coordinators in the collection of the required information from all the contributing partners.
- Theoretic background/principles and existing frameworks, solutions, references, technologies analysis and alignment to the project objectives.
- Follow up activities to monitor the work progress through principally two types of meeting: (1) Bi-weekly task leaders conference meetings specifically dealing with WP5-related activities; (2) Monthly conference meetings with all the work-package leaders focused on SERENA overreaching solutions specification and development.

1. Introduction

1.1 Motivation

Aim of WP5 is defining the cloud-based platform for versatile remote diagnostics enabling predictive diagnostics, by managing the data remotely, applying data analytics and predictive maintenance algorithms in a remote cloud and proposing corrective actions and guidance for maintenance in near real time and in the correct place within the factory.

The challenges faced by the different cloud implementations vary, therefore the requirements defined for the SERENA cloud-based system must encompass the combined set of all requirements, enabling several deployment approaches (e.g. private cloud, public cloud, or on-premises). To this end, the SERENA system should provide a layer of abstraction, which, to the extent possible, obscures the system from the underlying implementation.

One characteristic that most cloud-based systems have in common is that they are based on a distributed architecture (e.g. defining a microservices architecture), consisting of several independent services providing the application functions. Such an architecture has several advantages over previous monolithic or bespoke component architectures: a) they are more responsive to the demands of the high-variable of modern businesses; b) they are more scalable, as predefined templates can be instantiated quickly to meet increasing production demands; and c) it is easier to swap out one component for another, provided it conforms to the same API and behaviour. The last point is particularly relevant for the SERENA project as it facilitates a plug-and-play architecture, which is one of SERENA's core objectives.

Microservices architecture typically implement the different services in one, or a set, of container(s) in a virtualised environment, this gives the system the flexibility to instantiate preconfigured services from container templates and move containers around the physical IT infrastructure to optimise its performance. As most major CSP provide their tenant environments as a microservices architecture, and many private clouds are implemented in the same way, basing the SERENA system on a microservices architecture gives the manufacturing company the flexibility to implement their solution in either environment, or a hybrid of the two. It also means that the SERENA system can inherit the added benefits of a microservices architecture, as outlined in the previous paragraphs. Whilst each CSP implements their environment in a proprietary way, the industry is starting to converge on a set of common architectural patters, and support for common services; by exploiting this convergence, the SERENA system can be made highly flexible in how and where it is deployed.

1.2 Work package objectives

WP5 aims to design a cloud-based platform for remote diagnostics, providing specifications for the networking infrastructure, the cloud computing infrastructure, the data processing components, the digital models, and the shared situation awareness components and to instantiate the remote SERENA Cloud Platform for piloting purposes in the different industrial sectors.

To reach this objective, WP5 has been decomposed in 6 tasks (see Figure 2):

1. **Task 5.1 Communications and Data Processing Architecture design for remote diagnostics**. This task is responsible for specifying the **communication and data processing components**, from the shop-floor to the cloud and back and the designing **new communication capabilities** (green- and brown- field integration). The main results are the specification of an industrial networking infrastructure supporting both edge and cloud components and the selection of a service infrastructure (e.g. based on existing open source solutions).
2. **Task 5.2 Plug-and-play platform for data management and storage.** This task is responsible for developing techniques and tools for **sensing context data** and defining **semantic techniques for aggregation and fusion** and developing and deploying new integrated data-lifecycle management approach. The main results will be the Integrated process execution sensing service, the Cloud Storage Service supporting the **Plug-and-Store paradigm** and data

aggregation capabilities and the Real-time communication using self-descriptive communication protocol.

3. **Task 5.3 Multi-level data processing & correlation**
   This task is responsible for developing new techniques for **real-time processing,** analysing, and interpreting and enabling the execution of **machine learning and data analytics tasks.** The main results will be an infrastructure for distributed data analytics over the edge/cloud nodes.
4. **Task 5.4 Data confidentiality and security middleware**
   This task is responsible for defining the data protection approach, analysing existing standards and available open source solutions, and providing built-in functionalities using a **multi-layer Security-by-Design approach**. The main results will be the principles and the guidelines to drive the trustworthiness of the SERENA architecture and the development of a **Secure Middleware for distributed architecture**.
5. **Task 5.5 Implementation of Advanced HMIs for data presentation**
   This task is responsible for developing techniques and tools to support the **visual representation of the sensed and fused context data** and for using **multi-modal interaction technologies**. The main results will be the **Visualization-as-a-Service capabilities** and a set of web services to configure the visual features of the HMI (e.g. from AR tools developed in WP4)
6. **Task 5.6 Cloud-based platform prototype**
   This task is responsible for integrating the components of the previous tasks into a prototype, supporting the deployment on several possible technology platforms and support an easy and seamless integration with commercial SW (maintenance and production). The main results will be **SERENA Cloud Platform prototype.**

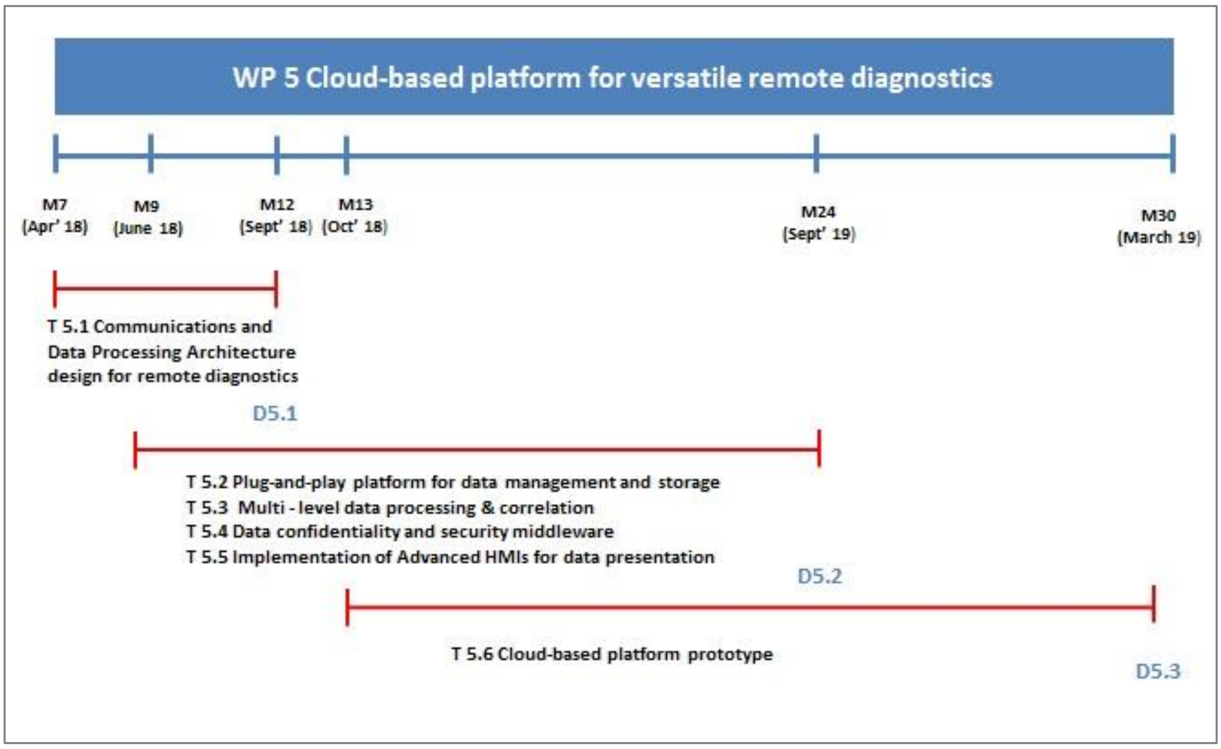

WP 5 Cloud-based platform for versatile remote diagnostics
M7 (Apr' 18)
M9 (June 18)
M12 (Sept' 18)
M13 (Oct' 18)
M24 (Sept' 19)
M30 (March 19)
T 5.1 Communications and Data Processing Architecture design for remote diagnostics
D5.1
T 5.2 Plug-and-play platform for data management and storage
T 5.3 Multi - level data processing & correlation
T 5.4 Data confidentiality and security middleware
T 5.5 Implementation of Advanced HMIs for data presentation
D5.2
T 5.6 Cloud-based platform prototype
D5.3

Figure 2 WP5: tasks and deliverables

Based on the requirements of WP1, the project will focus on developing the prototypes in terms of a) definition of the service-oriented architecture for remote control (WP2), b) AI condition-based maintenance and planning techniques (WP3), c) AR-based technologies for remote assistance and human operator support (WP4) and d) Cloud-based platform for versatile remote diagnostics (WP5) (see Figure 3).

These development activities will be the first step of an iterative process which will lead to the first prototype of WP5 developments in M24 and the final prototype in M30.

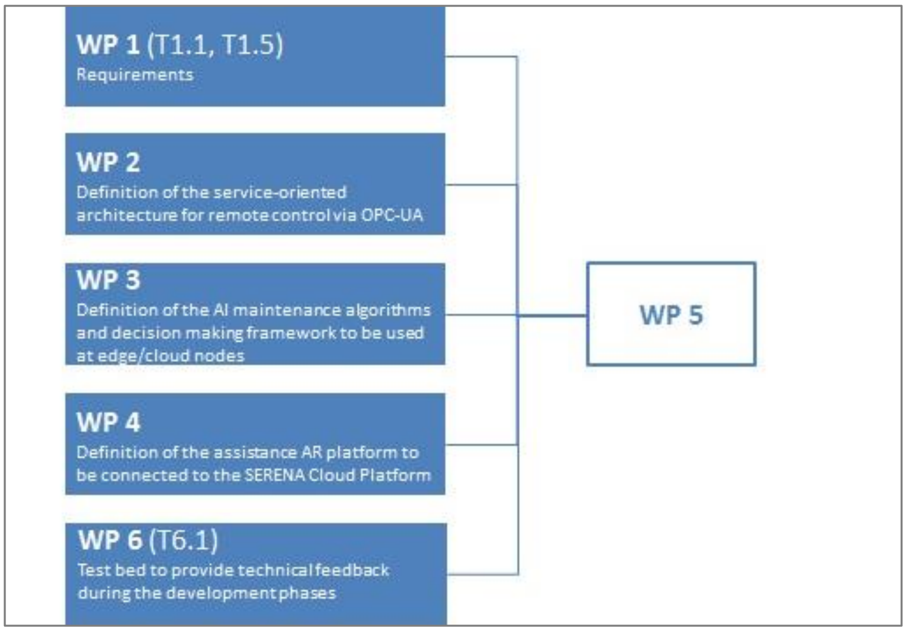

WP 1 (T1.1, T1.5)
Requirements
WP 2
Definition of the service-oriented architecture for remote control via OPC-UA
WP 3
Definition of the AI maintenance algorithms and decision making framework to be used at edge/cloud nodes
WP 4
Definition of the assistance AR platform to be connected to the SERENA Cloud Platform
WP 6 (T6.1)
Test bed to provide technical feedback during the development phases
WP 5

Figure 3 Relationship with other tasks

The main goals of the predictive maintenance are:

- avoid an unpredicted fault and predict when it could occur;
- avoid unnecessary machineries/equipment replacement, if they are still able to work well enough;
- providing valuable information to the maintenance director, who needs to evaluate risks and benefits that comes from a predictive scenario;
- produce cost savings over preventive maintenance, allowing a convenient scheduling of the maintenance operations.

These goals are pursued by the SERENA project, working with production data that comes from the field (from the IoT platform) and getting additional information from the operational systems (e.g. master data, ERP, etc.) used by the customer to manage the whole maintenance process and to provide direct feedbacks for received early warnings, with eventual related interventions (see Figure 4).
Using this additional information, the SERENA Cloud Platform can measure impact over costs and operations, fully supporting the decisional process concerning the maintenance plan.

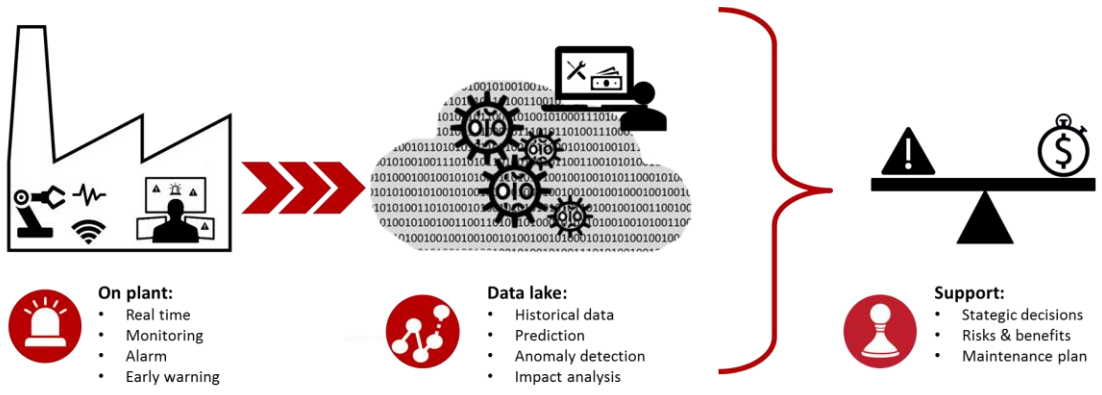


Figure 4 Role and goals in maintenance scenario

To achieve the listed goals data are collected from the field and loaded into a data lake (on-premise or on-cloud) at the end of every working cycle. Here, advanced algorithms based on machine learning techniques learn what is the standard behaviour of every machinery/equipment, predict what will be the expected one in the future, evaluating if that could be anomalous or not.

1.3 Requirements

The main requirements for the technical developments of WP2-5 and for the basis of the testbed design in WP6 have been defined in the scope of WP1. Specifically, these comprehend:

- an analysis of the status and requirements of the different pilot cases, including the equipment to be considered within the project, the maintenance needs, the expectations from the project;
- The identified requirements of the technical systems to be developed based on the needs identified in pilot cases analysis, focusing on the following aspects:
    - Remote factory condition monitoring and control
    - AI condition-based maintenance and planning techniques
    - AR-based technologies for remote assistance and human operator support
    - Cloud-based platform for versatile remote diagnostics

Focusing on WP5 - Cloud-based platform for versatile remote diagnostics, the main functional and non-functional requirements of the Cloud-based platform have been grouped in several families, covering the differne sub-sytems foreseen un WP5. The main logical functions has been decomponsed in ingestion, storage, processing, management (for further details on the identified requirements under the scope of WP1 please check Annex A).

2. SERENA Cloud Platform design

2.1 Concept

Designing the SERENA Cloud Platform, the following functions will be provided:

- **Communications and Data Processing Architecture design for remote diagnostics**
  - Specification of an **industrial networking infrastructure** supporting both edge and cloud components
  - Selection of a **service infrastructure** able to provide new communication capabilities
- **Plug-and-play platform for data management and storage**
  - **Integrated process execution** sensing service
  - Cloud Storage Service supporting the **Plug-and-Store paradigm** and **data aggregation** capabilities
  - **Real-time communication** using self-descriptive communication protocol
- **Multi-level data processing & correlation**
  - **Infrastructure for distributed data analytics** over the edge/cloud nodes
- **Data confidentiality and security middleware**
  - **Principles and guidelines** to drive the trustworthiness of the SERENA architecture
  - **Secure Middleware** for distributed architecture
- **Advanced HMIs for data presentation**
  - **Visualization-as-a-Service** capabilities
- Set of web services to **configure the visual features** of the HMI

2.2 SERENA Cloud Platform

The SERENA Cloud Platform relies on several logical components, described in the following picture:

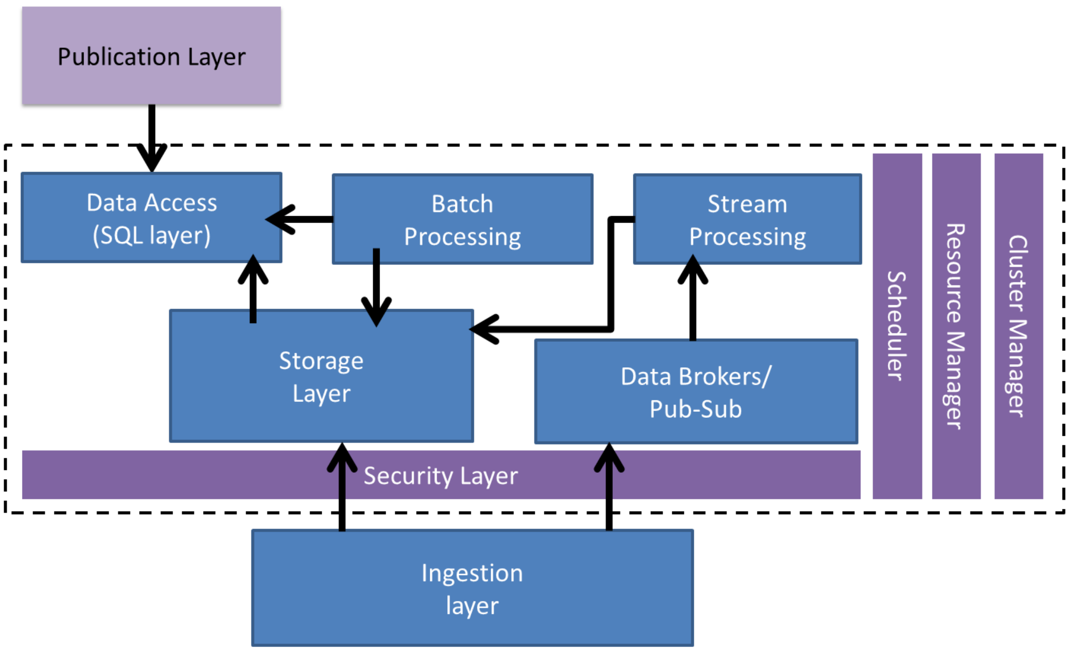


Figure 5 SERENA Logical Architecture

This reference architecture can be implemented over different platforms, because it is not strictly dependant from a specific solution provider. However, the actual identified solution adopts the Cloudera distribution of the Hadoop ecosystem, so the following each building block is described in general terms and with a reference to the Cloudera modules (please notice that the following content in Section 2.2

has already been described with D1.1, and it is replicated here for providing a coherent description of the designed solution).

Ingestion Layer
This layer deals with the task of collecting data from several sources, performing some pre-processing workflow, and saving them in the Data Lake. The data ingestion can gather data in real time fashion as well as in batch, depending on the source and on the use-case. For the current purposes, the ingestion is scheduled and gets data from FTP directories where files collected from the plant are available on daily basis. The aim of this component is to enable the transmission of files from the inside of the data lake to the outside (as happens with the model built on the big data platform that is made available to the early warning module in-plant). The tool chosen to accomplish all the above features is Apache Nifi.

Storage Layer
The storage layer is responsible for the persistence of raw data collected by the ingestion process and data which is the result of the distributed processes and analysis within the data lake. There are different storages that can be used since supported by each Hadoop distribution: distributed file system or NoSQL database. For the SERENA project, both HDFS and MySQL are used, depending on the data pipeline to build. HDFS stores incoming data from the ingestion process and the datasets computed by the algorithms, while MySQL holds metadata.

Information brokers/pub-sub
To satisfy real-time purposes, a publish-subscribe distributed message queue is available within the data lake platform, even if not configured yet. The role of this component is to stock data from streaming ingestion processes to feed the streaming layer of computations described below.

Stream Processing layer
Although not fully designed, streaming pipelines can be developed by using Spark Streaming libraries. It allows data to be filtered, processed, aggregated, and analysed event by event so that real-time results are available.

Publication Layer
In the reference architecture, this layer shows the results of the predictive maintenance algorithms run on a huge amount of data collected from the field by the batch processes described above. As default SERENA will provide a prebuilt set of analysis, but some other analysis can be added using any other analytics tools and libraries.

Batch Processing Layer
Once data is landed on the data lake it is processed by the distributed framework Spark, capable of managing huge amounts of data, dealing with cleaning tasks as well as analysis through custom algorithms for predictive maintenance objective. The batch jobs are scheduled and executed evenly across the cluster every day.

Data Access Layer
To access files stored in the data lake, because of the advanced analytics run by the batch processing layer in Spark, a SQL layer is configured. This tool acts as a gateway for applications that need to publish information generated in the data lake through a front-end UI, as well as perform some additional query on Hadoop, benefiting from the parallel computation that can be run on the platform. Impala is the chosen tool that allows the publication layer to perform insights on the data lake.

Security Layer
The Security layer involves authentication, authorization, encryption, and data lineage features, and strongly depends on the chose Hadoop distribution: SERENA is enabled to use Kerberos protocol to connect to Active Directory or LDAP authentication user domains. On HDFS privileges can be

configured using ACLs policies, while It is also possible to set proper permissions on Impala tables through Apache Sentry (embedded in the solution). To perform data lineage and leverage encryption at-rest policies Cloudera Navigator can be used, subscribing Cloudera Enterprise Data Hub license.

Scheduler
This layer addresses the scheduling of batch jobs and orchestrates them through a proper workflow of different actions. Within the current scenario, this task is dealt by Oozie.

Resource manager
Hadoop allows distributed jobs to be executed in the cluster, where data is hosted. Different jobs are run on the available nodes in the platform, considering the resources in terms of RAM and CPU and the data locality of the partitions of the files to be processed. All these tasks are managed and scheduled by YARN, which is the resource negotiator of Hadoop.

Cluster Manager
Every Hadoop distribution offers a tool to manage the cluster, in terms of hosts and services. Cloudera Manager is a web application, made for Hadoop Administrator to let them master the platform.

2.3 SERENA Infrastructure

As defined in section 2.2, the SERENA system is comprised of several logical components, which collectively provide SERENA's predictive maintenance functionality. These logical components reside in the SERENA cloud, but the functionality extends to the edge gateways and sensors on the factory floor. It also encompasses other SERENA functionality including a) adaptive maintenance scheduling, driven from the prediction results; b) augmented reality to assist operators and technical staff maintaining the factory equipment; c) equipment visual simulation applications; and d) other incumbent factory management system. Additionally, the SERENA system is intended to be flexible enough to be hosted on an on-premises environment, a CSP environment, or a hybrid of the two, as outlined in Section 1. To meet these varying requirements, the SERENA system will be designed on a micro-services architecture pattern [1], where each logical component is a service within the SERENA system.

Each service within the SERENA system communicates and collaborates with other services to perform its specific function, and extends to other components, such as the edge gateways. The principal communications protocol is based on HTTP REST, but other protocols can be supported as required. Whilst REST is a text-based protocol, and therefore not as efficient as some binary protocols, its wide spread support, both inside the manufacturing industry, and beyond, make it an ideal candidate for SERENA. In a **micro-services architecture** each service can communicate with a set of other services, to perform its function. Therefore, the SERENA infrastructure will implement functionality to facilitate this inter-service communication in a reliable and secure way.

The SERENA system must also support several non-functional requirements including a) flexibility; b) scalability; c) reliability; and d) security. As previously discussed, the SERENA system must be flexible enough to be hosted on a wide variety of on-premise and CSP environments, but additionally it should be agnostic to the actual technology used to implement a logical component. Whilst the SERENA reference architecture is largely based on the Cloudera technology stack, the reference architecture defines a logical set of the API and behaviour for each service. Therefore, the actual technology implementation of a service, can be swapped for any other suitable technology, provided it conforms to the logical component's API and behaviour. For example, the reference architecture implements the ingest service using Apache's NiFi[1] data flow engine, but this service could be replaced with an equivalent one based on Apache Camel[2]; it is the logical component's function within the SERENA system that is important, not its technical implementation. This implementation transparency is an important concept in SERENA's **plug-n-play functionality**.

[1] https://nifi.apache.org/
[2] http://camel.apache.org/

2.3.1 SERENA Auxiliary Services

In addition to SERENA's main functional services, there are several auxiliary services, which contribute to the overall operation of the system, such as DNS-SD and NTP services. The Domain Name System Service Discovery service is used by subsystems to discover service they need to perform their function and resolve their domain names into IP addresses. This functionality decouples the logical component providing the service, from the location of the service denoted by its static IP address. SERENA provides additional features to abstract services from their implementations, which will be described later. The Network Time Protocol (NTP) service helps maintain a synchronised system wide time across all SERENA services and edge gateways. When collecting sensor data from multiple IoT sources, it is important that the distributed subsystems all share the same system time, so that timestamped data can be accurately correlated with events.

2.3.2 SERENA Containerisation

The principal infrastructure technology to implement SERENA's services is **Docker containers** [2]. Docker provides an open source implementation of a process containerization system, which encapsulates the service, and abstracts it from the underlying infrastructure that hosts the containers. Unlike virtual machines, which are a mechanism for logically dividing physical machines, Docker containers are principally a mechanism to wrap an application, and the resources required to run it, into a simple executable unit. Therefore, Docket containers are isolated from the underlying host infrastructure, and can easily be distributed between the available hosts to improve the flexibility and agility of the system. Docker containers share many similar features to virtual machines, but, as explained, they perform distinctly different function within the infrastructure system. In fact, virtual machines and containers can be complimentary technologies, and used in conjunction with each other, the containers being layered on top of the virtual machines. One of the goals of the SERENA project, is for the SERENA system to have the flexibility to run on a wide variety of host infrastructures, from physical servers or virtual machines, to on-premises clouds and CSP hosted environments, Docker containers provide the mechanism to achieve this goal.

As well as being used to implement the SERENA cloud services, the same Docker containerization technology is used, to encapsulate and abstract, processes on the edge gateway devices, SERENA edge services. This abstracts the SERENA edge services, distributed around the factory floor, from the underlying gateway operating system and hardware that host them. Again, this achieves another of SERENA's goals, i.e. to give the implementer of the SERENA system the maximum flexibility in how it is deployed. Using the same containerisation technology in both the SERENA cloud and on the SERENA edge gateways, means that the SERENA system, has a unified architecture, which operates and can be managed. It also facilitates the migration of services, in the form of Docker containers, from the SERENA cloud to the edge gateways. This allows services to be moved around the SERENA system to where they are needed, or can be operated most efficiently, rather than being fixed in any one location in a classic static architecture.

Docker containers are instantiated from Docker images, which are like virtual machine templates, like a blueprint of how do build and run the contained application and the resources it requires. The container is a wrapper around the instantiated image, that provides a common API to manage the containers lifecycle, as well as exposing the application contained inside it. Typically, a docker image consists of a single application, which conforms to the micro-services architecture pattern. If several applications are required, to perform a specific piece of system functionality, such as a JEE server and its web server proxy, the discrete applications are implemented as separate images, and instantiated as a stack of individual containers linked together to perform their function.

Docker containers are instantiated and run on the Docker execution engine, which must be installed on each platform that hosts Docker containers. The execution engine is like the hypervisor used to run virtual machines. There is no conflict if the Docker containers are run on top of virtualised host infrastructure; in this case the virtualised host infrastructure hosts virtual machines, and the virtual machines host the Docket execution engine, with both abstraction layers providing different, but complimentary, functionality to the overall system. The execution engine, and its associated tools, manage the lifecycle of the containers running on the host, they also manage the images and how they are downloaded and/or built.

2.3.3 Container Management

Docker images reside in a Docker image registry. Each Docker execution engine has its own local registry, which hold images downloaded or locally built. There is a common Internet registry called **Docker Hub** [3], which holds open source images create and uploaded by third parties. When an image is instantiated into a container by the local Docker execution engine, it first tries to find the image in its local registry. If the image is not found locally, it is downloaded from a remote registry; the default registry is Docker Hub. Whilst this works for certain Docker implementations, it is based on some assumptions that a) the SERENA system would always have access to the Internet; b) the images correctly implement the required functionality; c) the image configuration exposes the containers network and storage in a way that conforms to SERENA's reference architecture; and d) the images do not contain malicious code [4]. To mitigate the risks of an Internet based registry, the SERENA system implements its own system wide local registry. This does not preclude images being downloaded from the Internet but means the process can be performed in a controlled manner, with the images always being available from the local system registry. For resilience and security, SERENA production Docker execution engine should not download their images from the Internet, but instead default to the local system registry. An additional advantage of using a local system registry, is that it is possible to ensure, through comparing image digests, that the same SERENA image is being run on each local Docker execution engine, in the SERENA system, which ensures consistency of behaviour across the system services.

2.3.4 Exposing Container Resources

The server that hosts the Docker execution engine shares a private internal network, that was created as part of the Docker installation process. By default, the application within the Docker container can access the host's external network, but the container does not expose any network ports, therefore the application cannot be accessed by any external entity. It is often necessary to expose an applications network ports to make it is features accessible, such as a database's ODBC port or an applications management graphical user interface. Docker containers can be configured to expose a port when they are instantiated, and the port is mapped to an available host port. Thus, the application running inside the container can be accessed from the hosts IP address and the mapped port. The internal application port does not need to be mapped to the same port number on the host, e.g. the application may provide an HTTP interface on port 80, but this can be mapped to the host's port 8090, see Figure 6.

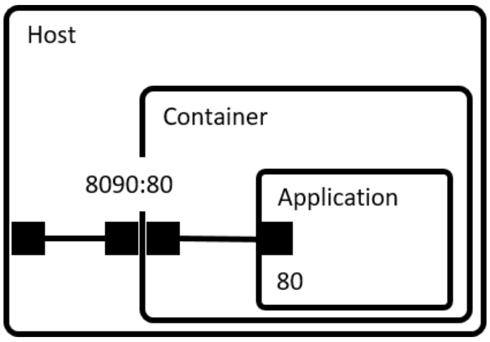


Figure 6 Container Port Mapping

This feature avoids conflicts with existing ports used by the host, but for the SERENA system it has an added benefit; some applications, such as node-red, use a standard port, 1880, to expose input nodes in their workflows. If multiple containers were running the same application image, on the same host, they would have the same internal port numbers, and a port conflict would occur. Instead each container instance can be configured to map to a different host port. So, in the node-red example, the internal node-red port, 1880, could be mapped to port 9880 for the first container, 9881 for the second container, and so on; thus, multiple discrete node-red instances, could be run on the same host, without causing a host port conflict.

By default, Docker containers are supposed to be stateless, that is they do not modify any application data internally. This is very powerful as it means that each container running the same image, are effectively clones. So, if a container dies, it can be replaced with another container running the same image. Likewise, if the system requires more capacity, additional contains can be started, sharing the workload between them. For example, multiple web proxy server can be started, and the Internet traffic balanced between them. However, many applications modify state, e.g. a database server continually alters its data and log files based on the SQL operations being performed. It is possible to store the state of an application by modifying the container's internal files, but in most cases, this is not desirable as it means that the containers are no-longer clones of each other. Instead Docker images can externalise their state by storing specific application directories outside of the container. How and where these directories are externalised is controlled by the Docker execution engine.

2.3.5 Docker Image Development

Whilst Docker images can be downloaded from a remote trusted source, they will typically need to be modified to conform to the SERENA architecture or to meet specific manufacturing process requirements. Alternatively, the images can be built locally from scratch. Either way there are two methods to build of modify images a) defining the configuration of the image in a **Docker file**, along with the configuration resources to build the image; and b) to instantiate an image in a container, then modify the application running in the container and saving the container back as an image. Whilst the former image build/modification method is the more usual, the later method has advantages in certain scenarios; the SERENA system will utilize both methods.

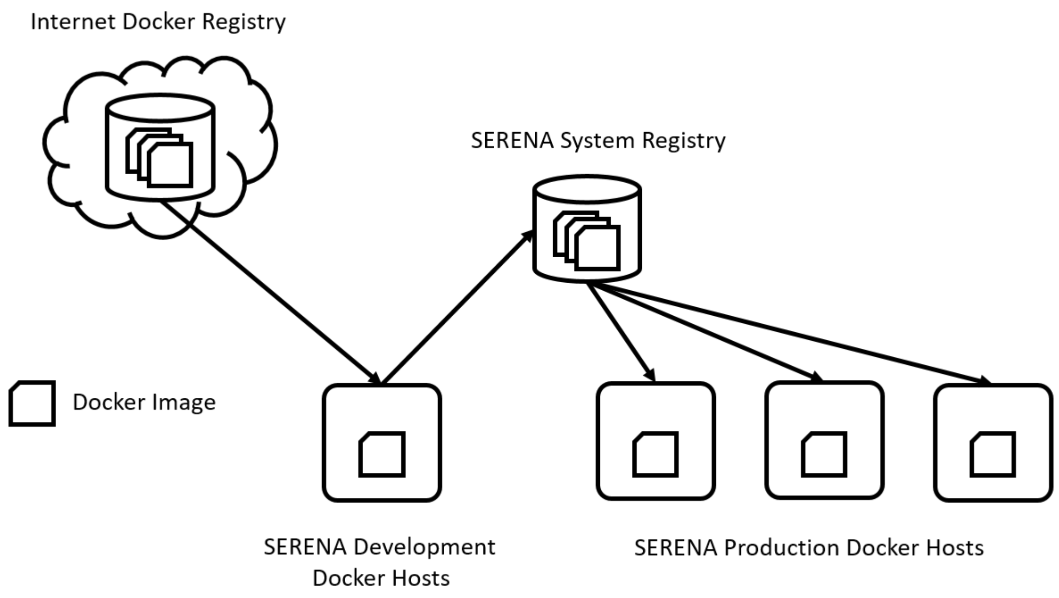

Internet Docker Registry
SERENA System Registry
Docker Image
SERENA Development Docker Hosts
SERENA Production Docker Hosts

Figure 7 Docker Development Environment

Figure 7 illustrates the concept of the SERENA Docker development environment, which consists of the Docker development host, the Docker production hosts, and the SERENA system registry. Docker images are built and tested on the development host, which is a sandboxed environment isolated from the production Docker hosts. More than one development host can be implemented to facilitate parallel development, or where complex inter host connectivity needs to be tested. The images can be downloaded from an Internet registry or created locally from scratch. As the development environment is fully sandboxed, images downloaded from the Internet can be fully verified and scanned for malicious code without exposing the production environment to potential risks. Once the images have been fully tested on the development environment, they are uploaded to the SERENA system registry, from where they can be rolled out to the required production hosts.

Typically, images for specific SERENA services would be built using a Docker file to define their construction and the required libraries, executables, and other resource; or downloaded from the Internet and modified to run on the SERENA system. Each service image is given a name consisting of the SERENA repository where it can be downloaded from, the name of the service it contains, and a sequential version number. The version number consists of three standard parts, the major release, the minor release, and the patch number. As an image is updated, its version number is incremented appropriately.

It is sometimes difficult to modify an applications behaviour by changing the Docker file, as the changes are embedded within the application and cannot be easily altered by command-line entries. In these cases, a different image modification approach is taken. The image is instantiated into a running Docker container on the development environment. Here the running application can be modified to meet the new requirements of the system. Once the desired modification has been made and tested, the container is saved as a new Docker image, with an incremented version number. The updated image can then be rolled out into production in the manner previously described. For example, a node-red process flow service, designed to handle sensor data from a specific piece of factory machinery, must be modified to collect additional sensor data. Node-red uses a graphical user interface, so its flows can be difficult to update from the command-line, especially if new specialized nodes need to be installed for the flow. Instead the node-red flow engine, the specialised nodes and the specific flow required to process the machineries sensor data, are packages as a homogenous Docket image. If the flow needs to be modified, the existing image is run in a container, modified via the graphical user interface, and saved as a new image. This technique should be avoided if possible, as it involves altering the internal state of the image but is the simplest approach in certain instances.

2.4 Container Orchestration Sub-system

Simple Docker environments, used for development and testing, can be managed manually using individual Docker commands; effectively, each Docker execution engine is managed individually. For large production environments a more holistic and automated approach is needed, which can be achieved using a container orchestrator. There are several excellent open source container orchestrators available, two of the main ones are **Kubernetes** [5] and **Docker Swarm** [6], but there are a number of open source and commercial container orchestrators available. The SERENA reference architecture uses Docker Swarm, but many of the alternatives have similar features, and in theory it should be possible to swap Docker Swarm for one of the others, such as Kubernetes.

Docker Swarm is bundled with the Docker execution engine and is a distributed peer-to-peer container management infrastructure. Docker execution engines can join a Docker Swarm as either a manager or a worker. Managers connectively control the Docker Swarm, and both managers and workers can run containers as part of the swarm. It is important to understand that Docker Swarm is a peer-to-peer system, so the swarm can be controlled by any manager in the swarm, but apart from the management functionality, every Docker execution engine in the swarm has the same status, and there is no central point of control, the swarm is managed collectively. In SERENA's case the swarm extends out from the SERENA cloud to the SERENA edge, forming a homogeneous container environment all the way to the factory floor.

Docker Swarm has a few features that help to fulfil SERENA's functional and non-functional requirements, these include a) the concept of resilient cluster services, which are location independent; b) container runtime policies, and a robust security framework; and c) the ability to extend Docker's functionality using plug-in APIs.

2.4.1 Container Services

Central to the concept of a Docker Swarm is the service. A Docker service is image that performs a specific function for a system, such as web proxy server. The swarm instantiates one of more images as containers, whose lifecycle are directly managed by the swarm; each running container is called a task.

The swarm creates the specified number of tasks, and distributes them between the available hosts, based on user defined policies, which will be discussed later in the section. If one of the tasks fails, it will be restarted by the swarm, and if a host fails its hosted tasks will be redistributed to other hosts in the swarm. Ideally the service images should be stateless, and the tasks are clones of one another, which allows them to be restarted in another location, without impacting the overall operation of the service.

In case an instantiated container fails, the local Docker execution engine takes no further action, and the application is not available. Creating a service consisting of a single task, has the advantage that if it fails, the swarm will restart another clone of the image, either running on the same host or a different on. Therefore, there is an advantage in instantiating an image as a service, even if it only has one task, as the swarm will automatically maintain the required number of instances making the service always available; and fulfilling one of SERENA's main non-functional requirements – component resilience.

Although a Docker service is made up of individual tasks, Docker containers are under the control of the swarm, they effectively operate as a single entity. As previously mention, if a task in a cluster fails, another one will be created to replace it; but the swarm can also dynamically increase or decrease the number of tasks in a service, so if the workload increases the user can modify the number of instances in the service, and the swarm will automatically start new tasks to comply with the updated policy. The swarm instructs each host running a task to download and run a specific image from the Docker registry. As the SERENA image registry resides in the swarm, as a service, and all SERENA's cloud production infrastructure hosts and edge gateways are part of the swarm, the swarm can instantiate any SERENA image from the dedicated SERENA system registry, which ensures that all hosts are running the same version of the image. By default, all tasks in a cluster share a common cluster port number, and the swarm load-balances incoming traffic between the tasks in the service, therefore a service is collectively defined by its port number. If a node in the swarm receives network message for a given service, denoted by its service port, and it is not hosting one of the tasks in a service, the node forwards the message to another node in the swarm that is hosting one of the tasks in the service, see Figure 8. SERENA concept of a service maps directly to Docker Swarm's implementation of a clustered resilient service and fulfilling another of SERENA's main non-functional requirements – system scalability.

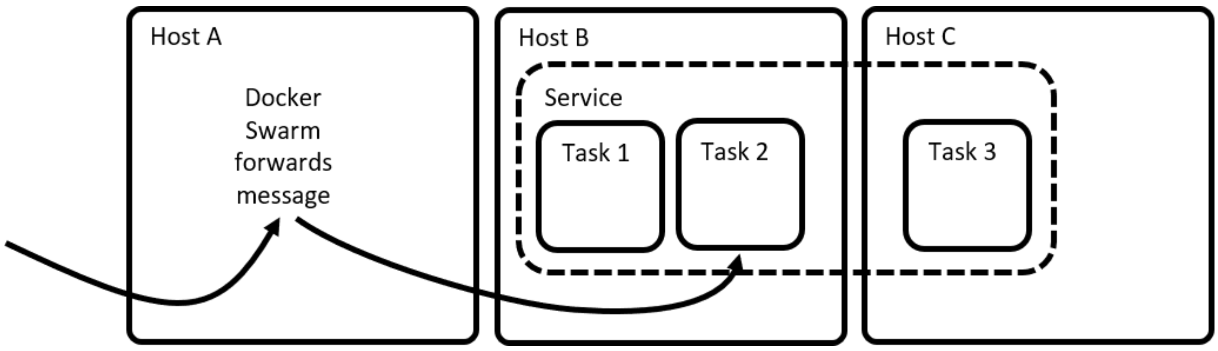


Figure 8 Docker Forwarding Service Request

One technical challenge for SERENA, is for the node-red flows running on the gateways, to be able to forward their sensor data to the SERENA ingest service, but how do they know the network address of the service. Hardcoding the IP address into the flow is not a production scalable solution. The SERENA DNS-SD service will help identify the service, resolve it to its domain name, and then resolve it to its dynamic IP address. Another implementation strategy would be to use the Docker service port forwarding functionality. The ingest service is hosted, as a cluster, on several servers in the SERENA cloud infrastructure, which are part of the Docker swarm. If the edge gateway is also part of the Docker swarm, it does not host an instance of the ingest service, but the local Docker execution engine knows where the task in the services are hosted and will forward any incoming message to one of the tasks. So, if a node-red flow image running in a container on an edge gateway, sends a message to its own host using the ingest services common port number, the host should automatically forward the message to an instance of the ingest service.

2.4.2 Container Management Policies

Docker manages service by means of **policies**, e.g. policies can be setup to only run tasks on specific hosts, to run a specific number of tasks in a service cluster, or that every instance of a host with a given policy label should run a single instance of a specific service. For example, if we have an edge gateway that monitors a given piece of machinery, it needs to host a specific node-red flow image to process the sensor data from that machinery; by defining a Docker policy label on the gateway, which identifies the required image, Docker swarm will ensure that the require image is downloaded and run on the gateway. As any number of policies can be defined for a swarm host. All Docker images that need to run on a specific host can by defined and automatically deployed.

Docker Swarm also can perform a staggered rollout for an updated image. For example, if a service image was updated and tested, in the development environment and uploaded to the SERENA system registry, Docker swarm can be used to perform a staggered rollout of the new version sequentially to every swarm node hosting a service task. In this way, production service updates can be, automated and rolled out in a controlled manner.

Docker Swarm has a strong security framework based on policies and certificates to authenticate entities and is like Archers distributed security framework. The intension for SERENA is to extend the Docker Swarm security framework to meet SERENA's security requirements.

2.4.3 Docker API Plugins

Docker and Docker Swarm provide an extensive set of APIs and plugins, which allow the functionality of the container management system to be extended and integrated into the broader SERENA system. For example, Docker provides basic externalisation of storage volumes, from the Docker containers, but this functionality can be enhanced to implement more sophisticated storage drives, which can implement virtual storage solutions. SERENA will make use of the storage volume plugin to develop its own plug-n-store storage driver. Docker and Docker Swarm also provide an extensive and secure management API, which enables third party products to extend and simplify the management of the infrastructure.

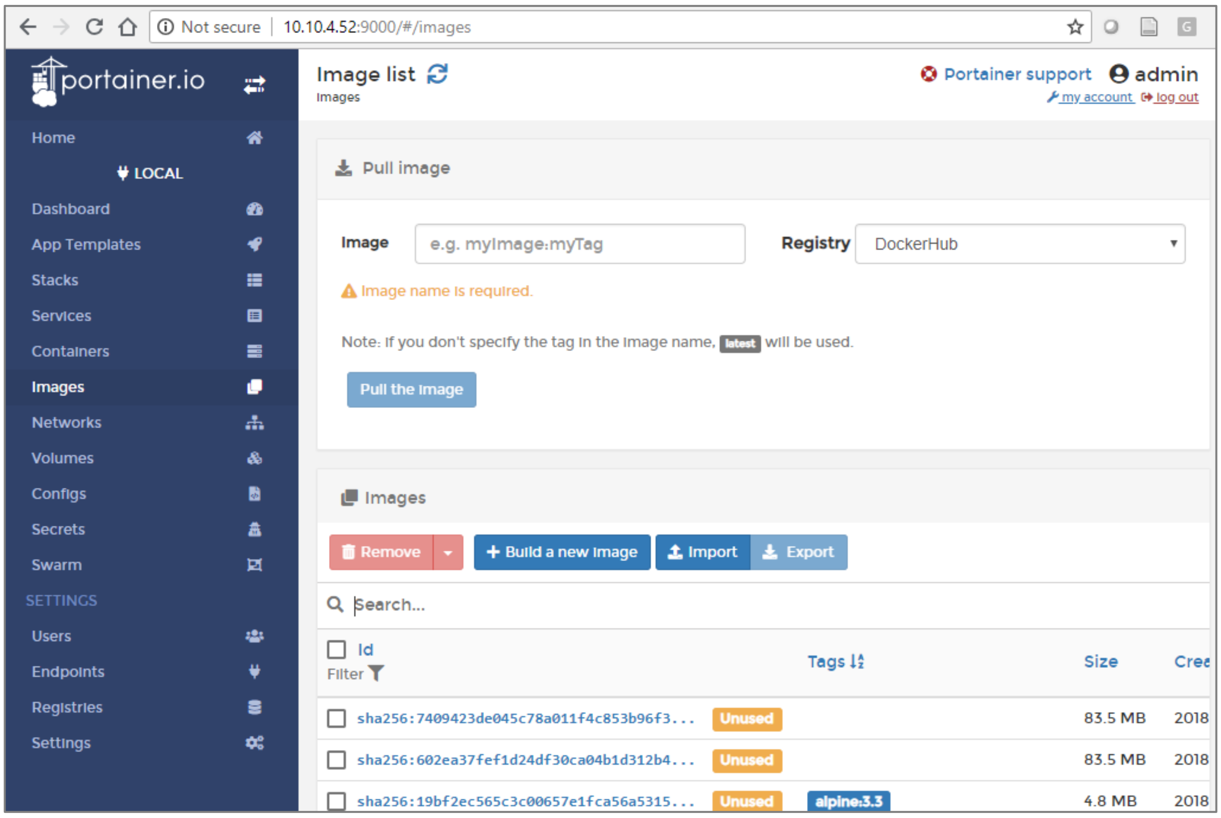


Image: e.g. myImage:myTag
Registry: DockerHub

Image name is required.

Note: if you don't specify the tag in the image name, latest will be used.

Id	Tags	Size	Crea
sha256:7409423de045c78a011f4c853b96f3...	Unused	83.5 MB	2018
sha256:602ea37fef1d24df30ca04b1d312b4...	Unused	83.5 MB	2018
sha256:19bf2ec565c3c00657e1fca56a5315...	Unused alpine:3.3	4.8 MB	2018

Figure 9 Portainer Orchestration UI

Portainer [7] is an open source graphical user interface to control the operation and orchestration of the container environment, and directly plugs into Docker and Docker Swarm's APIs. Portainer will be used to manage the underlying infrastructure of the SERENA cloud and the edge gateways. Figure 9 shows the Portainer graphical user interface, which greatly simplifies the management of the containerized infrastructure. For example, the number of tasks running in a service can be increased simple by going to the appropriate service and incrementing the spinner control. Portainer is itself implemented as a resilient service and is one of the auxiliary services implemented by SERENA.

2.5 Ingestion Sub-system

The ingestion service is the connection between the SERENA cloud and the SERENA edge gateways. It receives sensor data and metadata from the gateways and stores it in the SERENA cloud for subsequent processing by the SERENA analytic service. The ingest service is implemented as a resilient and saleable cluster of NiFi data process flow engines. Each engine is enclosed in a contained that runs as a task under the control of the Docker Swarm infrastructure. If a give task fails or the overall service needs to be scaled up to handle increased sensor data from the factory floor, Docker Swarm will start new instances of the task.

The ingest service exposes a RESTapi endpoint over an SSL connection, which uses the SERENA security service to mutually authenticate the entities and validate that the gateways are authorised to send data to the service. All the tasks in the service share a common service port number, and incoming traffic is load balanced between the available tasks in the server. The actual process flow is imbedded within the engine and wrapped as a single container image running as a Docker task. As the implementation and operation of the data process flow engines are stateless, any task in the service can handle incoming traffic from any gateway.

The purpose of the ingest server is to receive sensor data and metadata, from the edge gateways, as a single message, and split the data and metadata into two repositories, the data repository service, and the metadata repository service. It also cross references the data and metadata between the two repositories. The data repository service is the Cloudera implementation of Hadoop, which provides an HDFS data store. The metadata repository is a combination of relational database, and a semantic layer on top of it, capable of storing and referencing the metadata via both SQL and SPARQL queries. The message is received in a canonical JSON-LD format, which is a self-describing message structure that contains the data and a semantic context for the data.

The sensor data can be in a raw data format, as received from the sensor, or smart data format, which has been pre-processed by the edge gateways to produce an aggregated feature set. The raw sensor data is typically much larger than the smart data and is only forwarded to the SERENA cloud when deeper analysis is required. The metadata contains data relating to how and where the sensor data was acquired, as well as information relating to the specific piece of plant being monitored and its operation; this data provides addition contextual information about the sensor data and is used by the analytics service to search for relevant data and enrich its analysis.

The ingest service extracts the smart data and/or raw sensor data from the incoming message. Both types of data are converted into sets of comma delimited strings and stored in flat files in the data repository. Due to the size of the raw sensor data, it is stored in individual files, based on the collection window metadata. Smart data may only consist of a single string, and thus is typically appended to an existing file, whose collection window is defined in the metadata repository. If a new file is created, it is given a unique UUID file reference, the file reference of existing files is retrieved from the metadata repository. The ingest service also extracts the metadata from the incoming message and is converted into an enhanced MIMOSA schema data format and stored in the metadata repository. The metadata contains information providing context for the sensor data, such as the manufacturing operation being performed by a robot over the data collection window. The metadata allows the analytics engine to retrieve data based on the specific operation or configuration of the plant. The data file reference is included in the metadata, so that the SERENA services, or external authorised systems, can retrieve the required data. Thus, one of the functions of the metadata repository is as a smart index into the HDFS data store.

2.6 Repository Sub-system

The data repository service stores the sensor data collected from the factories manufacturing process. The data is received into the SERENA cloud and stored in the repository as comma delimited flat files, however other filetype can be supported. The service is implemented as a Cloudera cluster running on top of a Docker Swarm service cluster, so there is a one-to-one implementation mapping between a Cloudera node and a Docker container. This enables the scalability and resilience of the Docker Swarm infrastructure, combined with the Hadoop advanced functionality of Cloudera.

Sensor data stored in flat files on the data repository service will be cross referenced to metadata in the SERENA metadata repository service, so files can be retrieved from the data repository using SQL or SPARQL queries performed against the metadata repository. The data repository service can also store files from other sources, such as the results from the analysis service. When the files are stored in the repository, a matching entry will to be added to the metadata repository to cross reference the file to its metadata.

The metadata repository service stores the metadata associated with the data collected from the factory manufacturing processes, as well as other types of metadata, such as configuration data of the factory. The service is implemented as a resilient Docker service cluster. The metadata repository schema is based on the MIMOSA data model. The full MIMOSA data model covers many business areas, such as configuration management and resource management, and includes hundreds of connected tables; however, SERENA only requires a subset of these tables. Only the required tables will be implemented to support the SERENA functionality. Similarly, many of the MIMOSA tables contain optional fields which are not required for the SERENA system, so, to simplify the implementation, these fields will also be removed. SERENA needs to implement concepts that are not currently supported by the MIMOSA data model, in these cases, the MIMOSA data model will be extended to support the SERENA requirements.

The metadata repository will consist of a relational database with a semantic layer on top of it. The metadata repository service will expose two APIs, an ODBC endpoint and a SPARQL endpoint. The ODBC endpoint is a standard relational database connection and will allow other SERENA services and external entities to perform SQL operations on the metadata. The SPARQL endpoint provides a more expressive semantic interface to the metadata. Both APIs fundamentally access the same metadata, and applications can choose the interface that best meets their requirements, however as the semantic interface is more expressive, so some metadata will only be available via this interface. The interfaces support the full range of CRUD operations, but access to operations and classes of metadata are dependent on the authorisation level of the requesting system.

2.7 Processing Sub-system

It is known that the most popular languages for data scientists are **Python** and **R**. Both provide many modules or packages to solve data problems. But these tools traditionally process data on a single machine where the movement of data becomes time consuming and moving from development to production environments requires extensive re-engineering.

To help address these problems, Spark [8] provides data engineers and data scientists with a powerful, unified engine that is both fast and easy to use. This allows to solve data analyses problems interactively and at much greater scale.

Spark also provides many language choices, including Scala, Java, Python, and R. One of the most used components developed in the Apache Spark Open Source ecosystem is **MLlib** [9], a general-purpose library, providing algorithms for most use cases. The key benefit of MLlib is that it allows data scientists to focus on their data problems and models instead of solving the complexities surrounding distributed data (such as infrastructure, configurations, and so on).

For the above-mentioned reasons, and the presence of Spark in the Cloudera distribution, the design the SERENA Cloud Platform foresees (but without defining strong technical constrains) the adoption of Spark as the batch/stream processing engines, and Python as the preference language to build the analytics algorithms on top of the data arriving to the cloud repository.
Further details on the analytics framework can be found in D3.1 and in the other outcomes of WP3.

2.8 Plug-n-Store Sub-system

SERENA's plug-n-play storage facility extends Docker's external volume functionality by implementing a SERENA storage driver. The storage driver is a key component that separates the SERENA subsystem components from the underlying storage implementation. SERENA uses container technology to encapsulate discrete parts of its functionality, such as databases and analytics engines. This makes the SERENA system highly dynamic, scalable, and resilient, as each subsystem can be implemented as a cluster of stateless clones. The state of the cluster is externalized from the cluster containers by means of the SERENA storage driver, which maps the container's storage state to virtual volumes, where individual data assets are represented as storage objects. The storage driver, and the underlying storage virtualization infrastructure, synchronise access to the storage objects. When the individual containers in the subsystem cluster change location or new containers are instantiated, the virtual volumes are made available to the containers at their new location.

2.9 Internal communications

The following diagram depicting the high-level communications/data flow between the system and subsystem components developed within WP5.

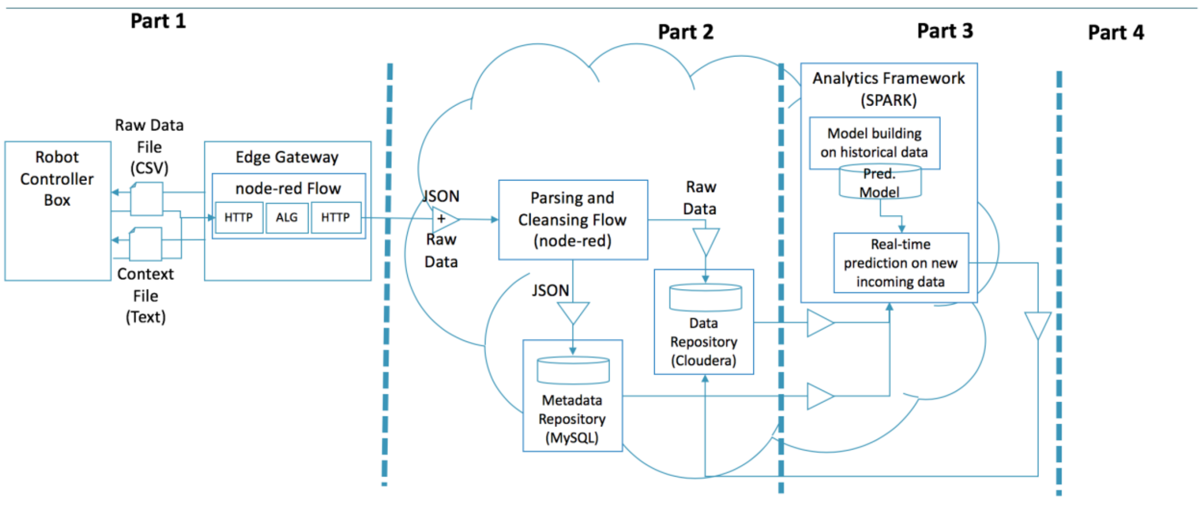

Part 1
Part 2
Part 3
Part 4
Robot Controller Box
Raw Data File (CSV)
Context File (Text)
Edge Gateway
node-red Flow
HTTP
ALG
HTTP
JSON
Raw Data
Parsing and Cleansing Flow (node-red)
Raw Data
JSON
Metadata Repository (MySQL)
Data Repository (Cloudera)
Analytics Framework (SPARK)
Model building on historical data
Pred. Model
Real-time prediction on new incoming data

Figure 10 Main information flow related to the SERENA Cloud Platform

2.10 Hardware architecture

2.10.1 Development Infrastructure

The infrastructure designed for the project pilots is based on the Hadoop ecosystem as far as the saving, the management and the analysis of big data is concerned. To simplify and speed up the installation and configuration of the environment we foresee to use a development infrastructure hosted in a dedicated tenant provided by ENG only for development purposes. This tenant is equipped with a software stack based on Cloudera Manager [11]. Specifically, the main components being selected are:

- HDFS
- YARN
- Spark
- Hive
- Impala
- HBase
- OOziei
- Zookeeper

The data flow coming from the edge gateway must be saved both on HDFS and on a relational database using a Mimosa data model subset. To this end Apache Nifi will receive incoming data, and thanks to dedicate flows, aimed at verifying the goodness and adequacy of the data received, data flow will be saved on the Hadoop file system in a raw format and simultaneously on database containing the metadata describing the raw data received. On top of this data, the analytics component will be able to start processing both data at rest and data in motion.

2.10.2 Pilot Infrastructure

The SERENA cloud is implemented in a dedicated SERENA tenant cloud on DELL's Infinite testbed, its components can only be accessed via an isolated virtual network implemented using VMware's NSX facility; access security is provided over a secure client channel. As the SERENA cloud can only be accessed over a secure channel to the client, even edge gateways must implement the secure channel. The cloud consists of several VMware virtual machines, which host Docker containers. All SERENA's cloud based functional components are implemented in containers, to provide agility of deployment and abstraction from the underlying physical or virtualisation infrastructure.

The hosts that make up the SERENA cloud are VMware virtual machines running the Ubuntu operating system; the hosts are a mixture of desktop and server implementations of Ubuntu version 18. The mixture of desktops and server hosts allow for different component requirements to be supported by the SERENA cloud. The Ubuntu variant of Linux was selected as the host operation system because it is open source and well supported in the IT industry.

3. System interfaces

3.1 Human – machine interfaces

3.1.1 3D viewer

3.1.1.1 Purpose

The purpose is to show and present in an effective and intuitive mode the data and maintenance operations with a virtual 3D view of the involved machinery/equipment, using the information coming from the results of the predictive maintenance algorithms of the SERENA platform. The data visualization will be used as a SaaS application, so it will be developed as a web application that can be deployed on a cloud. A WebGL HTML5 Unity 3D interactive application will be created, to show in a web browser, the corrective actions and guidance for maintenance operator within the factory.

3.1.1.2 Inputs

To better display the goals of the predictive maintenance, with an effective and intuitive visual impact, it is important to have at least a simplified but realistic 3D view of the machinery/equipment, showing the maintenance guidance and information directly on their mechanical, electrical etc. elements/parts.

The main required inputs are detailed below:

- 3D CAD simplified model export of the involved machinery or system (STEP format); this will be used in the construction of the virtual scene, porting it from the vector system to the rendering one (mesh triangulation), to make the virtual scene as light and usable as possible. In this way the engineering information of the CAD model are lost, so the VR/AR scene can be distributed without risk.
- User defined messages to show warning and alert alarms directly on the part involved of the system to immediately capture the operator's attention and provide an intuitive indication of what he will have to check.
- Preventive and predictive textual information to be displayed by selecting the involved part of the machinery/robot/system, which indicate high-level maintenance operations.
- Maintenance technical manuals from which extract the detailed maintenance procedure for the involved components and systems.

Practical tips and suggestions from expert personnel to better and accurately identify the maintenance activities.

3.1.1.3 Outputs

The development will focus on Unity 3D WebGL technology. This allows Unity to publish content as JavaScript programs which use HTML5 technologies and the WebGL rendering API to run Unity 3D content in a web browser. The applications will consist of interactive virtual scenes in which the machinery/equipment will be displayed in 3D, adding information coming from data collected and processed in the SERENA platform.

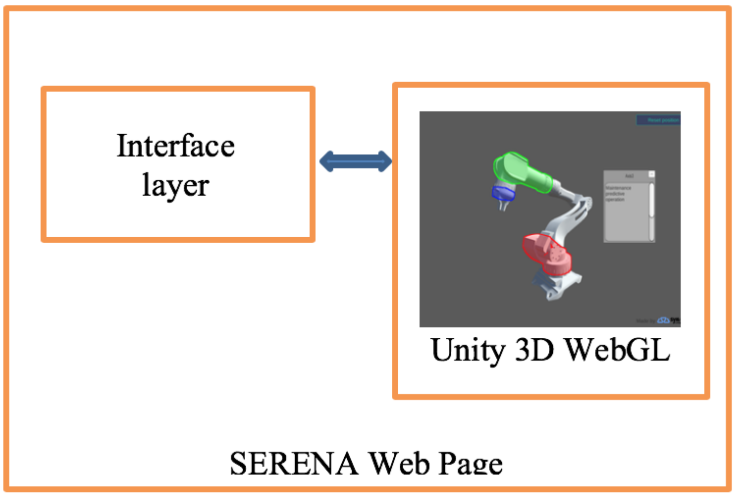


Figure 11 SERENA 3D viewer web-based visualization

The interaction with the maintenance operator and the Unity 3D virtual web scene consist on these features:

- Move/rotate/zoom of the 3D model in the space of the virtual scene
- Show in a visual mode (set colour/blink mode/led status indicator etc.) to the operator any alarms and anomalies directly on the part of the machinery which have problems, to capture the operator's attention and better understand on which part of the system he will have to operate
- Report in an informative panel the textual instruction and corrective action to be performed
- Display maintenance technical manuals
- Display virtual 3D interactive maintenance procedures, to make maintenance procedures more intuitive and effective even for less experienced personnel

This layer will provide the necessary methods to communicate and exchange information from the SERENA web pages to the Unity 3D WebGL application and vice versa.

3.2 External interfaces

All the communication from the edge gateway to the cloud platform will be further discusses in the scope of D2.1, please refer to this deliverable to complement the platform design provided within this document.

4. Integrity controls

Whenever data of any kind is sampled, acquired, or read from a source, it must be validated to ensure the quality of the measurement and the derived data. Especially in long term data capturing like done in SERENA, where many different steps of data transformation and analysis are performed subsequently, it is very important to include validation mechanisms into the dataflow.

The most important task for the SERENA DataBox is to ensure the correct timestamping of the data and a proper synchronisation of all component clocks. To realise this in the SERENA system, different protocols and other methods will be discussed to achieve enough accuracy for the timestamping of the collected data.

The validation of each measured/sampled value is another issue. Even in modern measurement systems, outliers occur and must be detected by a suitable filter algorithm as soon as possible. Which algorithms can be used and included/executed in the DataBox Software is still subject to discussion within WP2.

5. Operational scenario

The SERENA project is focused on the maintenance advanced techniques. The actual operational scenario provided by COMAU is based on scheduled maintenance using indications provided by supplier manual. The scheduling is contained in a machine ledger. Maintenance operations are planned during production stops to avoid downtime, therefore, preventive maintenance is very conservative, and machines are over-maintained. This approach does not consider machines real conditions and it could be uselessly expensive.

The purpose of the project is to create a monitoring and analysis system which allows the exploitation of all the components' life before the breakdown, enabling the condition-based maintenance and the reduction of maintenance costs increasing the equipment availability. Thus, the SERENA project will **avoid the over maintenance of the components** due to the preventive maintenance activities.

The purpose is to **predict the possible failures** of robots which is executing repeated operations. This will be achieved by gathering data through multiple sensors and processing all these measurements to create accurate models adequate to the real one. Furthermore, the scheduling of the maintenance operations is quite important in a production line both in terms of cost and time. Thus, apart from predicting accurately the failure, SERENA project will try to take into consideration the specific needs of the production line to optimize the maintenance process and plan the stoppage for maintenance.

Moreover, the **maintenance flowchart will be updated** to reduce the actors involved during a possible failure. More specifically, a possible failure or the health status of its components can be observed using a software. This software will be able to monitor the signals and measurements and identify a possible abnormal behavior. Thus, the physical existence of the operators is not needed to validate the error of the handling process. Furthermore, the implemented software can help the maintenance engineer, providing helpful decision proposals or even taking full control if instructed to do so. In this way, the maintenance activities to be performed can be instructed with a more precise and fast way to reduce cost and time in the production line.

A COMAU software can collect raw data using FTP protocol from the Robot Controller and send them to a centralized database or a Cloud using the standard protocol HTTP Rest or MQTT over a secure channel. The software developed for the robot analysis can access to the raw data and send some features to the same database or cloud. In the Cloud solution, some appropriated security policies must be implemented. In the on-premise solution, the security policies depend from the other aspects (e.g. physical access to the wired network for the unauthorized people).

To sum up, the SERENA system and architecture will be able to securely get data from the manufacturing plants – using scalable and cross-platform solutions – and use them to build a virtual status of the components to predict future faults and schedule maintenance activities only when it is necessary improving both the availability and the maintenance costs.

6. Conclusion

This deliverable described the first results of the tasks T5.1, T5.2, T5.3, T5.4 and T5.5, providing the high-level design of the SERENA Cloud Platform and outlining its implantation (to be further refined in WP2, WP3, WP4 and WP5 itself) before starting the piloting and validation activities within the WP6 scope. These results have been driven by earlier work and results from WP1, notably the analysis of requirements and reference applicative business scenario.

The baseline of the SERENA implementation can be existing open source frameworks, platforms, and tools, including background assets belonging to project partners. The integration of these tools has been designed to achieve the project objectives (e.g. the plug-n-play approach), taking also into account the commodities needed for easing the deployment (e.g. using Docker) and lifecycle management of such a cloud platform in different cloud infrastructure, provided by different CSP or even using an on-premises installation.

Overall, this document provides a sound basis for development and integration activities that will be performed as part of technical work packages, notably WP2, WP3, WP4 and WP5. It defines the main components and structuring principles of the SERENA Cloud Platform, also in terms of implementation tasks: this will ensure that inter-dependant activities can be streamlined in the best of ways. Hence, the document will be a valuable input for all partners engaged in technical design and software development and integration to release the overreaching SERENA solutions.

The SERENA Cloud Platform design will also drive the implementation of use cases in the scope of WP6. In general, use cases might require some customization, however not impacting on Platform components described in this document. Identified components might be extended, provide they are backward-compatible – i.e. systems using the standard interfaces are not affected.

It should be noted however that development and integration activities are likely to introduce revisions to this Platform design, resulting from new findings and technological choices made during the detailed design and implementation of individual components, as well as changes in requirements and use cases.

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Annex A – Requirements extract from D1.1

This annex provided an extract of D1.1, focusing on the requirements foreseen for the WP5 outcomes.

Functional requirements				
Id	**Name**	**Description**	**Requirement**	**Priority**
1	Ingestion layer	This layer deals with the task of collecting data from several sources, performing some pre-processing workflow, and saving them in the Data Infrastructure.	The data ingestion can gather data in real time fashion as well as in batch, depending on the source and on the use-case. The ingestion layer will provide API for streaming data (e.g. using REST services with data represented in JSON), as well as capabilities to use the Claim Check Pattern for asynchronous ingestion data transfer. The ingestion of large amount of data can be scheduled and gets data from FTP directories where files collected from the plant are available (e.g. on daily basis).	High
2	Storage Layer	The storage layer is responsible for the persistence of raw data collected by the ingestion process and data which is the result of the distributed processes and analysis within the data lake. There are different storages that can be used, such as distributed file system or NoSQL database.	Distributed file systems will be used to make persistent large amount of data, while relational or NoSQL database can be used for metadata of fine-grained feature sets. HDFS will store incoming data from the ingestion process and the datasets computed by the algorithms. Data archived on the distributed file system is formatted properly and partitioned by equipment, year, and month.	High
3	Batch Processing layer	Once data is landed on the cloud storage it must be processed, cleaned, and analysed.	Data should be processed by the distributed framework, capable of managing huge amounts of data, dealing with cleaning tasks as well as analysis through custom algorithms for predictive maintenance objective. The batch jobs are scheduled and executed evenly across the cluster every day. For instance, this layer could perform Spark jobs running on Yarn Hadoop Resource Manager.	High
4	Stream Processing layer	Streaming pipelines can be developed, for instance by using Spark Streaming libraries.	It allows data to be filtered, processed, aggregated, and analysed event by event so that real-time results are available.	Medium

5	Data Access (SQL) layer	To access files stored in the data infrastructure, as a result of the advanced analytics run by the batch processing layer, a SQL layer is configured.	This tool will act as a gateway for applications that need to publish information generated in the data lake through a front-end UI, as well as perform some additional query, benefitting from the parallel computation that can be run on the platform. Impala could be one of tool that allows Business Intelligence application to perform insights on the cloud storage	High
6	Scheduler	Scheduling and orchestrating activities.	This layer should address the scheduling of batch jobs and orchestrate them through a proper workflow of different actions. Within the current Hadoop-based scenario, this task can be dealt by Oozie.	High
7	Resource Manager	All Big Data distributions allow distributed jobs to be executed in the cluster, where data is hosted.	Different jobs are run on the available nodes in the platform, considering the resources in terms of RAM and CPU and the data locality of the partitions of the files to be processed. All these tasks could be managed and scheduled by YARN, which is the resource negotiator of Hadoop.	High
8	Cluster Manager	Every Big Data distribution offers a tool to manage the cluster, in terms of hosts and services.	A web application, made for Administrator, should enable them to master the platform.	High
9	SERENA Communications Broker (SCB)	The SCB will be providing the infrastructure needed to make all the other modules of the SREEAN ecosystem talk each other.	The SCB will act as a proxy forwarding server between SERENA components.	High
10			The SCB will provide a HTTPS/REST endpoint for the proxy forwarding server.	High
11			The SCB will add the original source of the message, to the message, to provide the provenance of the data	High
12			Data from the sender will be transferred in the body of the REST message in JSON format.	High
13			Larger amounts of data can be attached to the REST message as MIME files. The content of the MIME file is undefined and will be forwarded to the target unaltered. This provides a mechanism for components to exchange images, binary files, PDFs, etc.	Medium
14			The SCB will implement publish and subscribe functionality, which will	High

			decouple the sender from the target by means of a topic subscription, see http://www.enterpriseintegrationpatterns.com/patterns/messaging/PublishSubscribeChannel.html	
15			The sending component will specify the topic of the message in the URL, in the form "/topic/<topic>"	High
16			The SCB will provide a REST API for senders to request a list of all valid topics that they are authorised to communicate with.	Medium
17			The SCB may be enhanced by the "Round Robin" functionality, http://www.workflowpatterns.com/patterns/resource/push/wrp16.php. In the SERENA form of Round Robin functionality, the target components will subscribe to a topic. If there is one subscriber, a message posted to that topic will be forwarded to that subscriber. If there are multiple subscribers, a message posted to that topic will be forwarded only one of the subscribers, and the next message will be sent to a new subscriber, in turn. If there are no subscribers, the message is queued for a period until a subscriber register with the SCB. This is a scalable pattern designed to decouple the sender and the receiver, whilst providing a robust and scalable system	Medium
18			The SCB may be enhanced by Claim Check functionality, http://www.enterpriseintegrationpatterns.com/patterns/messaging/StoreInLibrary.html. In the SERENA form of Claim Check functionality, the sender specifies the repository the data is to be stored in and the target/topic to be notified when the data storage is completing; the target/topic is sent a claim check token by which they can retrieve the data from the repository.	Low
19			The SCB will implement lifecycle management of data that has been stored under the Claim Check functionality, including i) an expiry data after which the data will be deleted; ii) whether the data should be deleted after it has been claimed; iii)	Low

			whether the claimer has the right to access the data	
20			The SCB will provide message transformation functionality to convert one message format into another. The transformations will be limited to data in the body of the message and will support a restructuring of the data or conversion to another message format, such as XML.	Medium
21			The SCB will provide an API to able SERENA components to register with the SCB's component repository. The API will be in the form of a REST endpoint.	Low
22			The SCB will ensure that all communications between components (including edge devices) are over secure channels, typically using HTTPS or TLS	High
23			The SCB will ensure that all communications traffic, passing through the SCB and based on the security policies, will i) be from an authenticated source; ii) will only be forwarded to authorised targets/topics for that specific sender; and iii) the target is authorised to receive the message from the sender.	Medium
24			The SCB will keep an audit log of all communications traffic between components (communications event only, not data).	Medium
25			The SCB will periodically send the communications audit log to the SERENA Security component.	Medium
26			The SCB will provide a REST interface to monitoring and management its operations. Only authorised components and HMIs will be allowed to access this interface.	High
27	SERENA Repository API (SRA)	SERENA Repository API (SRA) will provide a common interface, regardless of the underlying storage implementation.	The SRA will implement a REST endpoint for the "algorithm and initialization parameters" repository. The repository holds all algorithms, parameters, etc. user by the predictive maintenance/Cloud AI components.	High
28			The SRA will implement a REST endpoint for the "historical data" repository. The repository holds sensor data (either raw data or smart	High

			data) sent from the Edge to the Cloud, which may be required for historical reports, stochastic analysis, etc.	
29			The SRA will implement a REST endpoint for the "metadata" repository. The repository holds all metadata relating to the sensors, which comprises of sensor metadata about the actual data being collected, such as the measurement frequency, and sensor context metadata about the situation/purpose of the sensor, such as the piece of machinery it is measuring	High
30			The SRA will implement a REST endpoint for the "scheduling information" repository. The repository holds all data relating to the scheduling of events within the **SERENA** system, such as uploading data from Edge devices.	High
31			The SRA will implement a REST endpoint for the "documentation and media" repository. The repository holds documents, videos, images, etc. user by the **SERENA** system, or provided to users of the system.	High
32			The SRA will implement a REST endpoint for the "component" registry. The registry holds a list of all component instances in the **SERENA** system, their type, and details on their communications channels. The registry is used by the **SERENA** communications broker to manage message traffic between components.	Medium
33			The SRA will implement a REST endpoint for the "security" repository. The registry holds all **SERENA** users, components, roles, and policies. It also contains the audit logs collected by the **SERENA** Communications Broker.	High
34			The SRA will store data in the form of data objects. A data object can also be a file or dataset. Many data stores, such as S3, ECS and HDFS, intrinsically handle data object. Where the underlying data store is a relational or column database, a facility will be provided to insert or retrieve data from the underlying implementation.	High
35			The SRA will ensure that users or components are authorized to read or	High

			write to specific data objects, or types of object.	
36			The SRA will encrypt data objects at rest, based on defined security policies. This feature is reliant on the technology of the underlying data store supporting encryption functionality.	Medium
37			When writing a data object to a repository, a component may request the SRA to encrypt the object.	Low
			The SRA will provide a REST interface to search the repository for a data objects that match a specific type or pattern. The requester will be provided with a list of matching data objects. If the list is too long, the requester will be provided with a truncated list, and warned to provide a more specific query. The type of search format will depend on the nature of the data objects in the repository. For example, the document and media repository may be restricted to text searches, whereas the metadata repository may use a more expressive query such as SPARQL	Medium
38			The SRA will provide data object facilities to manage its lifecycle, such as the data object is immutable or is to be deleted once it has been read at least once.	Medium
39			When writing a data object to a repository, a component may specify optional lifecycle parameters relating to the object, such as an automatic deletion date.	Low
40			The SRA will provide a REST interface to monitoring and management its operations. Only authorized components and HMIs will be allowed to access this interface.	High
41	SERENA Security Manager (SSM)	SERENA Security Manager (SSM) provide secure access to internal data and processes, to users and systems.	The SSM will conform to the corporate security policies.	High
42			The SSM will authenticate all users of the **SERENA** system, assign them roles, and assess control policies to data and processes, which are contained in the user's profile. For	High

			example, a maintenance engineer may be able to see the results of predictive analysis process but is not authorized to run the analysis process.	
43			Where available the SSM will connect to existing corporate user authentication and authorization systems, such as Active Director or LDAP, as the primary source of authentication and authorization information. The SSM will defer security policies to the corporate security system, where it exists. This means that if a user's policies are changed in the corporate security system, the changes will be reflected by the SSM.	Medium
44			The SSM will implement a basic user authentication and authorization system to be used if no corporate system is available.	High
45			The SSM provides additional security policies that are specific to the **SERENA** system. For example, the policies that control access to data types in specific repositories.	High
46			The SSM will authenticate all component instances that make up the **SERENA** system. When a new component is instantiated, it must be authenticated and allocated to role within the system. The role defines what data the instance is authorized to access, and which processes it is allowing to invoke, which are contained in the instance's profile.	High
47			The SSM maintains all **SERENA** roles and security policies in the security repository, in the form of profiles. Functionality will be provided for the system administrator to view, add, amend, and remove security roles and policies.	High
48			The SSM security policies will cover the access control to data artefacts, based on a user's or component's role. Data artefacts will be allocated a default role based on their type, but these roles can be overridden for specific data artefacts. For example, an	High

			instruction manual may be accessible to system users, but manuals containing restricted information, such as access codes, may only be accessible to maintenance operators.	
49			The SSM security policies will cover the encryption of data artefacts, based on the policies for specific data artefact types, but these policies can be overwritten for individual data artefacts.	High
50			All data in transit will be transmitted over secure encrypted channels, such as HTTPS and TSL, with at least 256-bit encryption.	High
51			Where defined by security policies, data at rest will be stored with at least 256-bit encryption. This may be superseded for specific implementation environments. For example, a **SERENA** system implemented on a CSP's public Cloud may have to conform to their specific security schema. Encrypting all data artefacts may not always be necessary or efficient. For example, there is no reason to encrypt a product manual that is publicly available on the Internet and doing so may preclude artefacts from being searched in the repository.	High
52	Sensor Data and Metadata	Sensor and machineries will produce raw data that eventually could be turned into smart data; in any case metadata will be added to them to add context or static information useful to exploit them in the overall system.	Sensor metadata describes characteristics of the raw data collected by the Edge devices and forwarded to the **SERENA** Cloud. A sample of the types of metadata includes i) sampling frequency of the sensor; ii) the physical property being measured; iii) the measurement units; iv) the time and data of collection; and v) notification of missing data samples.	High
53			Sensor context metadata describes context of the sensor and is typically defined in the **SERENA** Cloud and forwarded to the Edge devices. A sample of the types of metadata includes i) the ID of the sensor; ii) the piece of machinery it is measuring; iii) the status of the sensor; iv) the purpose	High

			of the measurement; v) the location of the sensor on the machinery; and vi) the location of the machinery.	
54			The metadata will have multilingual support.	High
55			The metadata will support dynamic and extensible schema(s).	High
56			The **SERENA** system will define one or more new, or preferable existing, metadata schema(s) to define the entities, terms, and relation that makeup the **SERENA** system.	High
57			The sensor metadata and sensor context metadata will be using a defined using Linked Data as defined by the W3C standard	High
58			The metadata will message format will be JSON Linked Data (JSON-LD)	High
59			Both the **SERENA** Cloud and the Edge devices will have metadata repositories. The **SERENA** system will implement a mechanism to exchange metadata between Edge devices and the Cloud repositories. The **SERENA** Cloud repository will hold a copy of all metadata for the system, whereas the Edge device will only contain metadata that relates to its sensors and the manufacturing processes it manages. The metadata exchange mechanism will ensure that the various repositories are kept eventually consistent.	High
60			The sensor data will be linked to the sensors metadata by means of a universally unique identifier.	High
61			The sensor data will be aggregated into data packages by the Edge device and pushed to the **SERENA** Cloud or pulled from the Edge device by the **SERENA** Cloud.	High
62			The sensor data can be sent in the body of a REST message in JSON format or attached to the REST message in a supported MIME format.	High
63	Component Container	SERENA Component Container (SCC), see individual functional	The **SERENA** components will, in general, be deployed in a containers or nested containers.	High

64		requirement priority. Only high priority items are planned to be delivered, medium and low priority items are stretch goals, and will be implemented if time allows.	The **SERENA** components will be defined as templates, which can be instantiated as the system requires their services.	High
65			The **SERENA** components instances will be deployed in managed clusters, to ensure that their common functionality is both scalable and resilient. Where possible the rest of the **SERENA** system should access the cluster as a single entity.	Medium
66			The SCC will provide functionality to enable inter-container communication	High
67			The SCC will police inter-process communication based on component policies defined by the **SERENA** Security Manager. This principal will provide multiple layers of security for the **SERENA** system.	High
68			The SCC will manage the lifecycle of component instances by managing the lifecycle of the underlying containers.	High
69			The SCC will be able to group and manage sets of containers instances as a single functional unit. For example, a component may be broken down into several function sub-components, of different type, that function.	High
70			The SCC will provide a management interface to allow System Administrators to manage the operations of the SCC and the container instances.	High
71			The SCC will manage the access to resources	High

External Interface Requirements		
Id	**Name**	**Requirement**
1	Presentation Layer	In the reference architecture, this layer shows the results of the predictive maintenance algorithms run on a huge amount of data collected from the field by the batch processes described above.

Non-functional Requirements		
Id	**Name**	**Requirement**
1	Performance	The SERENA Communications Broker (SCB) is an important component within the overall SERENA system, and therefore needs to be scalable and resilient, as well as having a low latency. To facilitate these performance requirements, the SCB will be implemented as a cluster of separate broker processes, which operate as a single component. If the performance of SCB is degraded due to the traffic load, new broker processes will be started and join the cluster. Likewise, if the traffic load on the SCB decreases, broker processes will leave the cluster and be stopped. If a broker process terminates, a new broker process will be started to take its place.
2	Data encryption to protect sensible data	Data will be guaranteed by using servers implementing multiple levels of security to protect and back up files such as encryption methods to transfer and store data, Secure Sockets Layer (SSL) and AES-256 bit encryption
3	Software Quality	Scalability requirements are dependent on the manufacturing domain. The following requirements should be supported by the SERENA Cloud Platform as a baseline: • Scalability must be easily “implemented” i.e. the SERENA Cloud Platform should scale easily and in a cost-effective fashion. • In some domains cross-factory scalability is needed in the future to support virtual production networks (e.g.

		in the plant-to-plant scenario).
4	Interfaces	The SERENA Communications Broker (SCB) will be implemented as a cluster of individual broker processes. However, the other SERENA components will perceive the SCB as if it was a single entity. Therefore, other components will access the SCB using a common network address
5	Implementation	The SERENA Communications Broker (SCB) is an abstraction of the API and behaviour the SCB provide; it does not prescribe the type of technology used to implement it, or the environment it is implemented in. The SERENA Cloud will follow the microservices architecture pattern, but the design must be flexible enough to be implemented as an on-premise Cloud or in a CSP's public Cloud offering. b. The SERENA Repository API (SRA) is a definition of the API and its behaviour; it does not prescribe the type of technology used to implement it, or the environment it is implemented in. The SERENA Cloud must be flexible enough to be implemented as an on-premise Cloud or in a CSP's public Cloud offering. c. The SERENA Security Manager (SSM) is a definition of the API and its behaviour; it does not prescribe the type of technology used to implement it, or the environment it is

		implemented in. When the SERENA Cloud is deployed in a CSP’s public Cloud offering, the CSP could impose a different security schema, that by necessity will take precedence over the SERENA security schema.