Production harmonizEd Reconfiguration of Flexible Robots and Machinery

Horizon 2020 – Factories of the Future, Project ID: 680435

Deliverable 1.1

Report on decentralized control & Distributed Manufacturing Operation Systems for Flexible and Reconfigurable production environments

Lead Author: SIEMENS

Version: 1.0
Date: 30.03.2016
Status: Final
Dissemination level: PUBLIC

Author List:

Version	**Date**	**Partner**	**Content**
0.1	15.12.2015	SIEMENS	Table of Contents
0.2	11.01.2016	ALL	Contribution from all the partners (Questionnaires)
0.3	29.01.2016	SIEMENS	Revision and integration of contributions
0.4	22.02.2016	ALL	Contribution from all the partners (Framework picture)
0.5	29.02.2016	SIEMENS	Final version for internal review
0.7	23.03.2016	SIEMENS	Integration of contribution from internal reviewers
1.0	30.03.2016	SIEMENS	Final version for EC

Abstract

Today new challenges in manufacturing sectors arise with the increasing demand of responsiveness to changes in product and production volumes. Many researchers have worked on the improvement of production systems developing a next generation of decentralized distributed control solutions.
The challenge that the PERFoRM project wants to address is the industrialization of previous work on agile, smart and evolvable systems.
As PERFoRM is an industry driven project, four use cases in four different sectors, i.e. white goods, automotive, compressors and aerospace, will validate the new solution in their factory site.
The intention of this deliverable is to provide an overview of the state-of-the-art methodologies and technologies of flexible and reconfigurable manufacturing systems. It gives a collection and classification of the approaches implemented and validated by former EU research projects in this theme, referring to a common reference framework that considers three different contexts: asset, process and architectural views.
Moreover, an analysis of the four PERFoRM industrial use cases is presented, focusing on their current status in terms of flexibility and reconfigurability and showing their possible advantages in using automation solutions.

This deliverable document provides input information for T1.2 and T1.3.

Table of Contents

List of Figures

1. Introduction

This deliverable is the first outcome of the work package WP1 "Vision and objectives for demonstration of new innovative production systems based on flexible and reconfigurable production assets". The main objective of WP1 is to provide a definition of the PERFoRM goals, requirements and Key Performance Indicators (KPIs) and to collect the best methodologies and methods.
Firstly, it aims to collect the results, methods and tools of the previous relevant EU projects (D1.1). Secondly, it intends to identify the use cases requirements and define the KPIs (D1.2). Thirdly, it will investigate and select the most appropriate set of technologies and tools to be adopted (D1.3).

1.1. Objective of the document

This document contains the outcome of Task 1.1 entitled "Collection and classification/clustering of existing decentralized distributed control approaches for flexible and configurable productions systems", which has four main objectives:

- Identification of the key manufacturing domains for integrating flexible machinery and robots in a common framework picture;
- Identification of the existing methodologies enabling an adaptable and scalable execution environment of a Manufacturing Operation System;
- Identification of existing industrial systems and components for using and integrating components in the production shop floor and into a Manufacturing Operation System;
- Description of the industrial use cases scenarios considered in PERFoRM project and their scope.

First of all, this report is important as a basic information source in support of other tasks and deliverables within the PERFoRM project by identifying relevant EU projects and research results. The information it provides are particularly useful for the development of the use cases' requirements analysis (T1.2) and the technology gap analysis (T1.3).
A definition of the strategic requirements and the identification of the technical and business KPIs is presented in deliverable D1.2 "Requirements for Innovative Production System Functional requirements and definition of strategic objectives and KPIs", while a technology gap analysis as well as a definition of evaluation criteria for appropriate technologies and tools is described in deliverable D1.3 "Requirements Review, evaluation and selection of best available Technologies and Tools".
In deliverables D7.1, D8.1, D9.1 and D10.1 can be found a deeper analysis of each industrial use case.

1.2. Structure of the document

This document is structured as follows:

After this brief introduction, chapter 2 will provide an overview of flexible and reconfigurable systems currently developed and it will describe the project viewpoints framework.

Chapter 3 will recall the methodologies and approaches towards an agile manufacturing system developed by previous projects. The focused areas and the solution's benefits will be highlighted as well as the necessary steps to implement those solutions in the industry.

Chapter 4 is dedicated to the description of the four industrial use cases and their currently available equipment in terms of flexibility and reconfigurability. Moreover, an overview of their goals and open issues is provided.

Chapter 5 will explain the importance in utilizing flexible and reconfigurable systems in the use cases, highlighting their focus areas within the PERFoRM framework picture.

Chapter 6 will summarize the outcomes of the collected results of the previous projects, comparing the gathered knowledge with the PERFoRM goals.

2. Manufacturing Operation System

2.1. State of the Art

Modern markets are characterized by shorter product lifecycles, increased product variety and shorter time-to-market. Consequently, to cope with these requirements, all industrial end user scenarios need to adapt to shorter product life cycles and to reconfigure more frequently their production systems to offer new products variants, while maintaining high-quality standards and minimizing costs.
The traditional approach to manufacturing control systems based on centralized or hierarchical control structures presents good characteristics in terms of productivity and optimization. However, they do not support efficiently the current requirements imposed by intelligent manufacturing control systems, namely in terms of flexibility, expandability, agility and reconfigurability, since they present a weak response to changed production styles and highly dynamic variations. [1]
Thus, it is needed a migration from traditional production systems characterized by vertical applications, centralized approach and rigidity, to an agile plug-and-produce system that is dynamically adaptable to changing production environment, open to new features and functions, flexible to different processing tasks and modular to enable quick and economical changes.
Several emergent distributed and intelligent approaches, such as Multi-Agent Systems, Service-oriented Architectures, Web Services technologies, Plug-and-Produce systems, Cyber-Physical Systems, Cloud Manufacturing, and so on, have been developed for years by a variety of consortia. However, the reality today still shows the dominance of production systems based on traditional approaches.
Previous European projects proved different individual solutions necessary to create an agile production system but none of them proved that concept in an integrated form, impeding the progress towards flexibility and agility. PERFoRM aims to integrate and harmonize these concepts and prepare standards to facilitate industrialization and dissemination of plug-and-produce devices.

A collection of the latest state-of-the-art standards and technologies in automation systems proved by former projects is given in Chapter 3.

2.2. PERFoRM framework picture

Figure 1 depicts the PERFoRM project framework. It aims to give a big picture of the flexible and reconfigurable manufacturing concept in three contexts: asset, process and architectural views.

The role of the picture in this deliverable is to give an overview of the methodologies developed, implemented and tested by the former projects, in order to see their areas of work in the three contexts, and the as-is situation of the industrial use cases in terms of flexibility.

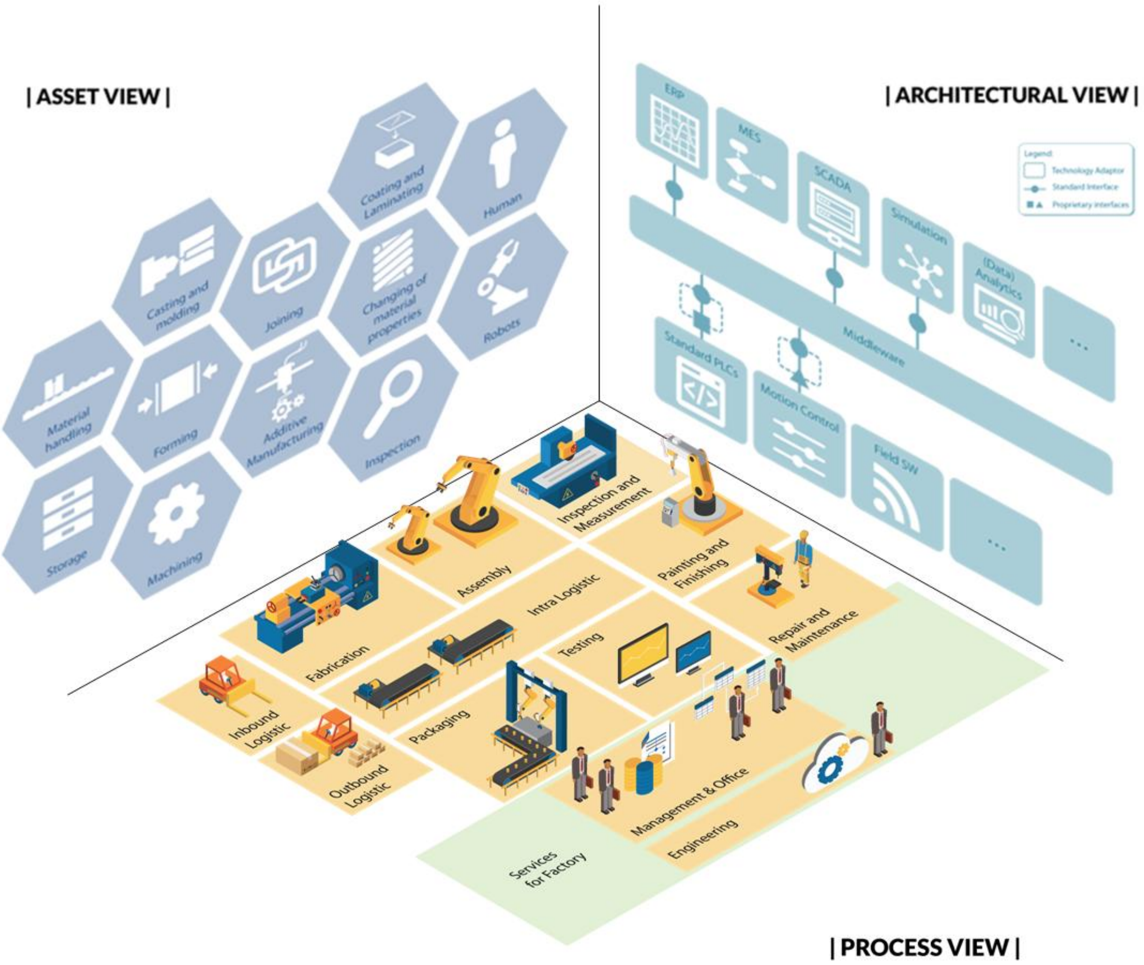

Figure 1: PERFoRM framework picture

A flexible manufacturing system is a highly automated system consisting of processing stations, material handling and storage systems and controlled by a distributed computer system. Thus, it requires hardware and software provisions. [2]

The asset view (Figure 2) represents the physical equipment of a flexible manufacturing system, which involves not only the workstations but also the human resources. These workstations usually are machine operations, inspection facilities, assembly stations and material handling systems. Taking into account the manufacturing processes defined in the DIN 8580 norm, the following assets have been considered:

- Casting and molding
- Forming
- Machining
- Joining
- Additive manufacturing
- Coating and laminating
- Changing of material properties
- Inspection
- Robots
- Material handling
- Storage
- Human

Figure 2: PERFoRM Asset view

The architectural view (Figure 3) represents the software provisions of a flexible manufacturing system thus, the immaterial things that are basically the information and communication technologies (ICT).

There are several IT systems that exist in the factory or plant floor today and data that are collected at various levels. PLC, SCADA and DCS systems are the basis for monitoring and controlling industrial applications at lower levels within the plant hierarchy. Upper levels are dominated by MES and ERP systems. Information exchange at lower levels is characterized by a data-centric approach utilizing industrial serial field bus systems or Ethernet-based communication supported by appropriate engineering concepts and tools. [3]

As next-generation systems will be highly collaborative and will have to share information, interoperability via open communication and standardized data exchange is needed. Hence, technology adaptors to integrate legacy systems will be created, which will interface between the proprietary control systems of the devices and the manufacturing service bus. The middleware will be responsible for managing the connectivity when new resources become available or are removed. PERFoRM will specifically focus on integrating a multi-objective dynamic scheduling approach to manage work orders with flexible production systems.

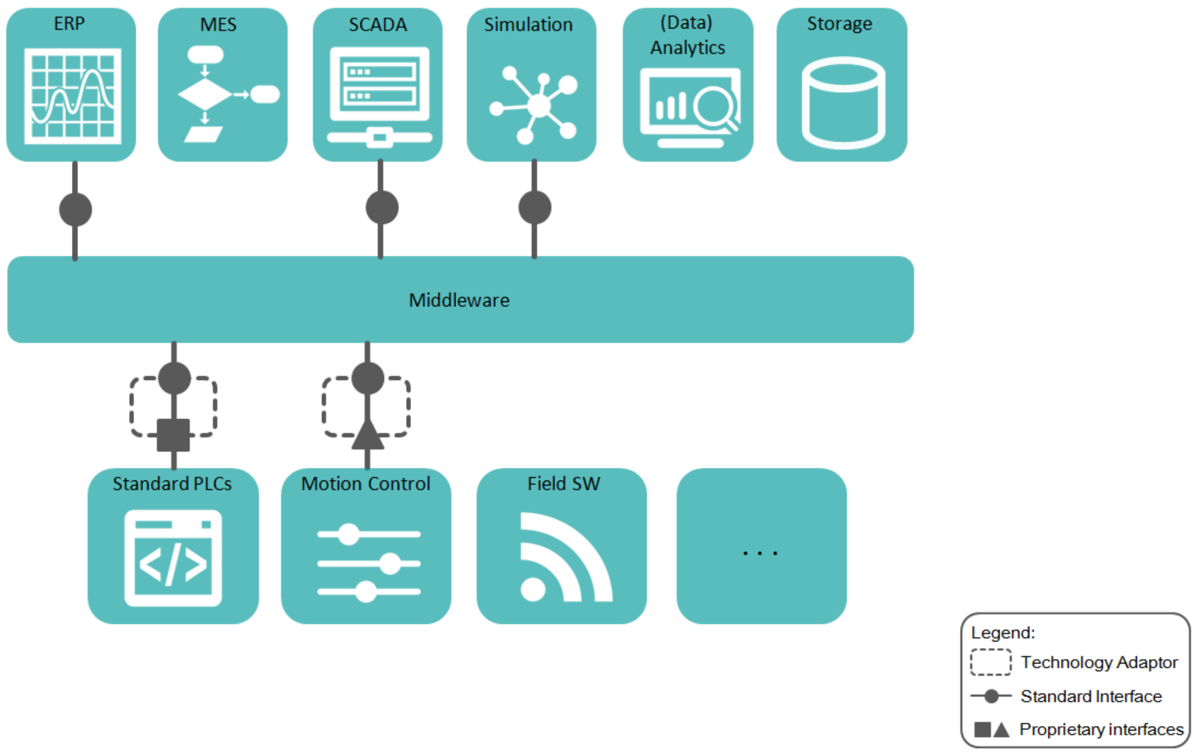

Figure 3: PERFoRM Architectural view

The process view (Figure 4) depicts the shop floor and the office space. It comprehends all the typical manufacturing workstations in a factory. Starting from the inbound logistic, the raw material comes into the factory to be processed by manufacturing machinery. The assembly or joining workstation means to mount the parts that will be then inspected. After the inspection and measurement process, the work pieces are finished in the painting and finishing workstation or repaired in the repair and maintenance process area. Finally, the products are tested and sent to the packaging station.

The logistical resources serve to fulfill the core and sub-logistic processes. These are functions with which piece goods are stored or changed without modifying their functional properties [4].

Also the services for the factory are considered, i.e. management, office (administration) and engineering (research and development).

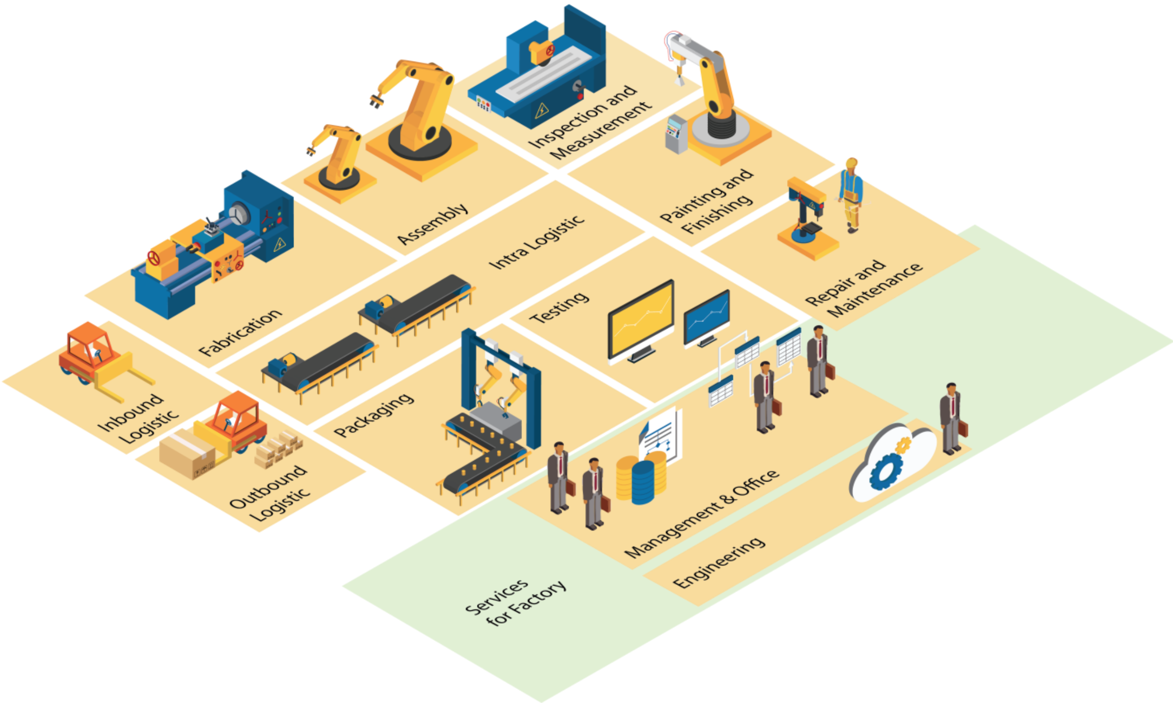

Figure 4: PERFoRM Process view

3. Previous Projects

In this chapter, an overview of the state of the art methodologies developed in previous research projects is presented. The PERFoRM consortium has been involved in all of these projects and their acquired knowledge on the described technologies can be reused to develop an integrated solution of agile plug-and-produce manufacturing system.
These methodologies, technologies and standards will be evaluated in D1.3.

Each project description ends with an overview of their areas of work in the three domains of the PERFoRM framework, in order to make them comparable and to highlight what the developed technologies cover. The covered areas will be colored in light blue for the asset view, in green for the architectural view and in yellow for the process view, while the elements that have not been scope of the discussed project will be grayed out.

3.1. GRACE

The main objective of GRACE (InteGration of pRocess and quAlity Control using multi-agEnt technology) was to study, develop, implement and validate a cooperative Multi-Agent System (MAS) which operates at all stages of a production line, integrating process control with quality control at local and global level (Figure 5).

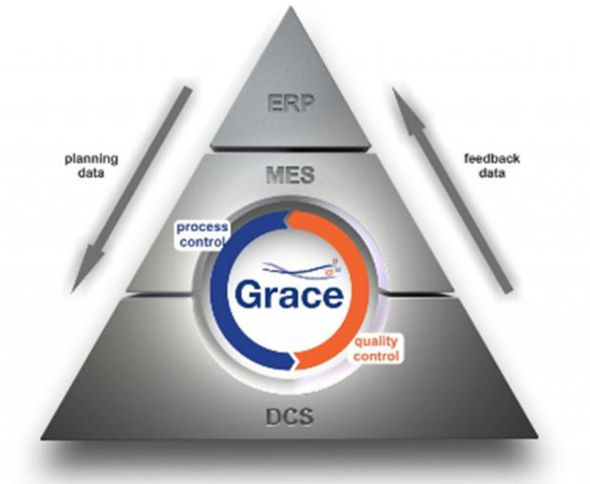

Figure 5: GRACE project

The project has developed a multi-agent architecture designed for a factory where production processes are subject to planned changes of set-point, typical of on-demand production systems, and to a large variety of disturbances and changes in process parameters and variables. This approach is in line with the current trend to build modular, intelligent and distributed control systems, called Decentralized Manufacturing System (DMS).
Within the GRACE project, self-adaptation procedures and optimization mechanisms for process and product parameters have been implemented and integrated into control and diagnostic systems at local level, i.e. at an individual agent, and global level, considering the data gathered in all the production system. Furthermore, an engineering methodology has been defined in order to efficiently implement the MAS production platforms in decentralized production systems with modular and self-optimizing quality controls, allowing the use of diverse algorithms.

Figure 6 represents the multi-agent system architecture based on the interaction among the individual agents.

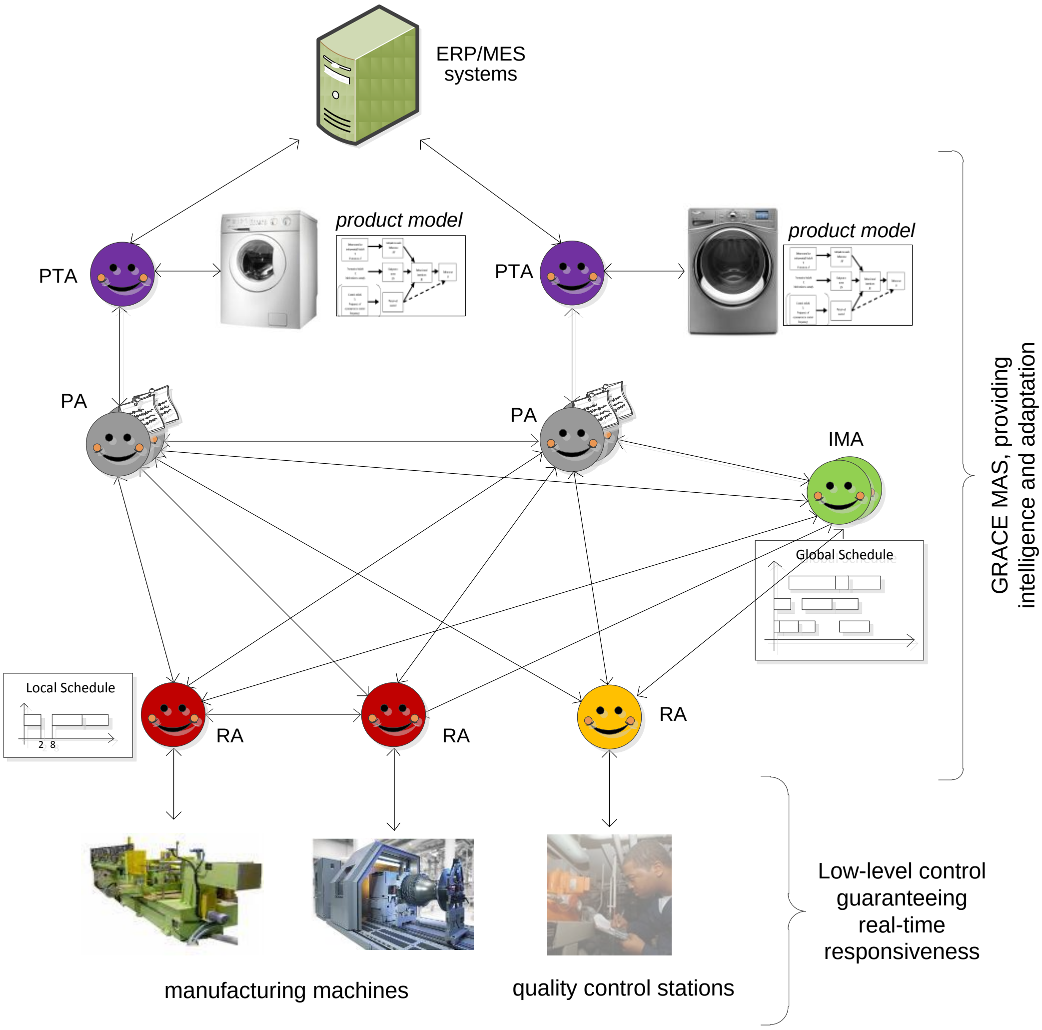

Figure 6: GRACE Multi-Agent System

Exemplary Use Case Flow:

- The Product Type Agents (PTA) receive orders from the MES system and launch Product Agents (PA), that act similarly to the Intelligent Production concept, executing the production requests, exchanging product and process planning information.
- The Product Agents (PA) interact with the Resource Agents (RA) during the execution of the process plan, adjusting process and quality control parameters according to the current production line conditions and querying about the progress of the plan execution. As an example, PAs have the accumulated knowledge from previous PA (from the same PTA) execution and are able to take the most suitable decision facing a similar past problem.
- Product Agents and Resource Agents interact with the Independent Meta Agents (IMA) to provide feedback information about the execution of the operations and the process plans and to receive optimized guidelines to improve their execution.
- The Resource Agents (RA) interact with each other during the physical synchronization of activities, such as for the transportation of the pallets between workstations.
- PAs inform the respective PTA regarding the production process, enabling the PTA to gather accumulated knowledge, making a continuous learning process.

The MAS architecture has been operated on a washing machine production line and tested against planned variation of variables and unforeseen ones. Production efficiency has been measured and compared to normal performance.

Field tests performed in order to validate the GRACE system showed very significant and encouraging outcomes:

- The adaptation of the functional inspection test plan can increase the efficiency of the functional testing (FT) area of about 8% (if 12% of the productions are tested with a shorter FT based on the high-quality indicators values).
- The introduction of self-optimizing quality controls reduces non-conformities of about 1,5%.
- The self-adaptation of the test plan parameters permits to reduce the downtime of the stations when new models are produced. Only for 20% of new models the human intervention is still required (the expected downtime reduction was 10%).
- The flow calibration permits to reduce of 50% the standard deviation of the washing machine water consumption. This reduction implies that more precise washing machine programs can be implemented with a 3-5% reduction in water and energy consumption.

Figure 7 represents an overview of the whole project:

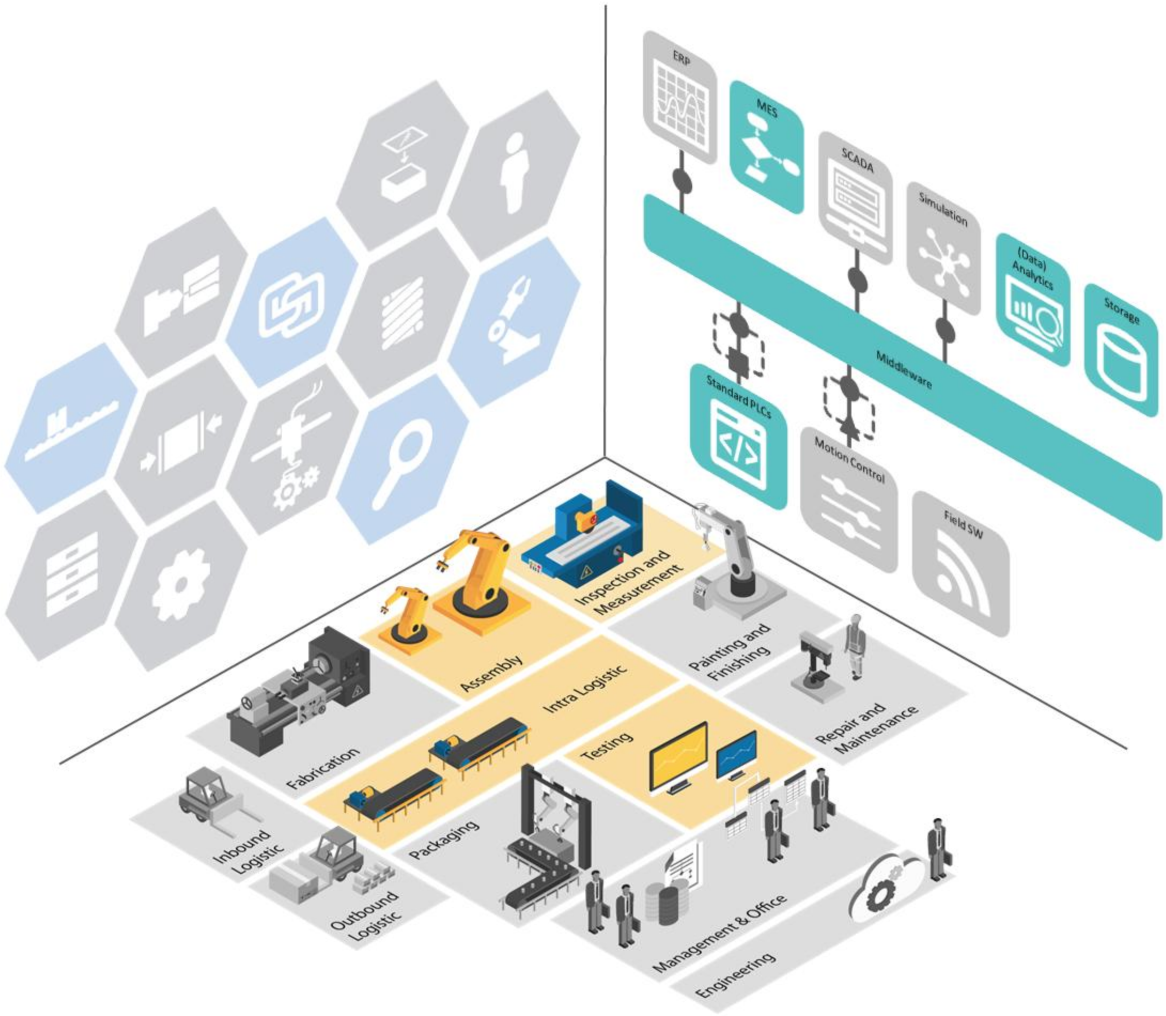

Figure 7: GRACE overall picture

The GRACE architecture consists of a multi-agent system that, as a middleware, allows storing, analyzing and exchanging data between MES system and the production line control (standard PLCs). The production floor considered to test the GRACE system consists in:

- Assembly – Bearing insertion station, screwing station, vision stations.
- Testing – Functional testing.
- Inspecting and measurement – On-board controller programming, drum geometry control station.

In order to apply the GRACE MAS architecture in industry, the availability of an IT infrastructure for the deployment of the multi-agent system is required. An analysis of the product and the production process is also necessary for customizing the functions and the behaviors of software agents to adapt the architecture to the manufacturing needs of the factory, i.e. find the production and quality relationships.

PERFoRM partners involved in GRACE:

- Loccioni: implementation and integration of process and quality controls
- IPB: design, development, deployment and testing of the multi-agent architecture and the integration of algorithms with the MAS infrastructure
- Siemens: definition of the engineering methodology for multi-agent system deployment
- Whirlpool: end-user and results validation

3.2. IDEAS

IDEAS (Instantly Deployable Evolvable Assembly Systems) had as a main objective the implementation of agent technology on commercially available control boards. The project developed a fully distributed and pluggable mechatronic environment capable to self-organize itself and control at the shop floor level.
The assembly system ran with a multi-agent control setup, could be reconfigured on-the-fly, and the modules self-configured. The obtained results are the integration of different modules at the shop floor, the pluggability in runtime and the distributed diagnosis. Each module is responsible for diagnosing itself and the entire system is capable of checking the propagation of problems and re-adapt whenever a component / module is plugged without requiring programming effort in order to manage unpredicted behaviors.

The IDEAS project provided a set of decoupled software tools that target the multiple stages of a system. The tools were developed independently following an overarching IDEAS architecture, which provides a clear integration between tools without compromising on the specificities of each tool (Figure 8).

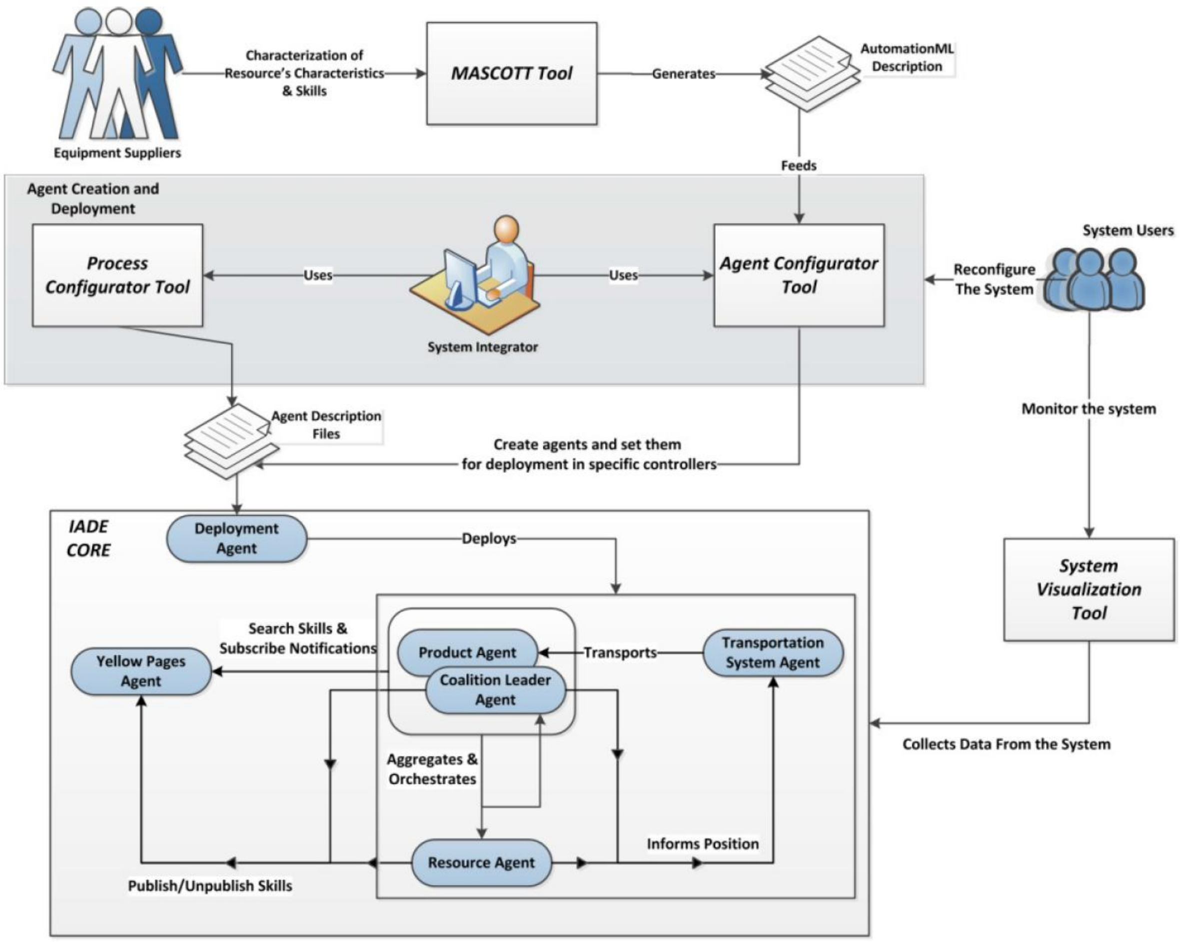

Figure 8: IDEAS software tools and their relations

The MASCOTT tool targets the physical system design and equipment module specification. This tool is built on existing state of the art description tools enhancing it with the mechatronic concepts. The tool provides the capability (Skills) of each equipment module to be present in a given system. This information is crucial for the creation of the Mechatronic agents that are able to control the equipment modules, and, in turn, the whole system. The Agent Configurator Tool is responsible for processing this information and deploys the respective agents. This tool provides the ability to deploy in the system Resource Agents and Transportation System Agents, which are able to execute the defined skills. The Process Configurator Tool provides the means to specify the product workflow, which will enable the system to produce products. This is achieved by the creation of a Product Agent, which contains a sequence of required skills for the system to execute. This tool can also check what skills are in the system and create Coalition Leader Agents that will be responsible for executing a given sequence of Skills (Composite Skills). In a production system, the agents follow the specified architecture to execute the product requirements that the multiple Product Agents provide. The System Visualization tool is used to monitor the operation of the system, the multiple products or equipment modules. This information can be used to verify the existence of bottle necks and trigger the system reconfiguration.

This implementation-oriented work aimed at showing how self-organization can be introduced in a mechatronic stack. Furthermore, the interactions among some of the agents were studied, in simulation, to uncover the hidden dynamics of self-organization.
An overall picture of the project is presented in Figure 9:

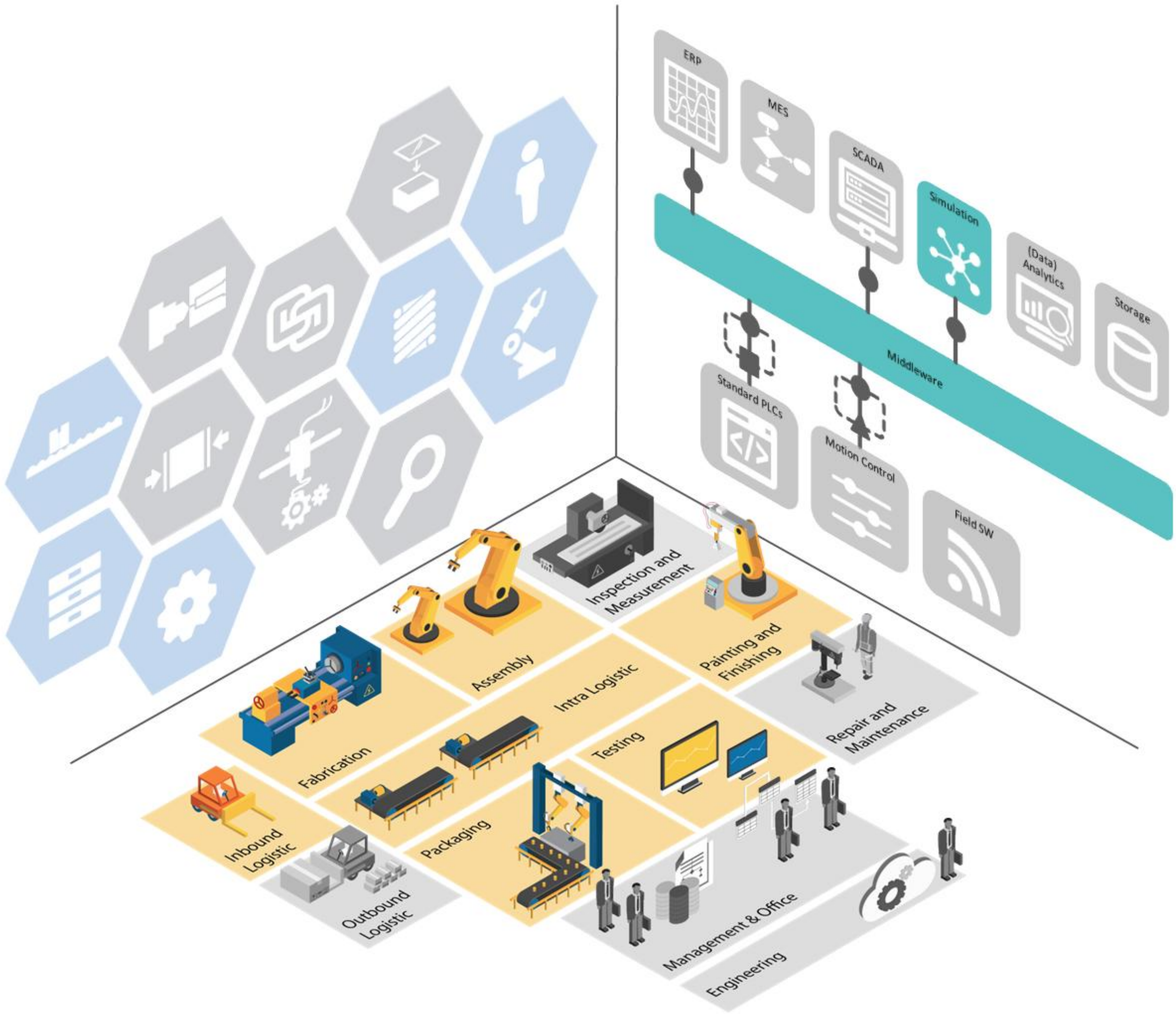

Figure 9: IDEAS overall picture

To go to apply this architecture in industry it is necessary to develop a powerful hardware capable of running the agents inside the modules, to have more specific and capable description of the shop floor using a semantic language, and to study new hardware development strategies in order to deal with modularity needs.

PERFoRM partners involved in IDEAS are:

- UNINOVA: Design of the multi-agent architecture and development of the mechatronic environment

3.3. IMC-AESOP

The initiative AESOP (ArchitecturE for Service-Oriented Process-Monitoring and -Control) investigated a Service-oriented Architecture approach for monitoring and control of very large scale Process Control applications (batch and continuous process).
The SoA-based approach proposed by the project can simplify the integration of monitoring and control systems on application layer. The networking technologies that are already known to control engineers could also simplify the inclusion of the next generation SCADA/DCS systems at network layer.
IMC-AESOP envisioned a SoA-based SCADA/DCS infrastructure enables cross-layer service-oriented collaboration, i.e. not only at the horizontal level, e.g. among cooperating devices and systems but also at vertical level between systems located at different levels of an enterprise architecture.

The major objectives of the approach were:

- Propose a system-of-systems approach for distributed dynamically collaborative monitoring and control based on Service-oriented Architecture.
- Build a foundation for predictive performance of such SoA architecture based on a formal approach to event-based systems.
- Propose a transition path from legacy system to the new SoA-based SCADA and DCS.

The architecture has been applied in four industrial use cases:

- Legacy plant lubrication system to SoA
- Implementing circulating oil lubrication system based on the IMC-AESOP architecture
- Plant energy management
- District energy management

Within these test cases, it has been proved that the AESOP approach is suitable for large-scale systems and simplifies the migration of legacy systems to a SoA-based approach.

IMC-AESOP presented an increased flexibility, reconfigurability and interoperability, focusing on large-scale process control systems (batch with the continuous process) and complex and distributed systems. It is also applicable for smaller systems.

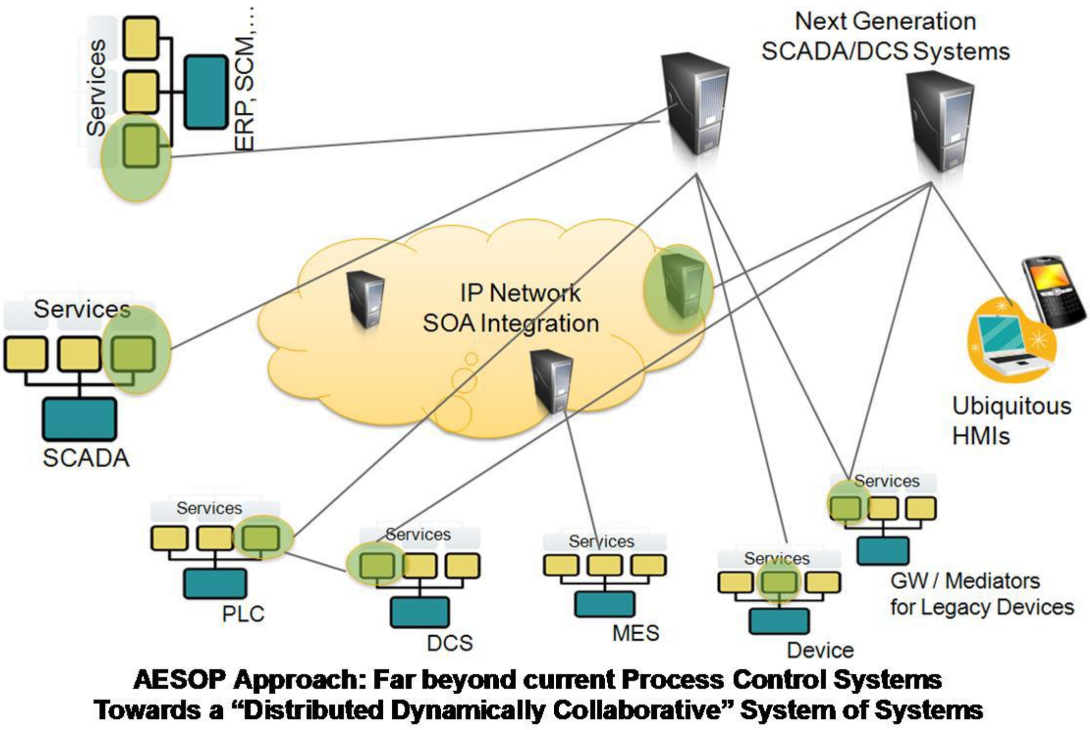

Figure 10: AESOP Approach

This approach can be implemented in industry after a research analysis on whether used tools and technologies are applicable for the considered case, including also higher-level systems (MES and ERP).
Figure 10 shows how SCADA systems will be able to act as a component of a distributed System of Systems, where different sub-systems of a production system are interconnected via a Service-Oriented network. A SCADA is able to offer different kinds of SCADA functionalities as Services and is able to retrieve process data from PLCs as well as information from higher domains (ERP, MES). This structure overcomes existing boundaries, as the typical hierarchies are flattened to allow each system to communicate with each other and therefore increase the collaboration inside a distributed system.

The architecture was built as a Service-Oriented Architecture, which connected field devices with higher-level systems, focusing on SCADA systems (but also allowing MES and ERP). This architecture has been implemented in energy management, process industry, district heating and engineering processes. Assets such as robots, storage, paper machines, lubrication systems, inspection and maintenance were considered. (Figure 11)

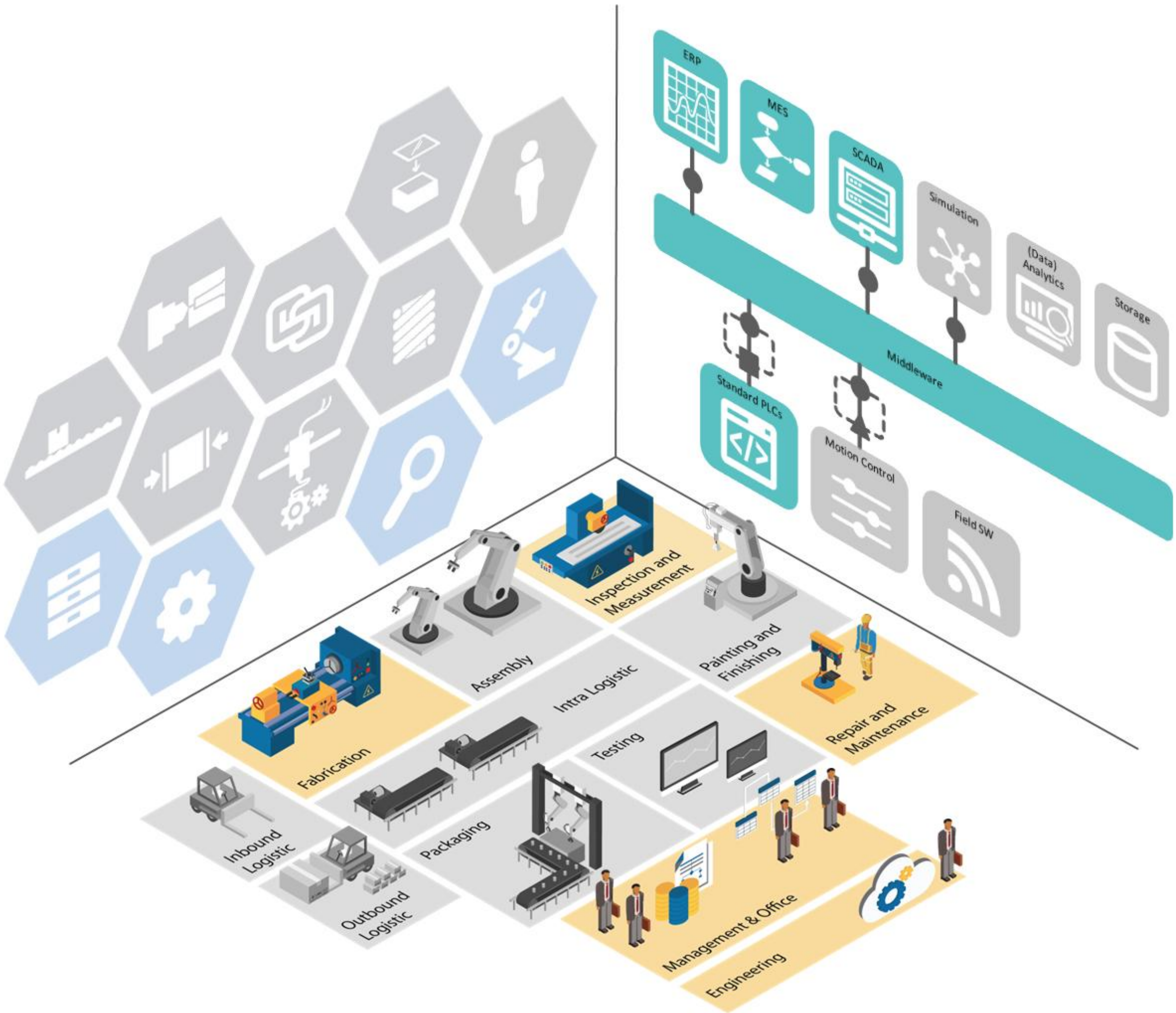

Figure 11: IMC-AESOP overall approach

PERFoRM partners involved in IMC-AESOP:

- Lboro: introducing Engineering aspects, such as specific virtual engineering tools, into the AESOP architecture
- HSEL: architecture design, prototype implementations in the Digital Factory of HSEL and various dissemination
- POLIMI: planning of the adoption of new technology, analysis of business processes, leading a business-driven study of the proposed approach.

3.4. Self-Learning

The objective of the Self-Learning project (Reliable Self-Learning production systems based on context-aware service) was to develop highly reliable and secure service-based self-learning production systems aiming at merging the world of secondary processes (e.g. maintenance, energy efficiency, scheduling) with the world of control by using context awareness and data mining techniques.

Self-Learning architecture is based on the service-oriented development approach that represents several different processes as services, which are fully interoperable and allow further re-use for specific process reoccurrences. In Self-Learning production system, service oriented integration is adapted at the device level to support the application from the upper level. This vertical collaboration between the device level SOA and enterprise layer are perceived using middleware technologies in Web Services platform.

The Self-Learning system (Figure 12) has been implemented as a generic system thanks to a SOA approach and to the context model. It enables the integration of secondary processes into the main control (typically secondary processes are detached from the main control) and the reconfiguration of machines and processes based on user experiences acquired during the system runtime. It includes Monitoring Services (extraction of data from the environment), Context Extraction Services (context identification from data extracted) and Adapter Services (usage of identified context for creating classification models by learning with the users).

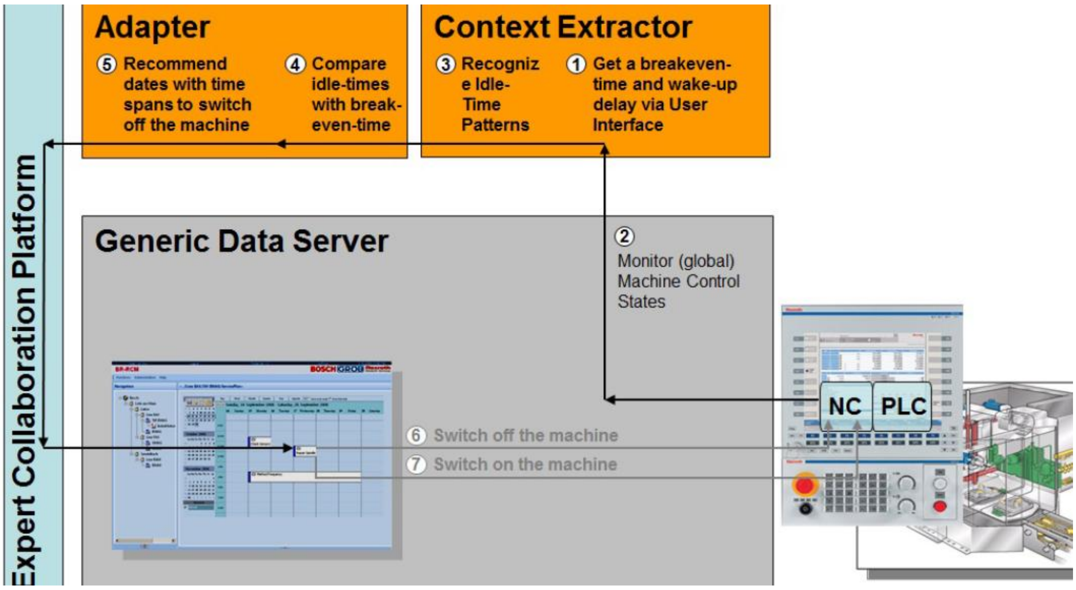

Figure 12: Self-Learning system

Thus, Self-Learning system has three must-have components: the Context Extractor, that is in charge with detection and interpretation of data from existing database systems, data servers, and file systems; the Adapter, that is in charge with real-time adjustments of control and maintenance parameters, generation of maintenance plans, execution and identification of new parameters to be considered in the control loop; and the Learning Module to learn relying on data mining and operator's feedback to update execution of adaptation and context extraction at runtime.

For the implementation of the Self-Learning system in industry, the following steps are necessary:

- Creation of a communication interface with process;
- Description of the domain, i.e. definition of an ontological model for describing the application context and/or scenario;
- Definition of the parameters to be used for prediction in a data mining process.

Figure 13 represents Self-Learning's areas of work:

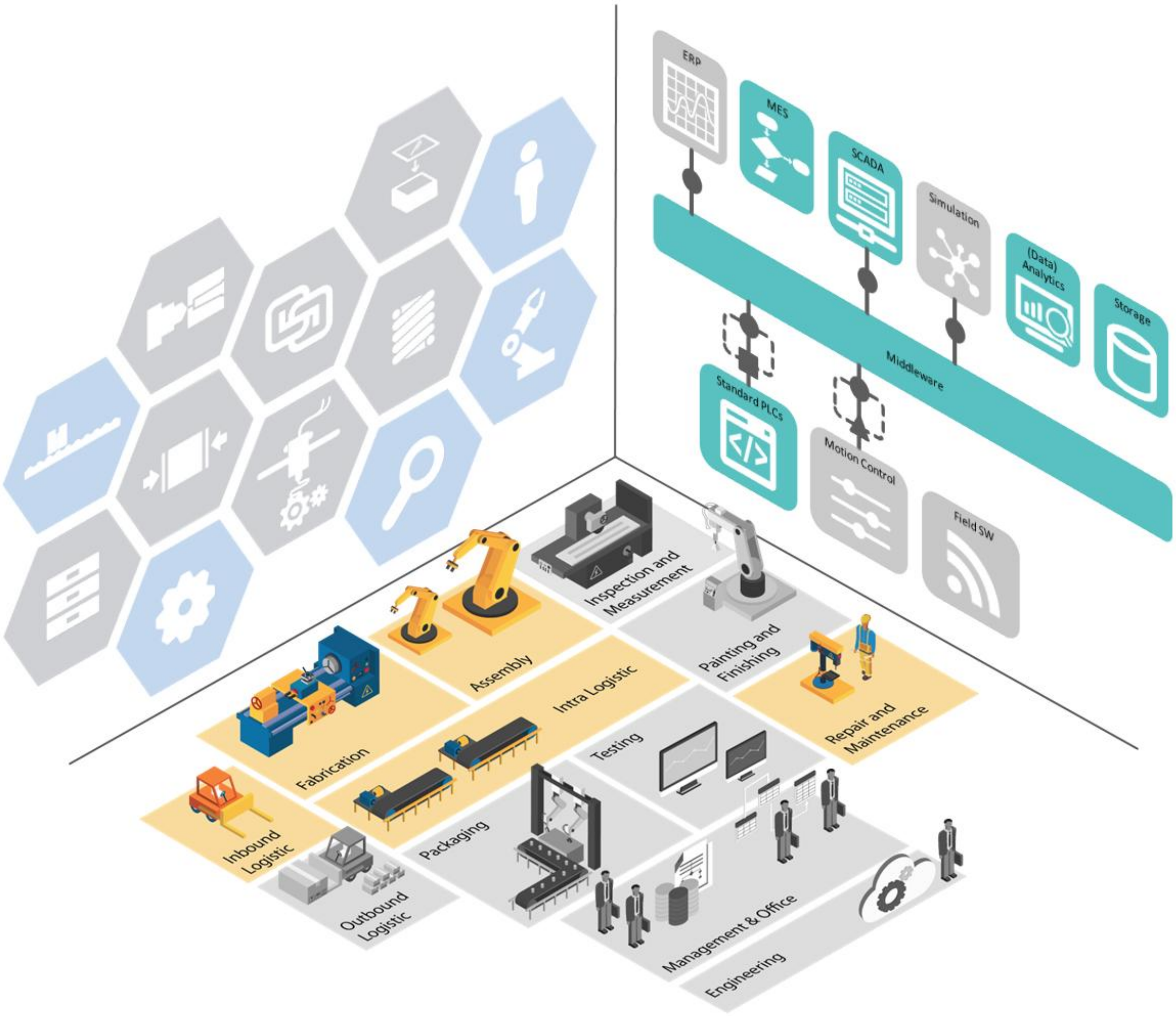

Figure 13: Self-Learning overall picture

PERFoRM partners involved in Self-Learning:

- UNINOVA: design and implementation of Adapter Services for model creation and predictive analysis

3.5. SOCRADES

SOCRADES project (Service-oriented cross-layer infrastructure for distributed smart embedded systems) developed a design, execution and management platform for next-generation industrial automation systems, exploiting the Service Oriented Architecture paradigm both at the device and at the application level focusing on four main technology areas:

- Ad-hoc networking service platform – Service-oriented Architectures (SOA)
- Wireless sensor/actuator networking infrastructure
- Enterprise Integration based on the Service-oriented Architecture (SOA) paradigm

- System engineering & management to automatically generate control logic software and to allow the support of distributed control system configurations

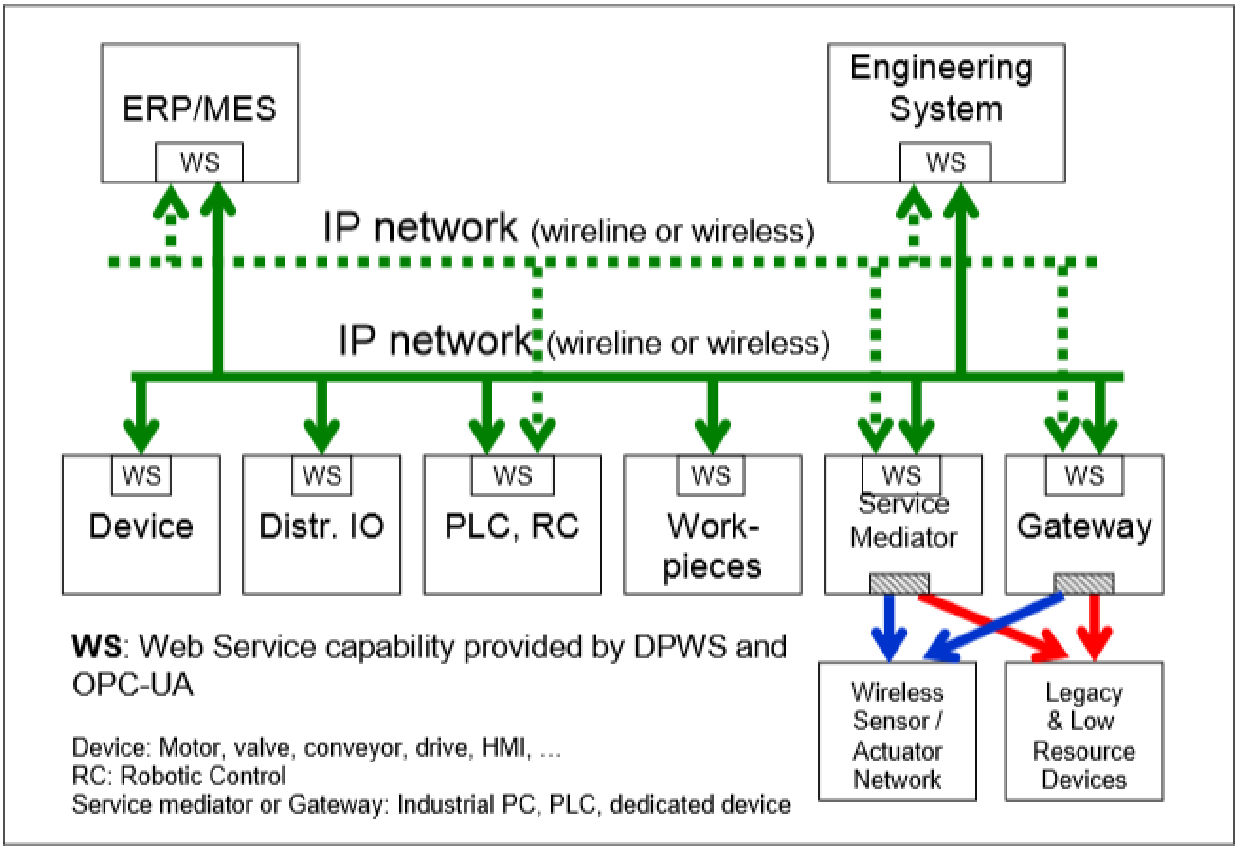

Figure 14: SOCRADES architecture

Figure 14 presents the structure interconnecting all the Web Services (WS) that compose the general architecture used in the SOCRADES project. More than developing and specifying models, protocols and general architecture for web services, SOCRADES focuses its efforts on the device level addressing problems concerning Wireless Sensor/Actuators Networks (WSAN) in order to develop reliable and efficient communication carriers. The Enterprise Integration (ERP/MES) is important to obtain and exploit benefits coming out from the use of SOA as middleware, and also system engineering and management (Engineering System) are relevant for the dynamic reconfigurability and re-configuration.

The project showed its benefits through five different scenarios (dynamic assembly system, cross-enterprise collaboration, car engine manufacturing, fault-tolerant wireless control of continuous processes, and SOA-based e-maintenance), emphasizing on platform independence, real-time requirements, robustness and security. As a middleware, SOCRADES allows the integration of heterogeneous embedded systems and devices into business systems.

The use of device-level service oriented architecture contributes to the creation of an open, flexible and agile environment by extending the scope of the collaborative architecture approach through the application of a unique communications infrastructure, down from the lowest levels of the device hierarchy up into the manufacturing enterprise's higher-level business process management systems.

The project is presented in Figure 15.

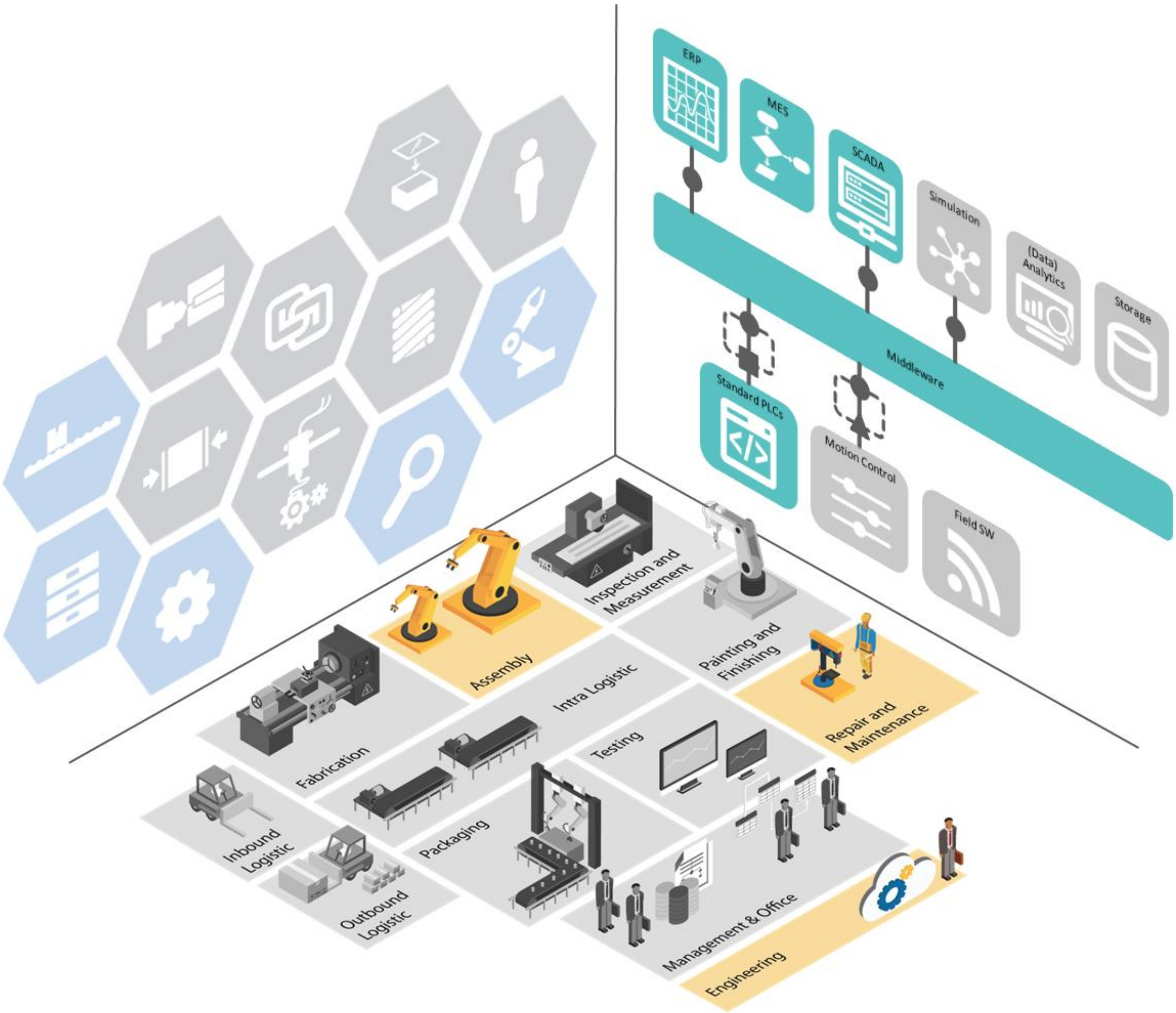

Figure 15: SOCRADES overall picture

SOCRADES is widely applicable in industry: it only required to previously support the application design, simulation and monitoring of real-time intelligent embedded components, and the integration of intelligent embedded devices with higher-level business process systems (enterprise dimension), supply chain partners (value/supply-chain dimension) and within a lifecycle engineering context (lifecycle dimension). It also needs to be evaluated, whether the results, that focus more on embedded devices, can also be integrated into real production systems.

PERFoRM partners involved in SOCRADES:

- Siemens: SoA in Wireless Sensor Networks, Webservices in smart sensors, demonstration on TRL 3-4
- Lboro: Engineering of SoA-based Automation Systems, component-based automation with services, demonstration of SoA in Automation in Use Case at Jaguar/Landrover, deployment of Webservices into smart I/O devices (FTB of Schneider Electric) (TRL 5-6)
- POLIMI: Roadmap of the SOCRADES technology and approaches, dissemination/publishing activities
- HSEL (indirect through project coordinator): Technical Coordination, exploitation of results via demo in TUT/Flexlink demonstrator, deployment of Webservices into smart I/O devices (STB of Schneider Electric) (TRL 5-6)

3.6. PRIME

PRIME (Plug and produce intelligent multi-agent environment based on standard technology) developed a multi-agent architecture using plug-and-produce principles for configuring production systems through innovative human-machine interaction (HMI) mechanisms.
In particular, it realized:

- A Software Toolbox (Figure 18) for integrating and enhancing machines and production systems with plug-and-produce agent capabilities and interfaces for seamless integration;
- A methodology for system behavior modeling and real-time awareness to support system evolution linked to process performance and product volume variability;
- Methods for rapid configuration, ramp-up, and system optimization and adaptation;
- Multi-agent control architecture for module integration including legacy equipment.

The PRIME approach is based on standard technologies and languages for the integration and networking of heterogeneous control systems from different equipment suppliers inside a production line (Figure 16).

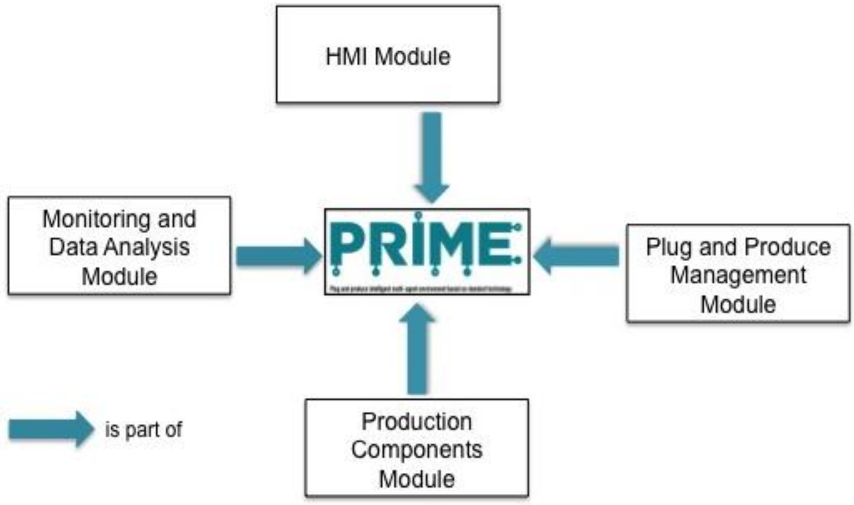

Figure 16: PRIME components

PRIME developed a pluggable, high-scalable and distributed framework for the creation of new solutions regarding adaptive, self-aware, self-monitored and reconfigurable plug-and-produce systems. These next generation assembly systems equipped with PRIME technology will be able to proactively support a distributed reconfiguration, as each module is capable of reconfiguring itself in order to produce different product variants without stopping the line or requiring further programming effort, and a distributed knowledge extraction to support monitoring, as each agent extracts raw data from its abstracted component, enabling the system as a whole to process it and extract relevant knowledge through data analytics.
These systems are capable to re-adapt themselves whenever a component or module is plugged without requiring programming effort (pluggability in runtime). Moreover, it is possible to have a flexible combination of plug-and-produce manufacturing technologies.

Figure 17 presents an overview of the multi-agent architecture that serves as the foundation that constitutes the backbone for the aforementioned system capabilities.

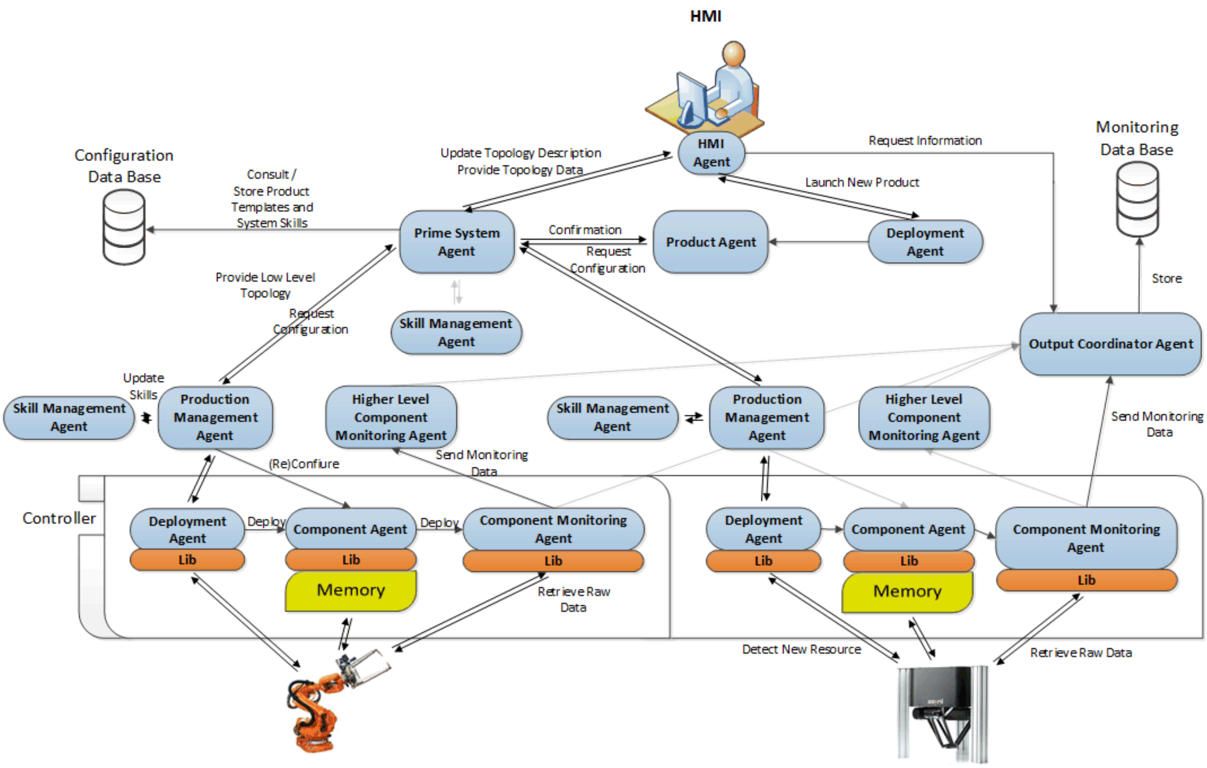

Figure 17: PRIME multi-agent architecture

The PRIME multi-agent architecture, as illustrated in Figure 17, comprises several different agents each with its particular functions and goals.

At the lowest abstraction level, three distinct types of agents can be found. The Deployment Agent (DA) is responsible for launching the remaining PRIME agents according to the system's topology, even throughout its execution, playing a vital role in the pluggability of both the reconfiguration and monitoring aspects of the framework. The Component Agent (CA) abstracts a physical resource, encapsulating all information pertaining to it and being responsible for reconfiguring the associated device. Similarly, the Component Monitoring Agent (CMA) shares a one-to-one relation to a physical component, collecting raw data and pre-processing it before propagating it to the higher-level entities. Each of these agents possesses generic communication interfaces in order to enable its communication with the hardware, making it possible for the agents to perform their respective tasks.

At the higher-levels of abstraction, it is particularly relevant to highlight four types of agents. The Production Management Agent (PMA) is responsible for managing subsystems composed of other PMAs or CAs, allowing the existence of multiple layers of complexity and improving the system's scalability. Each PMA is associated to a Skill Management Agent (SMA), which handles the possibility of generating more complex skills, based on a set of rules, from the pool of abilities provided by the elements that comprise the associated subsystem. Similarly to the PMA, the Higher-Level Component Monitoring Agent (HLCMA) improves the system's scalability by enabling the creation of a knowledge extraction tree. It abstracts a subsystem, handling not only raw-data related to it but also data pre-processed by other HLCMAs or CMAs. This information is then sent a cloud of Output Coordinator Agents (OCA), where one of the available OCAs can in turn store it in a historical database and relay it to external processing entities.

Other agents include the Product Agent (PA), which abstracts a certain product variant and plays a role in initiating the reconfiguration process as needed, and also the Human Machine Interface Agent (HMIA), which acts as the bridge between the user and system, allowing the HMI to acquire and display relevant information, enabling the launch of new Product Agents and displaying important monitoring information.

This architecture is a key part of the Prime Toolbox, being one of the main facilitators of the integration concept described in Figure 18.

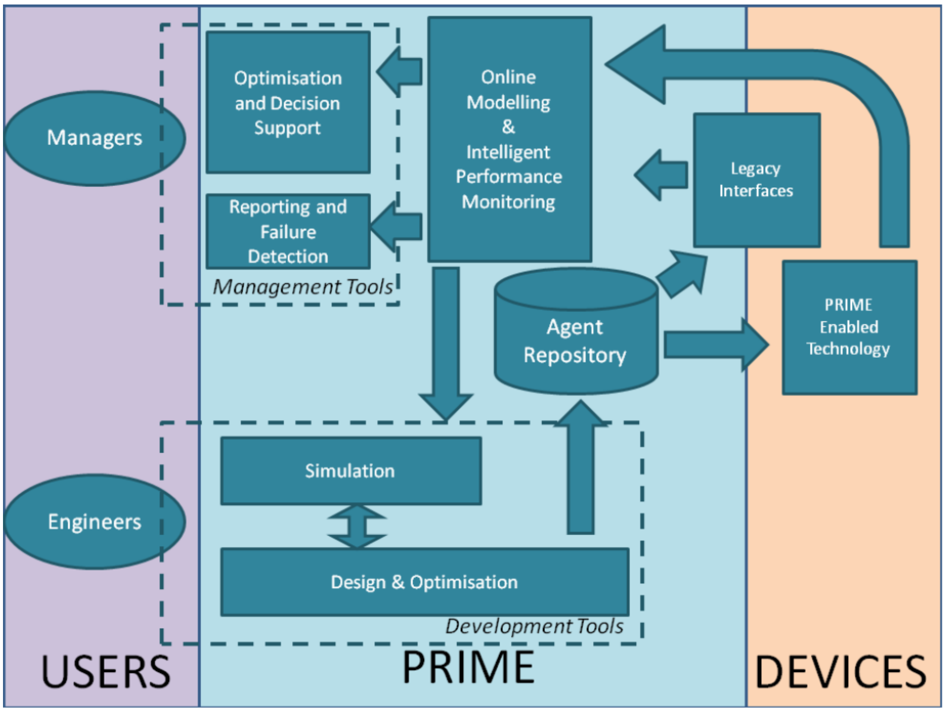

Figure 18: PRIME toolbox and integration concept

To apply PRIME approach in industry, the following is required:

- Description of the shop floor in PRIME's semantic language
- Structuring of the relevant data to be extracted from the system
- Requirements analysis of the targeted application on machine components, HMI needs and networking ability to other machines and servers
- PRIME System Integrator Toolbox: by a wizard the operator is guided through a collection of SW tools supporting the automation engineers in setting up the industrial automation solution, helping optimized configuration, simulate and optimize performance and enable rapid process setup.

An overview of PRIME is given in Figure 19.

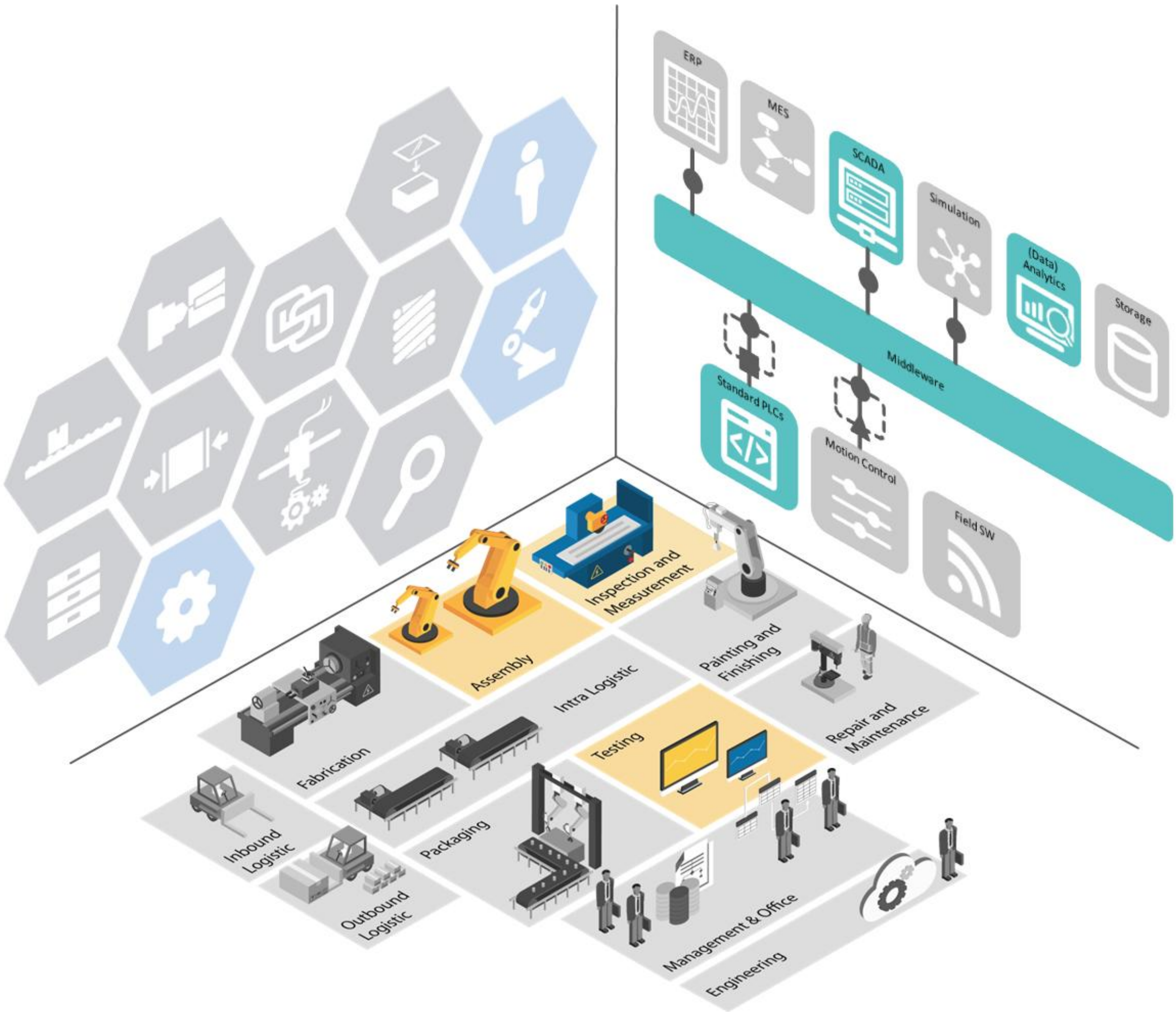

Figure 19: PRIME overall picture

PERFoRM partners involved in PRIME:

- Siemens: integrator and end-user, application in manufacturing, development of the plug-and-produce toolbox
- UNINOVA: design of the multi-agent architecture and data model in JAVA and JADE

3.7. FRAME

FRAME (Fast Ramp-up and Adaptive Manufacturing Environment) focused on experience capture, policy learning and decision support for rapid ramp-up and tuning of assembly machines and stations.
It aimed at introducing automation and software tools to the ramp-up process that will accelerate it and maximize re-use and storage of expert knowledge. Through these actions, it aims to reduce the time-to-market for automation solutions, reduce system integrators' costs for deployment and mitigate the risks associated with the inherently brittle reliance on human expertise.
The core objective of FRAME is the development of new control and human machine interaction strategies to enable future assembly systems to become self-aware, self-learning, and ultimately self-adapting during ramp-up und proactively react to disruptive events.

Within the project a framework for the capture of ramp-up experience, from both the automation system (sensors and actuators status) and operator observations, has been realized. Human and machine interface were developed to interface with operators and control PLCs in a semantically and time synchronized fashion. Moreover, a semantic model to map ramp-up information against the underlying product-process-resource model of the assembly system has been implemented.
Performance metrics have been defined for in process ramp-up and calibration tracking, as well as reinforcement learning methods for both off-line and online learning of best ramp-up practices (policies) from captured ramp-up episodes.
The project included also a decision support system to recommend the most promising ramp-up and calibration actions based on learned policies.
FRAME focused on assembly but the framework is transferable to machining as well. Line balancing and ramp-up team management was not considered as part of this project.

Different benefits have been proved using the FRAME solution:

- Faster ramp-up and integration of assembly equipment. Improved ramp-up time by approximately 20-30%
- Even untrained operators were able to ramp-up a similar technical system with a similar performance to trained operators
- Improved visibility of the previously ill-understood ramp-up process which allows the measurement and comparison of performance

Figure 20 represents an overview of the ramp-up learning approach:

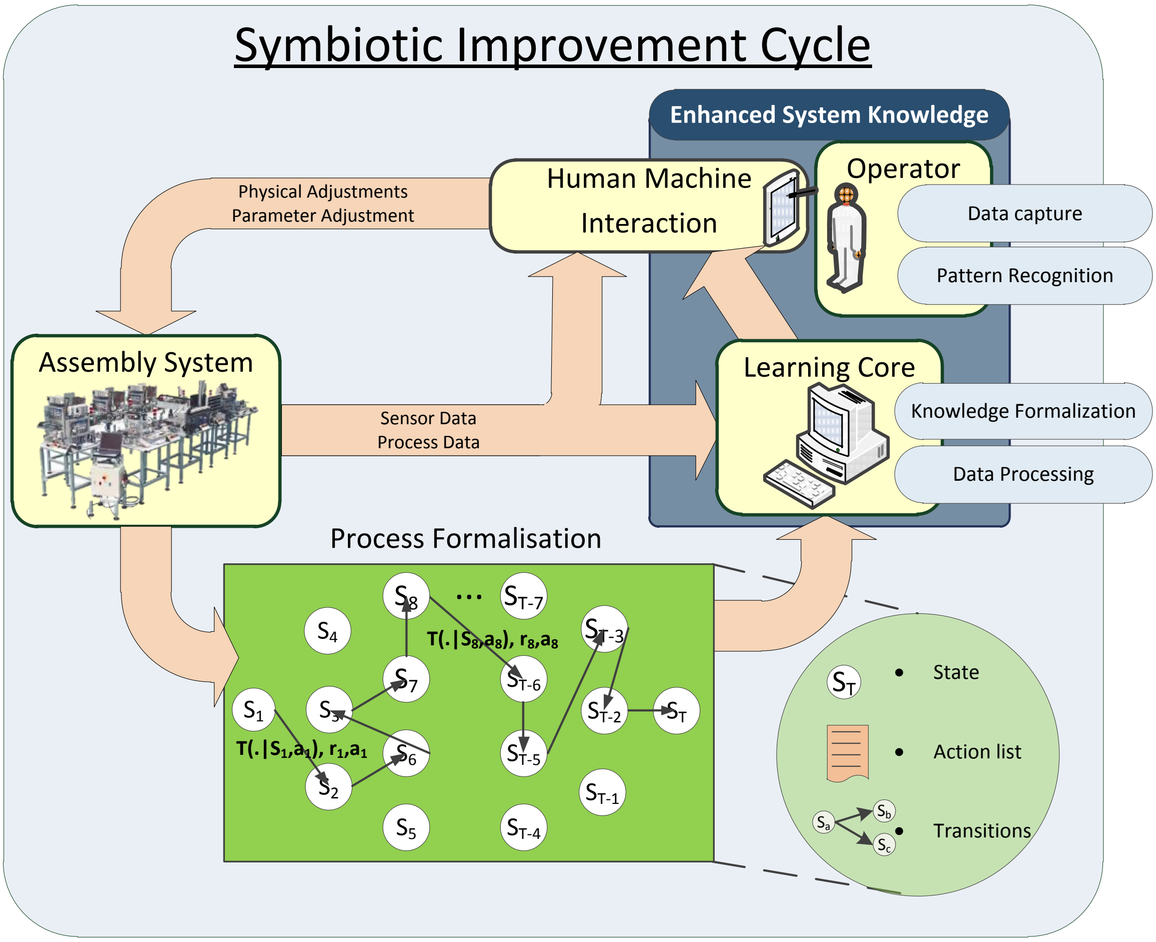

Figure 20: FRAME ramp-up learning approach [11]

Exemplary use case flow:

- Capture the current ramp-up (changeover) state of a technical system. Record both the technical status of the system, e.g. from PLC or other computer control, and any human observation, e.g. malfunctions.
- If the performance is below the desired level, ask for recommendations from the system based on past ramp-up cases and learned policies
- Implement the recommendation, or other action, and record what action has been taken
- Run a test of the system to capture the new state of the system and compare it to the previous state
- If the performance is still below the desired level, repeat the steps above otherwise the process is completed
- Store the ramp-up episode and apply the off-line learning algorithm to improve the ramp-up policy for this system

Figure 21 depicts the covered areas of FRAME project.

Figure 21: FRAME overall picture

In order to apply the FRAME approach to PERFoRM use cases, 3 steps are necessary:

- Create description of sensors, actuator and human observable state variables and discretized values

- Map performance metrics for change over
- Create semantic model to link product-process-resource information

PERFoRM partners involved in FRAME:

- Lboro: create semantic description of key equipment, process and product information to be observed during change over.

3.8. FLEXA

FLEXA (advanced FLEXible Automation cell) was a case-study driven project. The main objective of the project was to create the tools, methods, and technologies needed to define, prepare and validate an automated flexible cell that can manufacture a generic process chain allowing for safe human interaction and deliver quality assured parts for the European aerospace industry.
The end-users submitted real industrial problems, whose main features were abstracted to form the basis for the construction of two demonstrator cells. These proof-of-concept demonstrator cells were developed within the project, and the results were fed back to the end-user companies. The results were successfully validated and thus shown to be implementation ready.

The Volvo Aero Flexible Manufacturing System (FMS) was developed with the goal to compile the best characteristics. The idea behind the FLEXA project was to adapt and further develop the FMS concept by introducing new tools and technologies.
Examples of such tools were virtual manufacturing and knowledge engineering. Other examples were automatic restart of production cells and automated code generation for PLC systems.

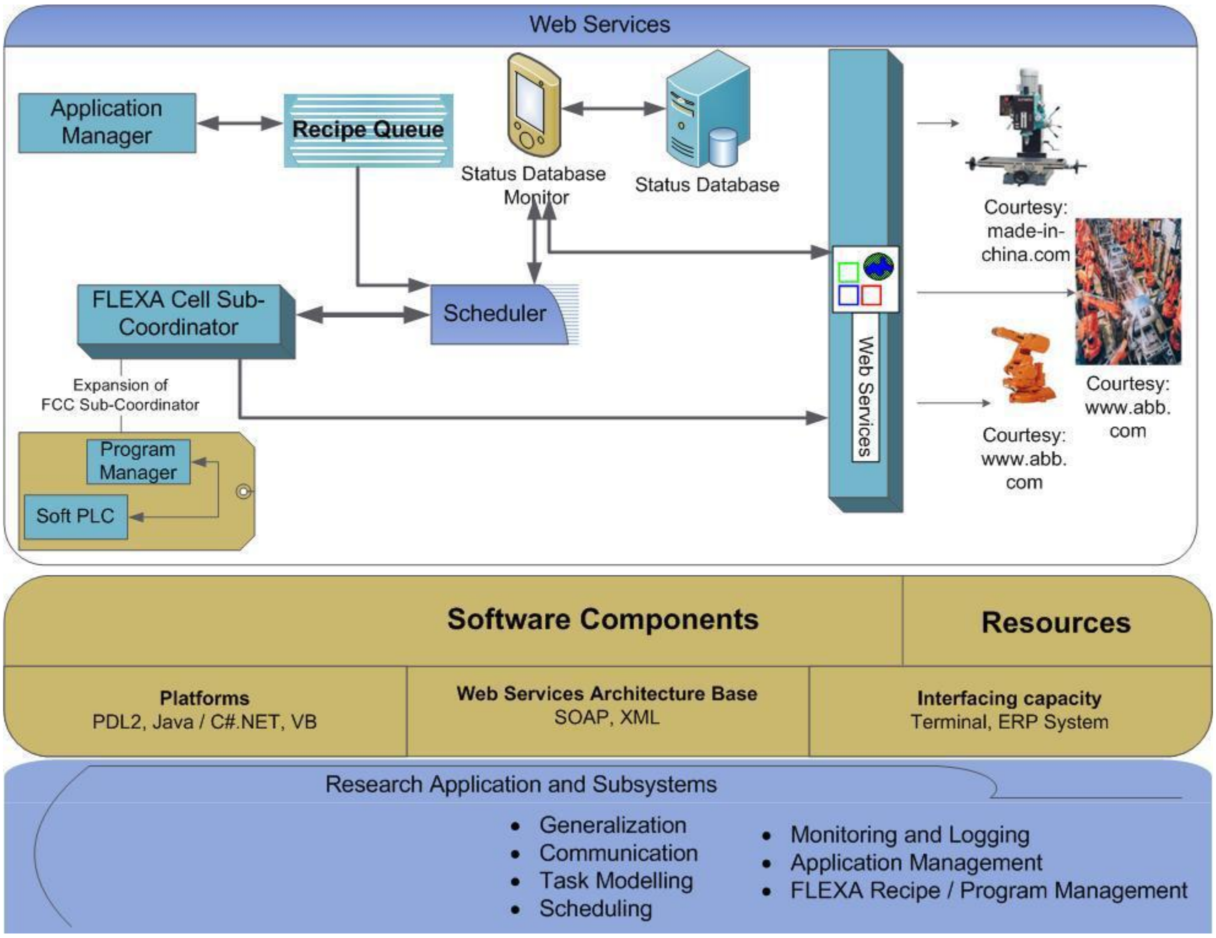

Figure 22: FLEXA Cell Coordinator architectural overview

The Flexa Cell Coordinator (Figure 22) takes recipe from FLEXA Database, schedules, and deploys on scheduled resources that are controlled by soft PLC. It also maintains its own log/activity database for tracking purposes and coordinates with external systems via web services.

The project realized and demonstrated a flexible cell controller, fully functional control software, in two cells. It also developed an integrated system from planning to production and a common interface for communication between automation resources.

Figure 23: FLEXA overall picture

As depicted in Figure 23, the FLEXA architecture was developed to provide a very flexible system capable to produce a large variety of products/product variants. It developed a solution for a FLEXA Cell Controller that uses an architecture that connects to ERP using middleware/MES, database, simulation and planning and the connection to automation resources (assets).

The demonstrators built to test the FLEXA system were equipped with assets such as robots using different kind of tools, inspection, joining and material handling, supported by inspection/testing and operators.

The assets were used in the following processes:

- Assembly – putting parts into fixtures before welding
- Joining – tack welding and final welding
- Grinding/deburring – process equipment in the cell or in the robot tool
- NDT (Non Destructive Testing) – Ultra sonic inspection of welds and machined surfaces
- Inspecting and measurement – geometry control station

FLEXA has developed the next generation production environment from an automation and flexibility perspective by introducing flexible automation and intelligent simulation tools that significantly can reduce installation time, time to reconfigure production and productivity.

The long term objectives are to deliver technology readiness by 2020 in the following three subjects:

1. Reduce aircraft development costs by 50%
2. Create a competitive supply chain able to halve the time-to-market
3. Reduce travel charges

Strong connections have to be considered between the performed activities corresponding to the three overall 2020 objectives. Successful improvement in production efficiency will be highly dependent on abilities to adapt to the further need for flexibility and use of reconfigurable manufacturing equipment.

Partner organizations represented three different groups – aerospace component manufacturers, SME companies and research practitioners.
PERFoRM partners involved in FLEXA:

- GKN: component manufacturing, design knowledge and authority regulations for manufacturing

3.9. ReBorn

The vision of ReBorn (Innovative Reuse of modular knowledge Based devices and technologies for Old, Renewed and New factories) is to demonstrate strategies and technologies that support a new paradigm for the re-use of existing production equipment in factories. It aims at delivering models and methods for innovative factory layout design with modular plug-and-produce equipment and flexible low-cost mechanical systems.
ReBorn will make a significant step towards 100% re-use of equipment focusing its approach on 3 main areas: modular plug-and-produce equipment, in-line adaptive manufacturing; innovative factory layout design techniques and adaptive (re)configuration; flexible and low-cost mechanical systems for fast and easy assembly and disassembly.

In order to achieve its goals, ReBorn (Figure 24) combines the knowledge from the technical experience made by former EU projects:

- From XPRESS
    - Production configuration & Optimization approaches
    - Self-description of devices (partly)
    - Workflow handling
- From EUPASS and IDEAS
    - Task driven production approaches
    - Manipulator, feeder and gripper technology
    - Agent technology
- From TRANSPARENCY
    - Self-description of devices (partly)
- From COPERNICO
    - Requirements capturing software approaches

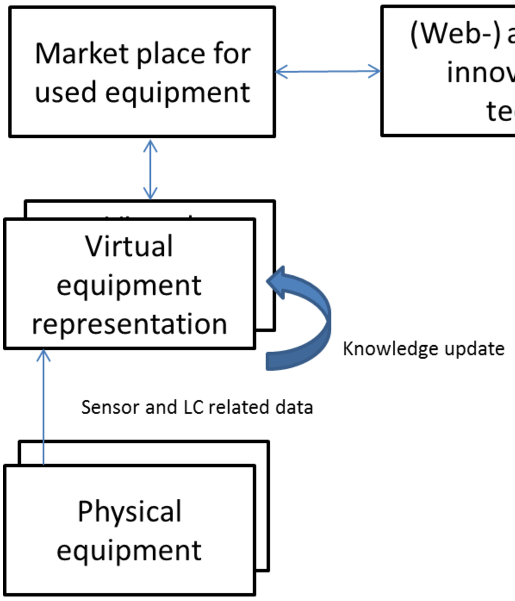

Figure 24: ReBorn approach

Re-use strategies will contribute to a greener manufacturing due to longer equipment use and reduction of investment costs. This approach will allow faster ramp-up and manufacturing system changes, with easier and more efficient factory planning processes. It also expected a higher flexibility of the manufacturing system due to reduced reaction times on changing markets.

ReBorn is predominantly focusing on the development of hardware (modular reconfigurable assembly equipment, electric presses, AM cells for automatic production of specific tooling and highly flexible resistance welding cells). Apart from this core activity there are development activities in the field of MES, i.e. additional software tools to retrieve maintenance relevant equipment status information and processing it, and layout planning, i.e. software to semi-automatically support the factory layout planning.

An overview of ReBorn is represented in Figure 25.

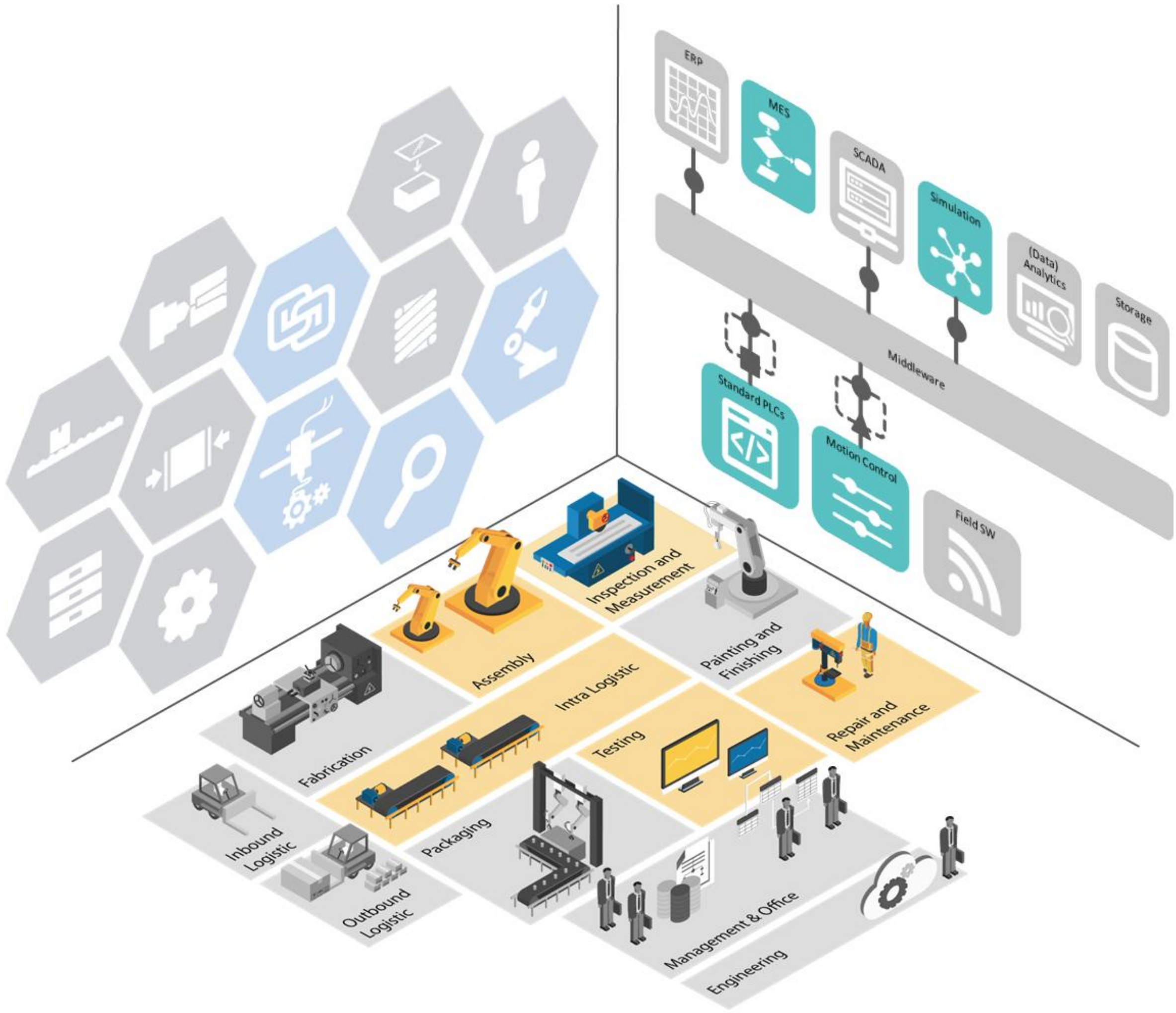

Figure 25: ReBorn overall picture

The ReBorn production system concept and its singular process units (AM production cell, electrical press, and resistance welding unit) consist primarily of physical equipment that is characterized by its re-usability and reconfigurability.

The physical demonstrators developed during the ReBorn project encompass the following elements:

- Flextreme assembly system developed and built by PARO
- An AM production cell with automatic pallet changer developed and built by Fraunhofer IPA
- An electrical press for very sensitive joining processes developed and built by IEF Werner
- A highly flexible resistance welding cell developed and built by TECHNAX

Necessary steps to apply ReBorn in industry:

- Implementation of ReBorn extensions in existing equipment or use of an external ReBorn enabled component
  - Self-description with extended life cycle information as specified within ReBorn specifications;
  - ReBorn model executors that are able to calculate information required for re-use.
- Use of online web application
  - Provide class libraries of own equipment in AutomationML format.

The consortium consists of software partners, responsible for developing applications and models, and industrial partners (machine builders, producers), that embed technology in controls, test and validate systems.
PERFoRM partners involved in ReBorn:

- PARO: developed a flexible modular assembly platform for small products.
- FhG-IPA: developed and built an AM manufacturing cell with automatic pallet changer, communication architecture and intelligent device concept.

3.10. SelSus

The vision of SelSus (Health Monitoring and Life-Long Capability Management for SELf-SUStaining Manufacturing Systems) is to create a new paradigm for highly effective, self-healing production resources and systems to maximize their performance over longer lifetimes through highly targeted and timely repair, renovation and upgrading. These next generation machines, fixtures, and tools will embed extended sensory capabilities and smart materials combined with advanced ICT for self-diagnosis enabling them to become self-aware and supporting self-healing production systems. Distributed diagnostic and predictive repair and renovation models will be embedded into smart devices for early prognosis failure modes and component degradations.

Figure 26 illustrates the overall system integration concept for SelSus. The *SelComp* component is attached to sensors or machine components. This component internally consists of a local data storage, statistical data processing and local Bayesian models to predict the health of the component. Additionally, this component has the ability to share the data acquired via the sensors to the MES cloud or store the data locally in the occurrence of a connection failure. The SelSus system also has a (1) global Bayesian model engine for diagnostics and prognostics of machine failures, (2) data store for sensor data and for supporting decision support of maintenance and repair activities as well as (3) SPC/APC. Components that have no SelSus capabilities are also able to communicate via the use of a Gateway.

The key objective of SelSus is to build an approach for systematic knowledge generation in the design phase and knowledge gathering and refining in the usage phase of the assembly station. This knowledge can be integrated into an assembly system and the knowledge transfer can be offered as benefit to the end-user of the machine. The transition from reactive and preventive maintenance to predictive maintenance enables the optimization of production line KPIs and better utilization of maintenance resources. By the early detection of hypercritical situations, caused by malfunctions of specific subsystems or component degradation, there is still a chance to avoid total breakdowns by implementing the appropriate repair, refit or refurbish activities. Thus, the lifetime of machinery and equipment can be extended significantly. Predictive maintenance, renovation and repair help to avoid failures of machinery and equipment and consequently lead to more human safety and thus to social sustainability.

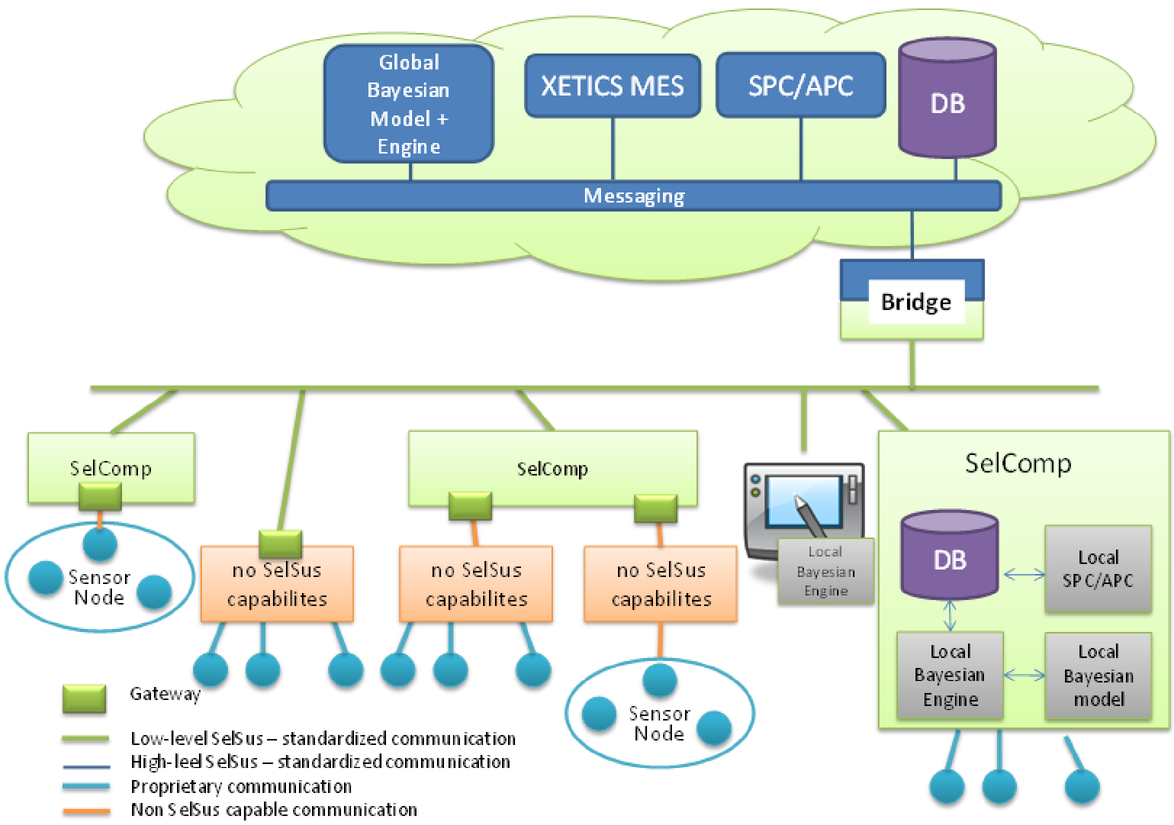

Figure 26: SelSus System Integration Concept

SelSus has developed a cloud-based common data model (Figure 26) integrated into the Xetics Lean MES system, connecting and storing the several components together:

- The SelComp components (machines, sensors, etc.) containing self-description, capabilities and measurement data;
- Components like SPC/APC system, FMEA, and DSS system, providing interfaces for other components to acquire data and run processes on them, e.g. decisions using the FMEA data and measurements.

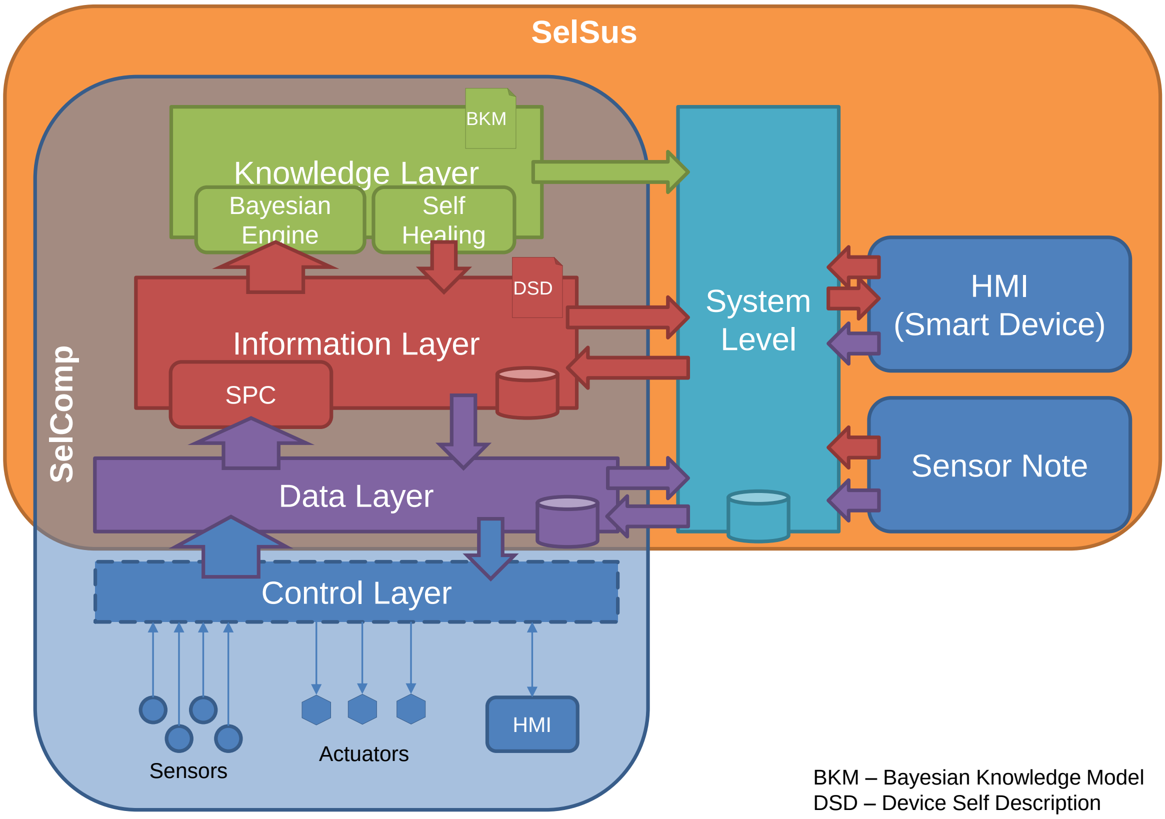

Figure 27: SelComp internal architecture concept

The overall strategy of the architecture is based on the concept of independent Smart automation Components that will be integrated bottom-up into a wider automation system. SelComp components (Figure 27) can be added to an existing production system and co-exist with components with no SelSus capabilities. As seen in Figure 27, there are four layers such as the: (1) *Control Layer* which is responsible for the interaction with the sensors, actuators and the HMI, (2) *Data Layer* which interacts with the system level, (3) *Information Layer* which comprises of the Device Self-Description (DSD) and (4) *Knowledge Layer* which consists of the Bayesian engine and the self-healing knowledge. Some parts of the SelSus system such as the developed decision-support system for maintenance and repair activities can be implemented with no risk of affecting production. The only requirement for the system to be able to generate predictions and suggestions on maintenance and repair activities is to enable access to sensor data, which can be stored in the production system of the end-user. The end-user would, however, need to create a copy of the sensor data in the SelSus cloud.

As a pilot experience, the system can be implemented in a single cell. For this cell, the operator should run the system at the beginning of each shift. The operator can then follow the maintenance suggestions provided by the system or perform tasks input into the system by the maintenance manager. If the pilot outcome is satisfactory and the system is to be adopted for the entire production line, diagnosis and prognosis models for each cell and component will have to be developed.

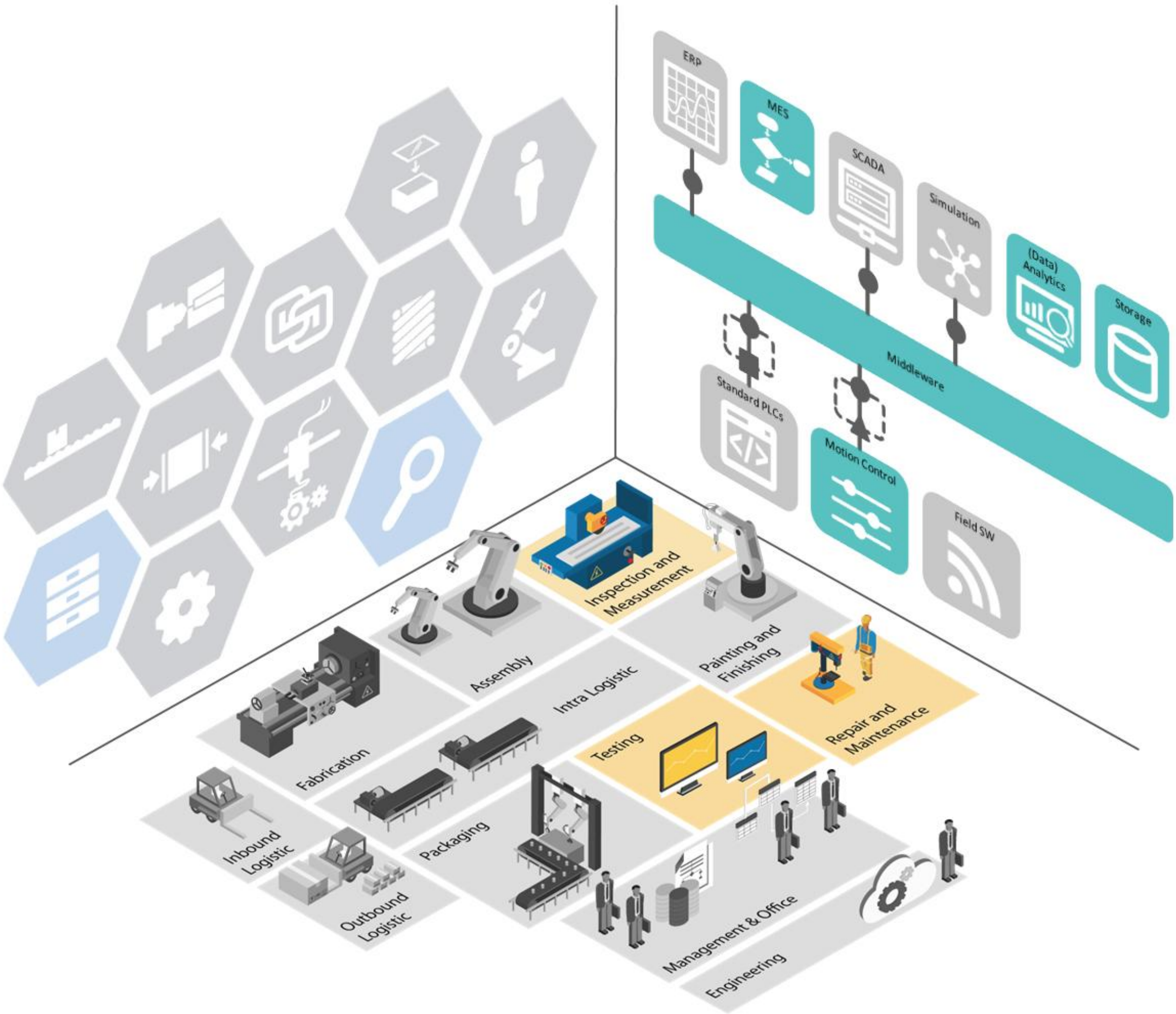

Figure 28: SelSus overall picture

The Selsus architecture consists of an MES system, simulation, decision support and distributed sensors to enable self-healing functionality. The production floor was equipped with self-healing machine components to enable the processes of repair and maintenance. (Figure 28)

SelSus provides several major economic advantages compared to the conventional procedures for monitoring, maintaining, renovating and repairing manufacturing equipment. The end user benefits from a high availability and reliability of the system and thus is able to produce a higher number of products at a better quality. By the deployment of the maintenance / renovation and repair, monitoring model costs can be reduced drastically. Firstly, increasing the lifetime of equipment comes along with a considerable reduction in costs of machines and components as well as energy. In addition, since the specific equipment problems are known in advance, maintenance work can be scheduled. This makes maintenance work faster and smoother. As machines are stopped before breakdowns occur, there is virtually no secondary damage, thus reducing repair time and cost. Studies have already shown that the implementation of a proper maintenance plan results in average savings of 20-25% in direct maintenance costs.
Multi-modal data acquisition techniques like smart devices, sensor network systems or Web-based services assure that all information on failures, failure modes, degradation states as well as renovation and repair activities is valid, up to date and well documented. This helps to optimize the life cycle of production systems.

PERFoRM partners involved in SelSus:

- FhG-IPA: project coordinators
- MTC: decision support system development for scheduling and maintenance activities based on HUGIN Bayesian models and a Ford Discrete Event Simulation model of their production plant; development of one of the self-healing components.
- Xetics: development of a common data model for life-cycle knowledge and the human – sensor cloud interface, Cloud MES system.
- Lboro: technical leadership

3.11. EMC²-Factory

The EMC²-Factory (Eco Manufactured transportation means from Clean and Competitive Factory) objective was to develop a radically new paradigm for cost-effective, highly productive, energy-efficient and sustainable factories, and apply it to selected cases in the transportation industry. It focuses on main energy-intensive processes within three industrial sectors in Europe (automotive, rail and aerospace), developing tangible and industry relevant results to be easily implemented in manufacturing environments.

EMC²-Factory project has developed procedures for systematic identification of improvement measures for energy efficiency in factories (direct production processes, shop floor, environment) and several methods and tools for energetic improvement (production and factory planning, scheduling, process chain planning).

The key project goals can be summarized in:

- Energy and resource efficient process technologies with specific focus on machining, joining and assembly.
- Innovative production planning and control systems and efficient process control devices, such as drives, actuators, and sensors.
- Methods and tools for planning, optimization and life cycle evaluation to support the design and management of eco-factories.
- Development of a novel holistic approach for eco-factories, integrating new as well as existing interdisciplinary solutions.

The main results in the EMC²-Factory project are classified into three different levels: Machine, Process chain, and Factory. For each level, two different types of results have been achieved: Planning and Operation. (Figure 29)

1. Factory level: solutions presented at this level are meant to support stakeholders with a broad perspective of the manufacturing system, considering not only the process of value creation but also the surrounding and enabling sub-systems of a factory. This includes managers and engineers of technical building services, facility management, production management as well as factory management with all related planning and operation disciplines.
2. Process chain level: it represents the arteries of the factory. Production planners design them around the product to achieve the best possible quality at the lowest possible resource input. Industrial engineers and technical experts operate the process chains at highest usage rate and with the lowest possible waste emission.

3. Machine level: the machine is the smallest but the most important entity of a factory system. A large group of actors, such as procurement managers, industrial engineers, maintainers and production managers requires an optimal information basis to obtain support in their daily business around the shop floor. Considering the machine also as a product, even more stakeholders such as research engineers, developers and after-sales staff come into play.

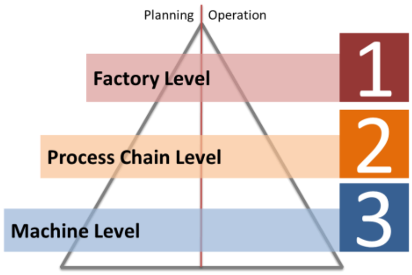

Figure 29: EMC²-Factory levels

The project (Figure 30) realized a systematic procedure for KPI-based, situation-adapted identification of measures and improvements within certain areas:

- Welding: mainly use of process gases;
- Scheduling: reduced energy through reduced process times and better adjustments;
- Factory planning and EMS: improved knowledge on consumption patterns and numbers, energy reduction through better adjustments of e.g. air pollution and required filtering/cleaning efforts.

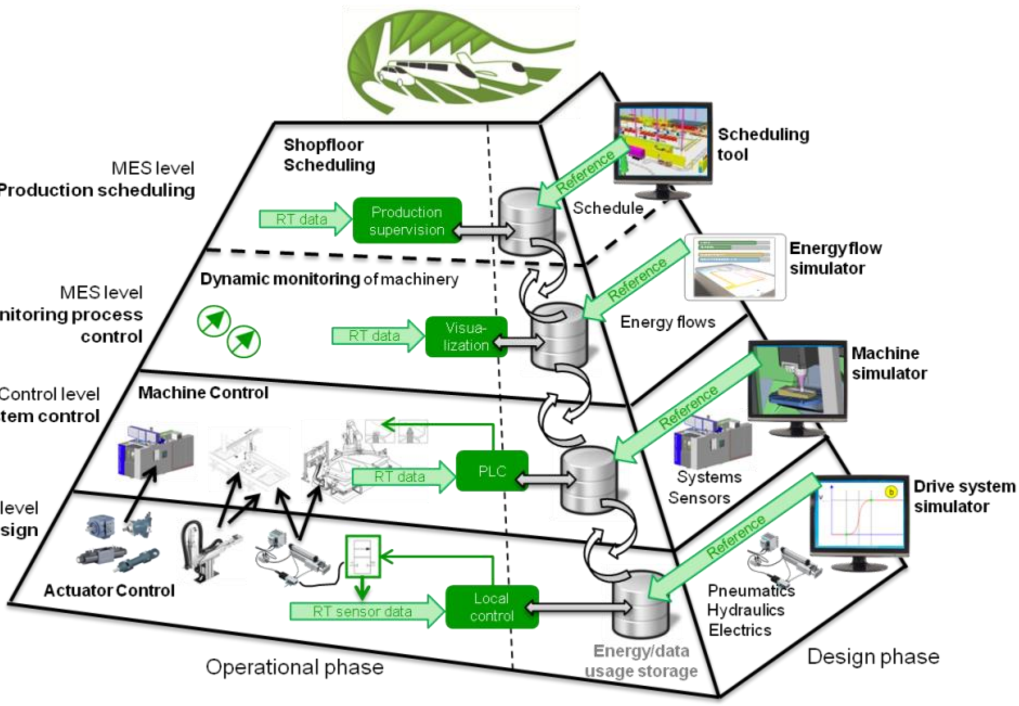

Figure 30: EMC²-Factory approach

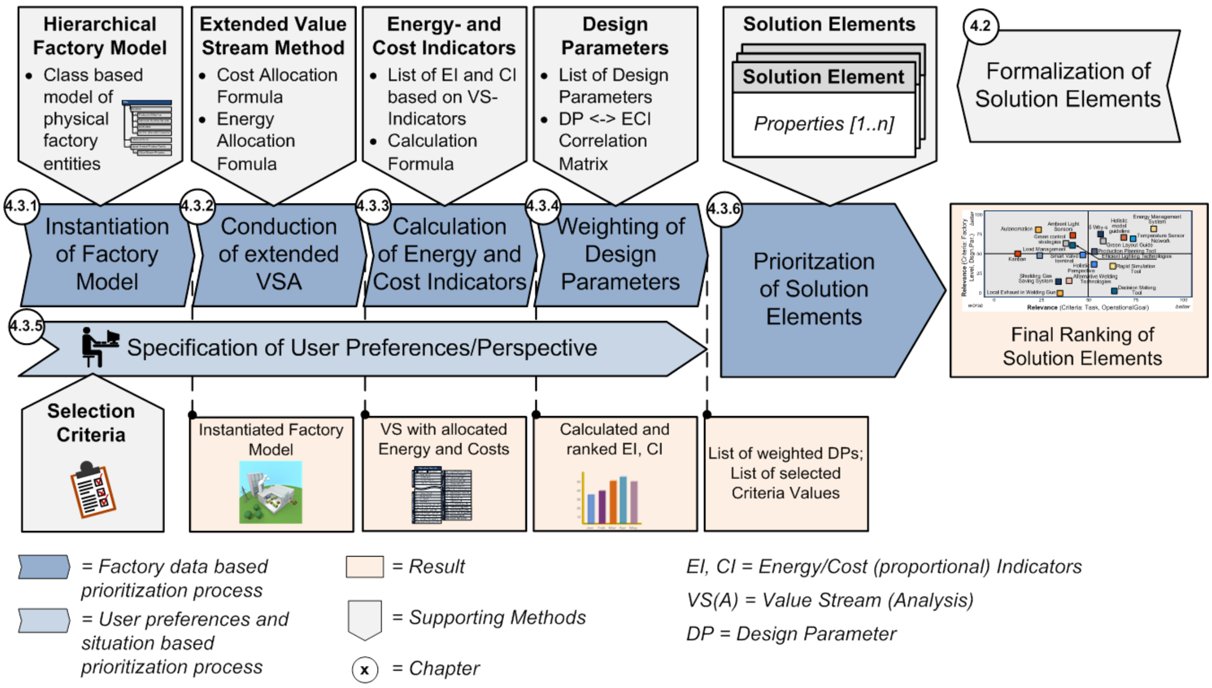

Figure 31: EMC²-Factory architecture concept

Figure 31 gives an overview of measure identification process:

- Model of factory as a class based hierarchical model;
- Conduction of extended value stream (energy data, cost allocation);
- Calculation and weighting of indicators for identification of cost and energy drivers;
- Prioritization of possible measures ("solution elements") leads to ranking of most suitable measures for given actual situation.

Several benefits have been identified in the three industrial contributors of the project:

- Aerospace: thanks to the MQL methodology (Minimum Quality Lubricant), a reduction of general coolant waste from machining operations of about 90% has been achieved. Through the implementation of control strategies, the energy waste during machining operations has been redubbed by 15%.
- Automotive: the achieved benefits are related to powertrain and body assembly operations. In particular, energy saving (-12% during work and -30% in standby), compressed air saving (-11% working and -35% in standby) and liquid coolant saving (-45% working and -90% in standby). Moreover, by redesigning and standardizing the main components of welding operation a welding gun weight reduction of ca. 30% has been achieved. This led to robot payload downsizing from 175 to 90 kg, with a robot number increase and line optimization.
- Railway: achievement in the area of compressed air saving, due to the application of intelligent valves to detect leakages and minimize waste, and welding technologies improvement, limiting the energy requirements in the process and all auxiliary systems. The development of a production planning software has improved the decision-making, reducing delays, setup operations and improving resources utilization.

Figure 32: EMC²-Factory overall view

The EMC²-Factory project involved fabrication, assembly, management (planning and scheduling: energy management) and engineering processes, focusing on material handling, machining, welding and robots assets. From the architectural view, scheduling (ERP), SCADA, simulation, data analytics and motion control, have been considered (Figure 32).

The necessary steps for application in industry comprehend the further development of wizard for measure identification for an extension to CPS-based targets and knowledge transfer of e.g. system integration experience towards integration of different data acquisition systems. Two points need to be considered as well: the industrialization of the solutions developed by EMC²-Factory and the customization of the solutions by tailoring the applications to specific needs and environments of the PERFoRM end-users.

The consortium included both research partners (manufacturing service, engineering service) and industrial partners (aeronautical, railway, automotive, machine tools, automation technology, and process control).

PERFoRM partners involved in EMC²-Factory:

- POLIMI: Holistic Perspective, methods and tools for energy-aware line and machine modeling and total factory modeling and simulation.

- COMAU: design and development of advanced body welding and powertrain systems for the automotive sector.
- SIEMENS: manufacturing processes assessment with a focus on joining processes, development of energy-oriented production planning tools, and factory planning and life cycle evaluation methods.
- TUBS: methods and tools to enable energy metering and monitoring, life cycle evaluation factories and dynamic energy and resource flow simulation of factories.

3.12. ARUM

ARUM (Adaptive Production Management) project aims to improve planning and control systems for complex, small-lot products manufacturing such as aircraft, aircraft interiors, and ships in order to overcome the following challenges: increasing risks from product immaturity and production disruptions due to market pressure; complex and highly customized products for small production series; planning and control of automation and ICT controlled manufacturing systems; weak integration of engineering to production (horizontal) and enterprise ICT to shop floor automation (vertical).

ARUM's approach is based on a new generation of service oriented enterprise information platforms. A holonic multi-agent system combined with service architecture will improve performance and scalability beyond the current state of the art. The solution integrates multiple layers of sensors, legacy systems and agent-based tools for beneficial services like learning, quality, and risk and cost management.
The project proposed a solution that includes:

- Intelligent Enterprise Service Bus (iESB), to validate the ARUM solution in different environments.
- Operational multi-agent system schedulers, combining agent-based technology with mathematical solvers.
- Strategic Planner (SP), i.e. medium-long term planning tools for strategic and tactical level.
- A set of ontologies, to support the data representation and exchange between the different set of tools and to allow the different tools to have a transparent access to the ARUM data.
- Factory and Scenario designer, which allow the design of the factory (resources, tasks, process) and the creation of the scenario where the ARUM solution was to be applied.
- A set of ESB enhancements, namely life-cycle management tool, node manager, transformation service.
- Event analysis tool, enabling the adjustment of the manufacturing process parameters, e.g. adjusting the processing time due to processing past events.

This solution allows: the improvement of the reactivity during ramp-up time in small-lot complex manufacturing; a better information flow in the manufacturing shop-floor; a more accurate and responsive scheduling and strategic planning tools; and seamless tools integration by the use of the iESB backbone.

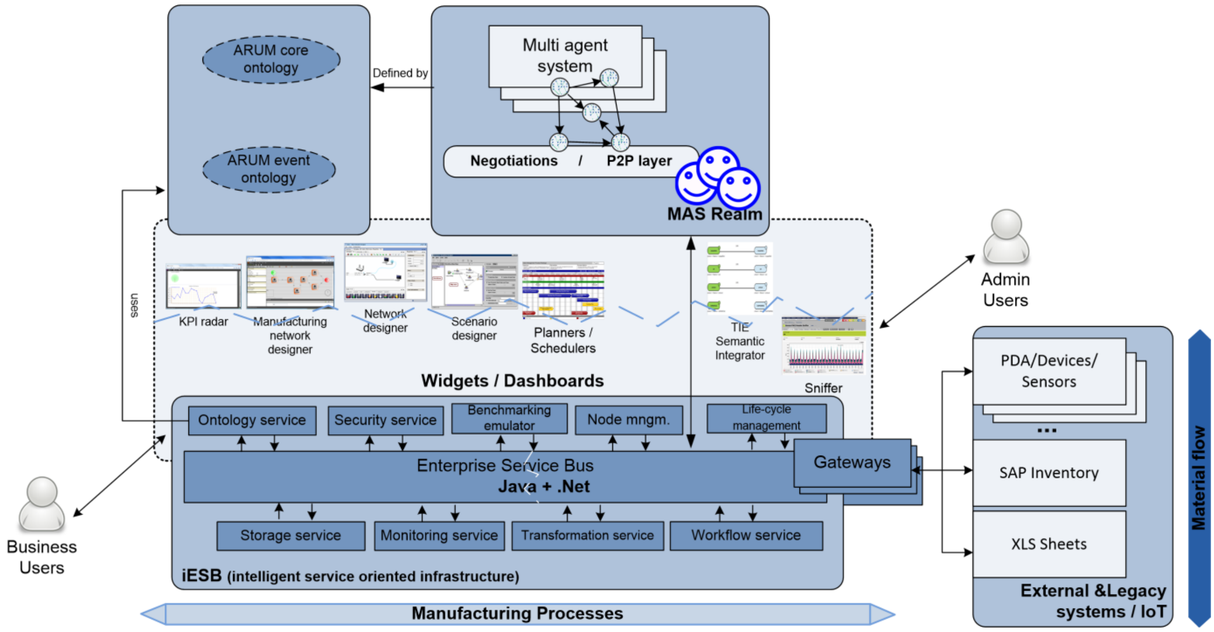

Figure 33: ARUM architecture concept

Exemplary Use Case Flow (Figure 33):

- Strategic planner user scenario:
  The factory manager loads the data of the company using the ontology service. This data is then customized accordingly with the user demanded planning scenarios; for example, the factory manager can introduce a peak of demand during a limited time interval or design a steady increase of a particular demand. After the scenario design, the user can then initiate the planning step where capacities can be adjusted to foresee what is the best strategy to overcome the designed scenario; as example, the factory manager, if realizing that the production capacity is over-passed, can initiate a situation of overtime working hours or the introduction of extra production lines.
  Naturally, each of the aforementioned situations has different costs and therefore, the strategic planning tool shows several KPIs screens to help the factory manager to select the most suitable solution. Additionally, the factory manager can initiate the strategic planning (SP) in the "what-if game more" where the tool, based on previous situations, calculates the most promising solutions.
- Operational scheduler scenario:
  Before the shift starts, all the operations are allocated to the available resources by the operational scheduler. In the case of a production disturbance, e.g., there's a missing part, the scheduler reacts by selecting the most appropriate actions; these actions can pass by a delay on the production cycle time, a process sequence change (if possible) or even by introducing travelling work where the affected operation will be postponed to be realized in a different station.

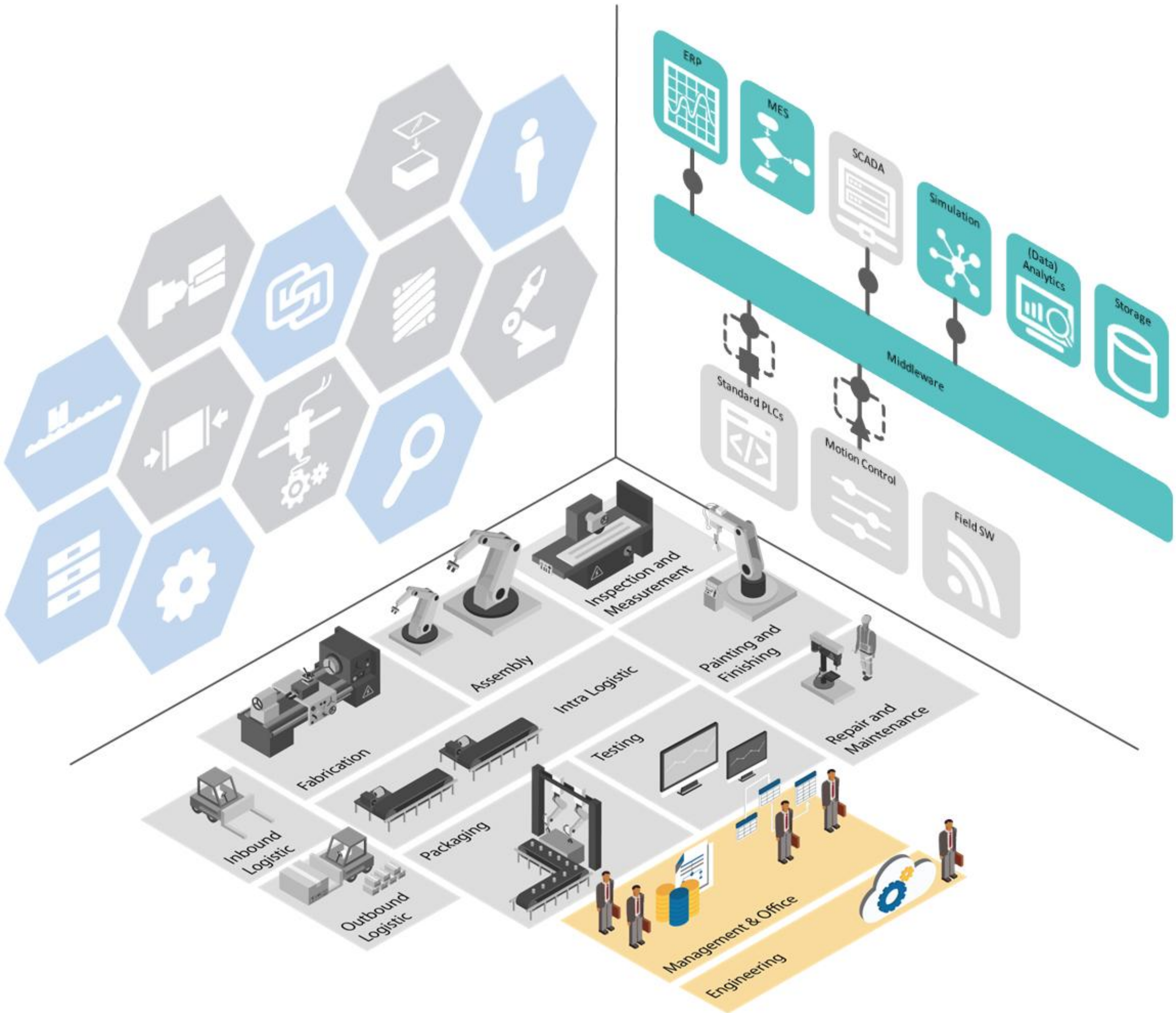

Figure 34: ARUM Overall picture

The ARUM project (Figure 34) focused its activity on engineering and management processes with strategic planning, production planning and operational scheduling. The approach has been validated in different environments.

In order to apply this approach to industry an ARUM compliant IT infrastructure is required, particularly the iESB, ontology service and desired tested tool. It is also necessary to have a design of the use case scenario where the ARUM solution is to be applied and data connectors' customization, enabling the conversion of legacy data into the ARUM ontological format.

PERFoRM partners involved in ARUM:

- IPB: specification, design and development of the strategic planning multi-agent architecture. Specification and development of the life-cycle management module. Specification of the conceptual view of a swarm of schedulers.

3.13. ManuCloud

The MANUCLOUD (Distributed Cloud product specification and supply chain manufacturing execution infrastructure) objective is the development of a service-oriented IT environment as a basis

for the next level of manufacturing networks by enabling production-related inter-enterprise integration down to shop floor level.
In order to achieve that in an efficient way, the project also developed self-descriptions for equipment, process- and factory level manufacturing services and related mapping mechanisms.
The ManuCloud solution consists of flexible composition of production facilities (throughout production sites) for simplified production network composition for personalized products, integration of production facilities by means of self-descriptions of "manufacturing services", and platform for manufacturing service management (including e.g. composition of higher level manufacturing services based on these descriptions).

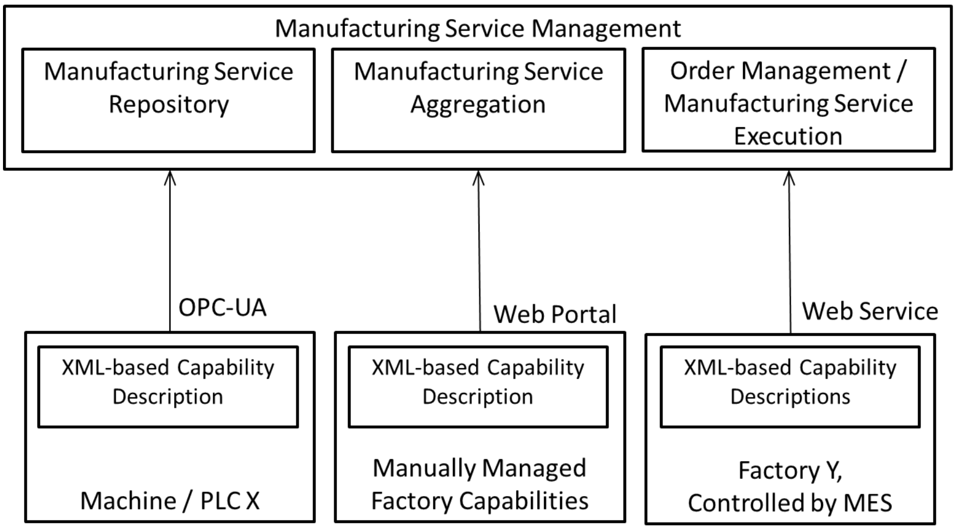

Figure 35: ManuCloud architecture concept

In Figure 35 is shown an overview of the ManuCloud solution:

- Capability Descriptions are generated (semi-)automatically during equipment engineering or MES configuration, or manually for non-automated production systems;
- Capability Descriptions are published to Cloud Manufacturing Platform (Manufacturing Service Management);
- Capability Descriptions can be searched, selected, and aggregated to higher-level manufacturing services (customer-specific end-products);
- Implementation of end-products based on these higher-level manufacturing services is controlled by order management / manufacturing service execution.

By means of using the ManuClod development, a considerable reduction of manufacturing equipment integration to high-level systems and factory-level IT configuration efforts is possible (up to 70% effort reduction). The platform can provide also a more flexible combination of configurable manufacturing services to higher-level manufacturing services (end-product production routes), that supports wider product variety, smaller lot sizes and personalization.

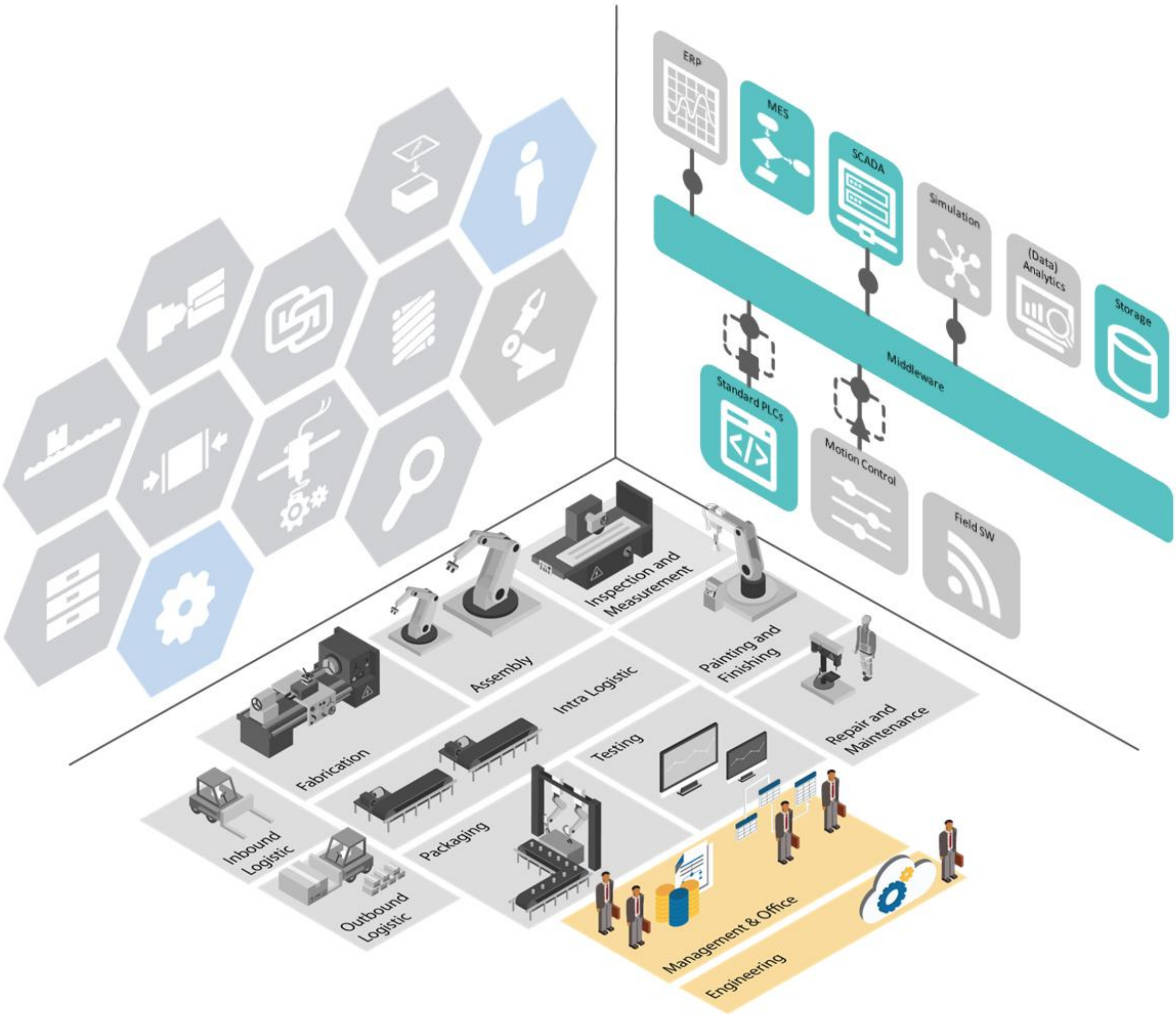

Figure 36: ManuCloud overall picture

ManuCloud validated its Manufacturing Service Management platform within a conventional production equipment, focusing on production planning and system integration, supply-chain manufacturing and equipment engineering. (Figure 36)

For applying ManuCloud in industry it is necessary to implement the creation of self-descriptions during the production equipment engineering, e.g. with PLC programming.

PERFoRM partners involved in ManuCloud:

- FhG-IPA: manufacturing service management platform and manufacturing service description structure.

3.14. I-RAMP[3]

I-RAMP[3] (Intelligent Reconfigurable Machines for smart Plug & Produce Production) vision "[…] is to enable the European manufacturing industry towards smart manufacturing systems in conventional production […]"[14]

I-RAMP³ aims at enabling the industry towards zero ramp-up time integration of additional capabilities in existing and new production networks. Four specific objectives were targeted:

- Plug&Produce devices, sensors and actors with built-in intelligence for fast exchange of components.
- Standardized communication and collaboration mechanisms in heterogeneous production environments.
- Intra- and inter-device optimization models for automated device configuration.
- Enhanced Manufacturing Execution Systems (MES) for workflow optimization and production data assessment.

I-RAMP³ allows component suppliers and system integrators to integrate knowledge in NETDEVs (NETwork-enabled DEVices), making hidden knowledge of NETDEVs available for factory optimization/reconfiguration. It also allows component suppliers and integrators to provide fast and tailored optimization services to end users.

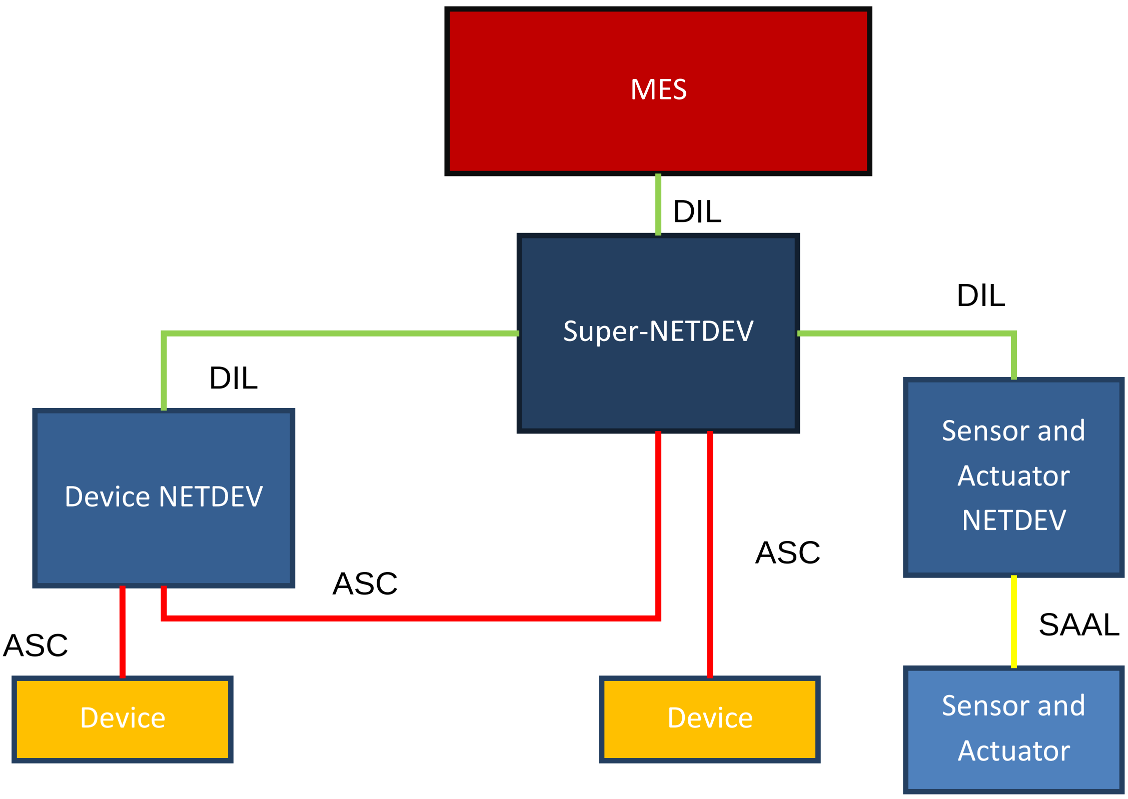

Figure 37: I-RAMP³ architecture concept

For its application in industry it is necessary to develop the I-RAMP³ shell for existing equipment or, when developing new control software, implement a NETDEV interface in parallel with other open or proprietary interfaces. It also necessary to create a NETDEV Self-description Document (NSD) that describes the capabilities of the I-RAMP³ enabled device. That NSD document can be a static file, but also a dynamically-generated one reflecting changing capabilities.

Figure 37 shows an architecture concept proposed by I-RAMP³ to verify the transformation of conventional production equipment into Network-enabled Devices (NETDEVs). Furthermore, NETDEV-based manufacturing system enables to integrate sensors with their actuators and sensor

grids. The standardized communication protocols and interfaces as well as self-descriptive capabilities are applied to realize the data transfer functionalities.
Lastly, I-RAMP[3] architecture enables to form the building blocks of a heterogeneous production network with optimal configurations and, thus, to adopt NETDEVs to varying production setup and conditions. As a result a "[…] fast component integration and exchange as well as rapid integration of entire manufacturing system […] "becomes possible [15].
In Figure 38 is showed an overview of the project within PERFoRM vision.

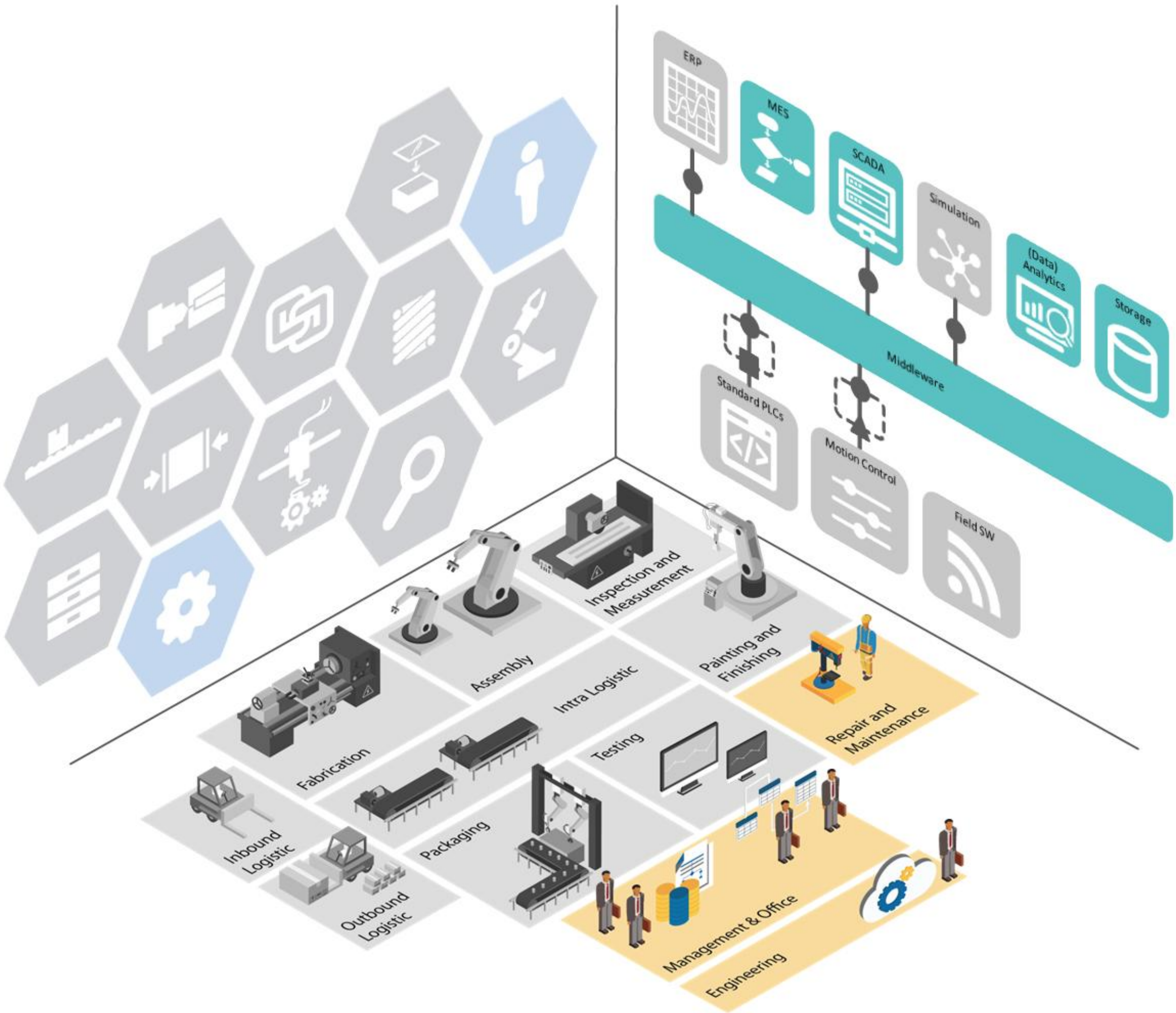

Figure 38: I-RAMP³ overall picture

PERFoRM partners involved in I-RAMP³ are:

- FhG-IPA: StationViewer visualization and control software with I-RAMP³ control point interface.

3.15. CassaMobile

The main goal of CassaMobile project (Flexible Mini-Factory for local and customized production in a container) is to develop a new kind of local, flexible and environmentally friendly production system for highly customized parts based on a combination of different manufacturing processes like 3Dprinting, CNC-milling and 3D-assembly technologies up to cleaning in clean room environment inside an enclosed unit such as a container.

The production system is based on a truly modular architecture, allowing rapid adaptation to new requirements. This ‘plug & produce’ architecture includes mechanical and control system adaptation. The footprint of the CassaMobile production container is minimized to enable transportation to and deployment in areas with severely limited space, whilst minimizing investment and infrastructure costs.

CassaMobile is implementing a self-adaptive control system for the container, which is able to handle the new challenge of modularity created by the modular CassaMobile concept that allows the user an easy interchange of different process modules. It is also developing a software suite with all necessary tools for the process chain of highly customized additive manufacturing parts (e.g. CAD/CAM, HMI, MES, quality tracking software for medical products, software-based interface coupler for various control systems).

The concept will be demonstrated by three use cases: bone drill guides for orthopedic surgery, medical orthotics and individual industrial gripping products.

In Figure 39 is presented the CassaMobile concept:

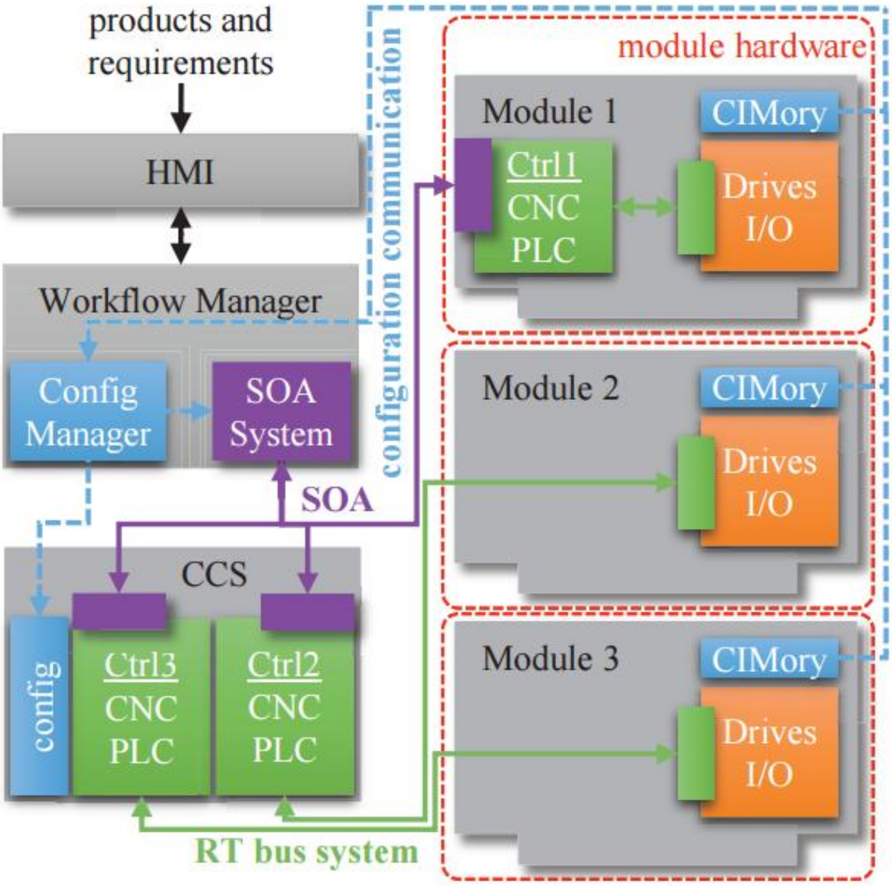

Figure 39: CassaMobile architecture concept

The Main Control of the CassaMobile container is the communication coupler between the HMI/CAD-CAM conversion software and the individual process modules and comprises the Configuration Manager, Workflow Database, and the Workflow Manager. The Main Control enables

an easy configuration of the production system and the product itself, even for an unskilled user. The Workflow-Manager is the central software tool of the Main Control and orchestrates the individual modules via the ModuleViewer (on each module control). The ModuleViewer is a general-purpose software solution to visualize, control and automate the process modules.
The Central Control System (CCS) of the CassaMobile container provides the possibility to operate modules without their own programmable logic controller (PLC). If a module does not have its own integrated control system, the developed Configuration and Information Memory (CIMory) of the module provides such information to the Configuration Manager, which in turn uses the CCS module to implement a separate, software-based real-time control system for that particular module.

By means of CassaMobile, it will be possible to realize plug-and-produce production systems for industrial and consumer goods with high flexibility with respect to products, production volumes, processes and production environments. These production systems will be also easily reconfigurable being equipped with intelligent, self-adaptive process modules, which can be brought into operation by inserting them into adaptable production systems without expert knowledge.

Figure 40 depicts CassaMobile project.

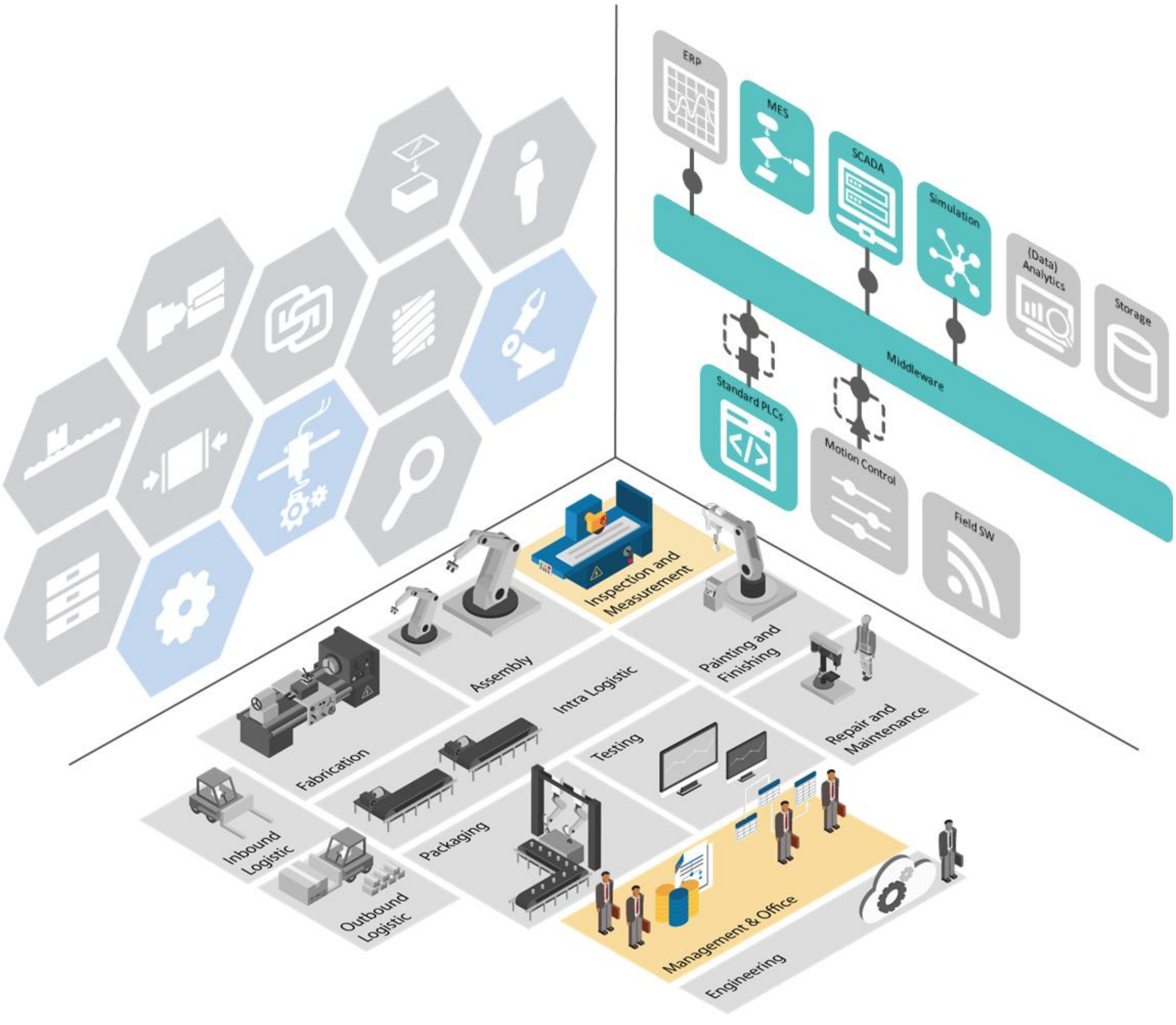

Figure 40: CassaMobile overall picture

CassaMobile can be easily applied in industry, it needs to be equipped with a PC-based control system like soft-PLCs with the software based coupler system called "ModuleViewer": for modules without an own control system, the CentralControlSystem (CCS) provides the possibility to operate these modules. Moreover, it is required a compatible self-description file for the developed Configuration and Information Memory (CIMory) system. Finally, to facilitate the "plug and produce" integration of the modules, it must be compatible within the CassaMobile container architecture

PERFoRM partners involved in CassaMobile:

- FhG-IPA: Software coupler system (ModuleViewer), MainControl of the CassaMobile container, Assembly module, 3D-printing module, cleaning module, system architecture.
- Lboro: adapting and optimizing the selected AM processes for integration into the proposed whole system, including hardware adaptation, and in-process inspection.

4. Industrial Use Cases

PERFoRM will define a common parameterized plug-and-produce approach based on the cyber-physical production system concept applied to four different industrial use cases:

1. Siemens AG – Compressors (D7.1)
2. IFEVS – Micro electrical vehicles (D8.1)
3. Whirlpool – Home appliances (D9.1)
4. GKN – Aerospace (D10.1)

This chapter mainly provides an overview of each use case current scenario within the PERFoRM framework picture, describing also open issues and their scope of the project.

4.1. SIEMENS – Compressors

The Siemens use case focuses on the production of compressors (Figure 41) in a highly individual customer market environment. The Duisburg factory provides an ideal use case for the investigation of handling small lot sizes (1-30) in an increasing rapidly changing manufacturing environment with balancing costs, quality and customer demands at the same time.

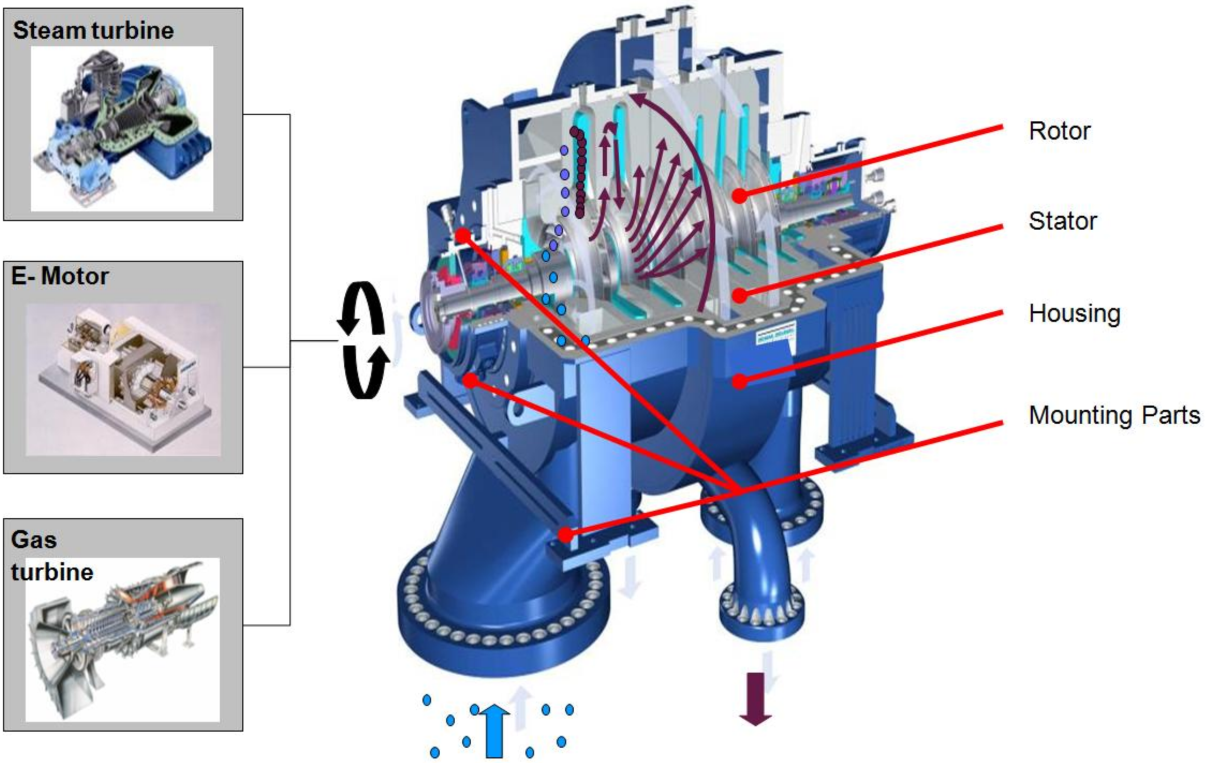

Figure 41: Siemens compressor and its main components

The use case main objective is to improve the maintenance planning and equipment availability in the mechanical production area in order to reduce delays, improve quality and reliability, reduce downtimes, and move from reaction to errors to preventive maintenance.

Today the Siemens manufacturing of industrial compressors (Figure 42) is characterized by:

- One-of-a-kind-products and small lot sizes

- Mainly machining processes and assembly
- Flow principle being established currently
- High share of manual labor
- High complexity especially in assembly

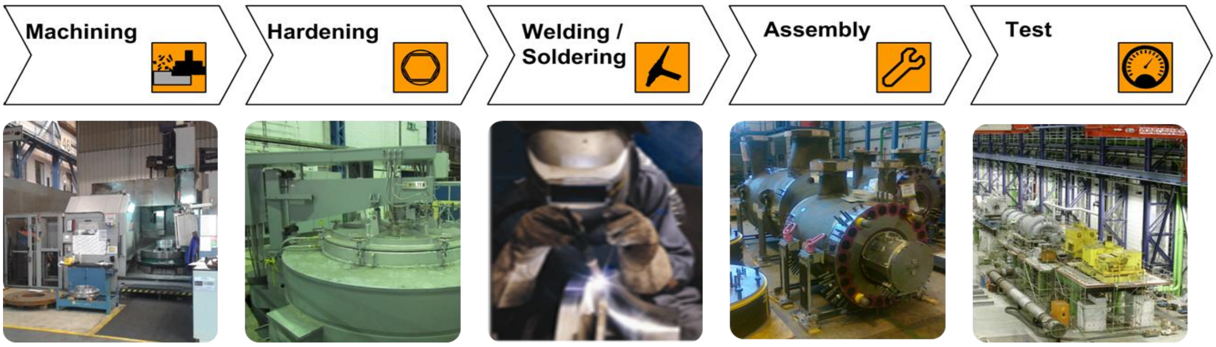

Figure 42: Siemens compressors process chain

The departments involved are:

- Manufacturing: machining (turning and milling)
- Maintenance
- Production planning and scheduling.

The application targets on improving machine availability in the area of rough machining of stator castings. Turning machines in the target area are equipped with machine data logging and manufacturing data acquisition systems (proprietary applications), SAP for ERP/MES levels, and manual adjustment of maintenance scheduling in place (using factory task planning application with the underlying database).

The in-house Windows software for machine data acquisition and for maintenance planning and failure reporting are neither synchronized nor integrated. Moreover, there are no dedicated sensors implemented in machines.

At present, physical data cannot be acquired in an adequate manner, due to the unavailability of sensors and the impossibility of data correlation to draw planning decisions. There is also no transformability from machine to machine (single purpose solution) and it is necessary to have higher skilled operators.

The scope of the project is to improve machine maintenance by predicting maintenance needs using existing manufacturing data and additional newly implemented sensing technology for data acquisition. Furthermore, it is required an integration of production data acquisition (logs machine failure codes) and maintenance planning system (controls maintenance and spare part management). It is also necessary to increase the detail of failure data immediately, which needs to be acquired as working base.

The expected advantages are:

- Improve the prediction of machine health
- Derive maintenance tasks
- Reproduce and learn maintenance objectives and executions (knowing tasks when coming to machine)
- Schedule tasks within production schedule for avoidance of breakdown / unplanned downtime
- Increase productivity (available machine hours)

- Reduce maintenance costs
- Better align maintenance planning and reality (execution time, costs, spare part procurement and availability)

Figure 43 depicts the current status of the use case:

Figure 43: SIEMENS use case overview

4.2. IFEVS – Micro Electric Vehicles

The IFEVS use case deals with the assembly of low cost full electric vehicles with high variants and high quality on low budget assembly lines. It aims at making available low cost automated flexible turnkey assembly lines starting rapidly manufacturing of safe, ergonomic clean and efficient vehicles adapted to local needs. Highest flexibility is needed here to process all variants (Figure 44) on the same workstations, which so far can only be provided by human operators.

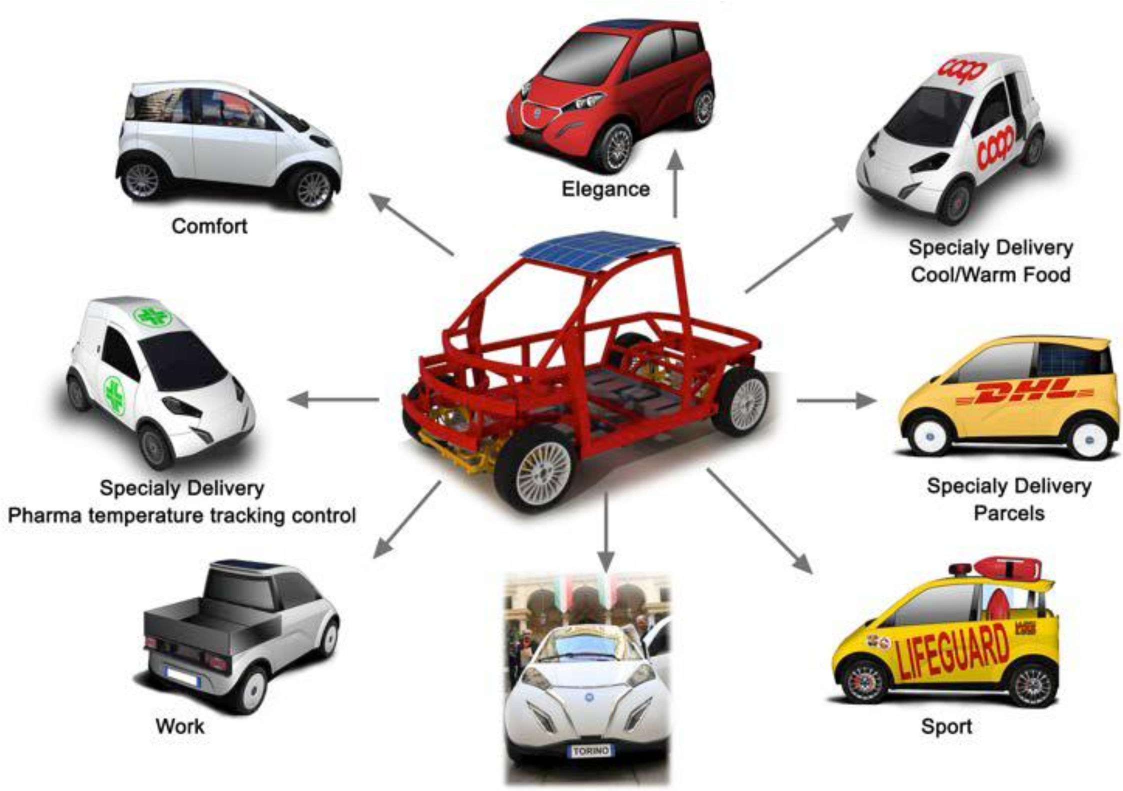

Figure 44: IFEVS Micro Electrical Vehicle variants

Each vehicle, powered by Ion-Lithium batteries and photovoltaic cells, is planned and designed as a modular product and it is composed by:

- Two identical axle systems using a parallelogram suspension system;
- Two motor power trains with two identical motors and transmission systems in 4WD configuration;
- Tubular chassis and rotomodular bumper coupled with two identical axle systems.

The production of micro electric vehicles consists of:

- Research and development (e.g. testing labs)
- Manufacturing: manual welding
- Assembling
- Painting (outsourced)

The main objective of IFEVS use case in PERFoRM is to demonstrate a prototype robotized line capable to potentially assemble 50 chassis per day that could be used for at least two different purposes (with a focus on non-passenger vehicles) derived from a single chassis with minor changes, low upfront investments, easy to find materials and components.

In order to introduce flexibility and cost reduction, it proposes the application of a parallel like method of manufacturing against the most usual approach based on the criteria "*the larger the plant the lower the final cost per unit produced*".

Because the expectation is for a large demand variability of vehicle typologies, to take the full advantage in utilizing the flexible systems the following open issues have to be addressed:

- Quick adaptation of the production line from small lots of specific vehicles to larger lots of passenger cars;
- Minimizing human errors when selecting settings and parameters;
- Minimizing the variability of operations such as manual welding of the tubular chassis by introducing a high degree of robotized welding;
- Satisfying the highest automotive quality standards by tracking the incoming parts, sub-modules processes, and integration phases;
- Introducing testing methodologies on sub-modules before their integration.

The production line has not been set up yet, it is manual and there are no technologies available. To realize those objectives, the assembly line has to be upgraded from manual operations to robotized systems leading to relevant implications on the existing components used on the production floor.

The Figure 45 below gives an overview of the micro electric vehicles use case:

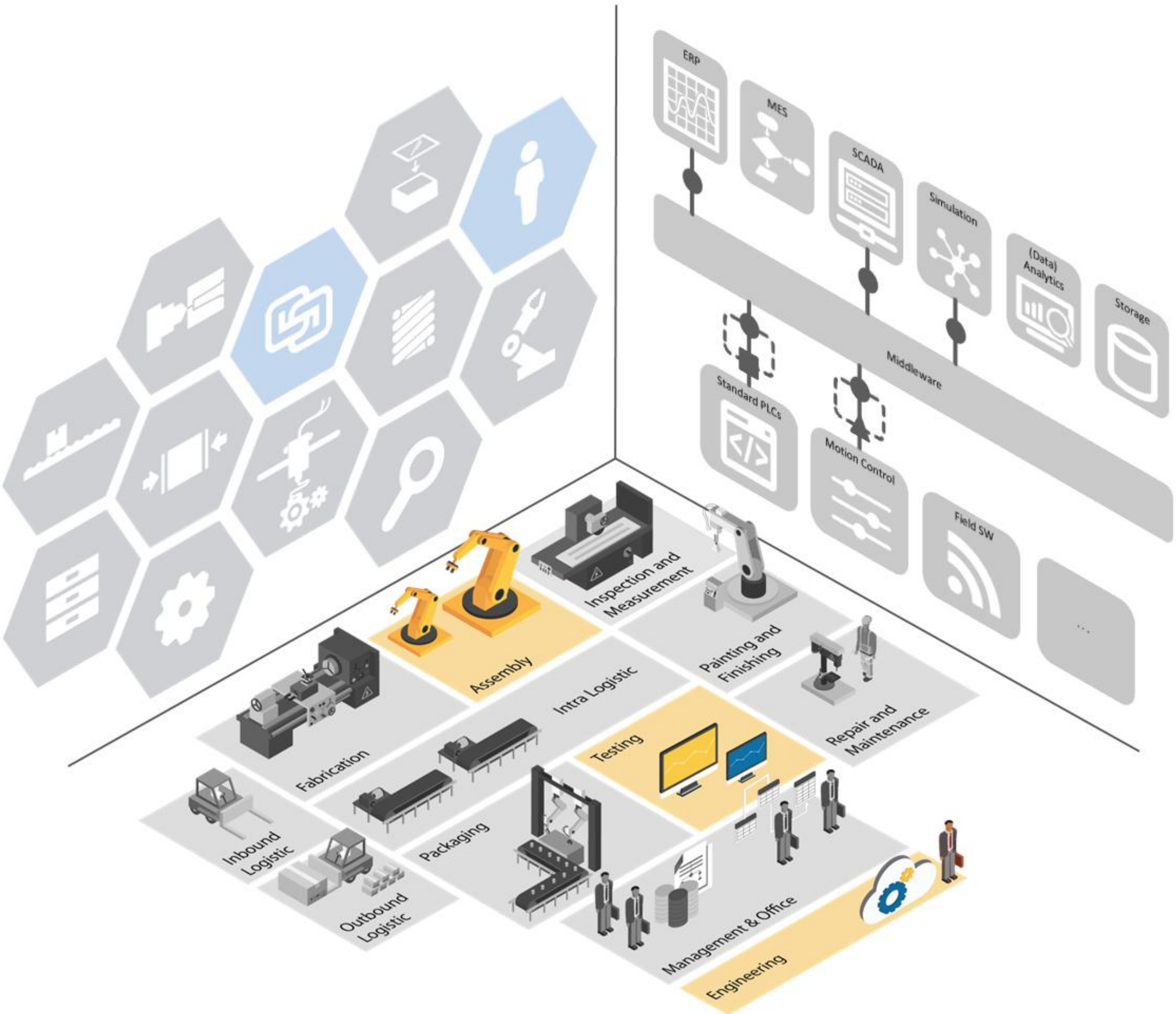

Figure 45: IFEVS use case overview

4.3. WHIRLPOOL – Home Appliances

The Whirlpool use case focuses on the production of four types of built-in microwave ovens in already partly automated production systems. The challenge of this use case is the lack of available real-time shop floor data and its integration into the production system controlling and planning (Figure 46).
Currently, the company monitors the behavior of the factory by measuring some KPIs that are then used to take decision on both dynamic and static factors and monitors the behavior of a selection of single equipment or departments (i.e. dynamic factors) measuring some of their performance in order to put in place local optimization actions.
The Whirlpool use case will be based on a real factory in order to establish a real-time monitoring system able to correlate the dynamic behavior of the factory to its Key Performance Indicators (KPI) and static Key Business Factors (KBF), and enable its fast reconfiguration.

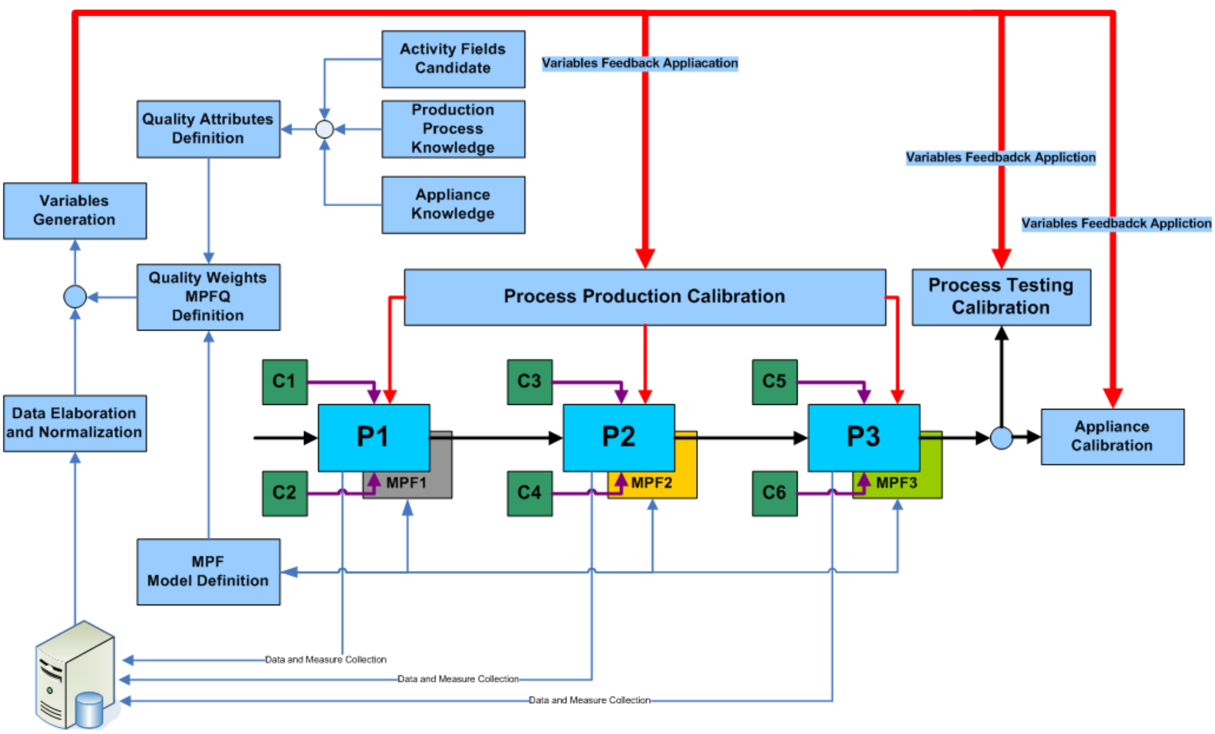

Figure 46: Whirlpool current logic for process control

The factory is a mix of production lines and cells with automatic, semi-automatic and manual operations and a production capacity of 500K to 1M pcs/year.
Data are gathered with different Quality and Production systems (MES tools). The decision-making process is a sum of the different levels of operations based on KPI elaboration without any real time support tool. Only post elaborated data (excel, Minitab, etc.) is sometimes used to support medium to long-term decisions. Moreover, Production and Quality KPIs are communicated in a point-to-point way, i.e. only needed data to needed people at specified time.

The use case considers four typologies of microwave ovens composed by:

- Metallic frame
- Microwave door
- Turn-table
- EMF source

The processes involved in the production are:

- Research and development (e.g. testing labs)
- Manufacturing: plastic processing
- Industrial foaming
- Assembling
- Painting
- Industrial bonding
- Quality control

Plastic and metallic semi-products are fetched from the warehouse, and then the pre-assembling of these semi-products is regulated from scheduling process. Assembling of macro-components and bonding are automated while the assembling of final components is manual.

The production system is equipped with statistical process control (visual measurement system for the correct components alignment), PLC and robot alarm system (sound system to warn the line block), assembly kit (part-number collected in suitable kit in line with the logic KANBAN), and production control (display panel which shows the updated production status).

The main challenge of this use case is to overcome the following issues:

- KPIs are currently analyzed and monitored in a “silos” way.
- Each KPI family is used for a specific objective
- Re-configuration activities are driven by single KPIs
- No high-level simulation of factory exists and thus, reconfiguration can’t be tested in a dry environment

It must be taken into account that legacy sensors, PLC and SCADA layer cannot be modified in the short to medium term, Standard and well-established components, protocols and operating systems are required, bearing in mind that some equipment services, logic and software are not owned by Whirlpool.

The use case can be summarized in Figure 47 :

Figure 47: WHIRLPOOL use case overview

4.4. GKN – Aerospace

GKN manufactures different families of complex, high-value jet engine components (Figure 48) with very stringent quality characteristics. The use case will be based on the plan to build and demonstrate a flexible and reconfigurable production line. The components are designed and produced using advanced materials and processes to meet the specifications and requirements for their function, performance and reliability. The production system is largely a functional workshop with standalone work centers and a mix of dedicated and common resources. Cycle times are relatively long, typically 6 – 12 hours. The level of automation is usually rather low and more of separate process automation cells with low level of process flow integration. The production system has to cope with a large variety of different components, low volumes, and varying demands.

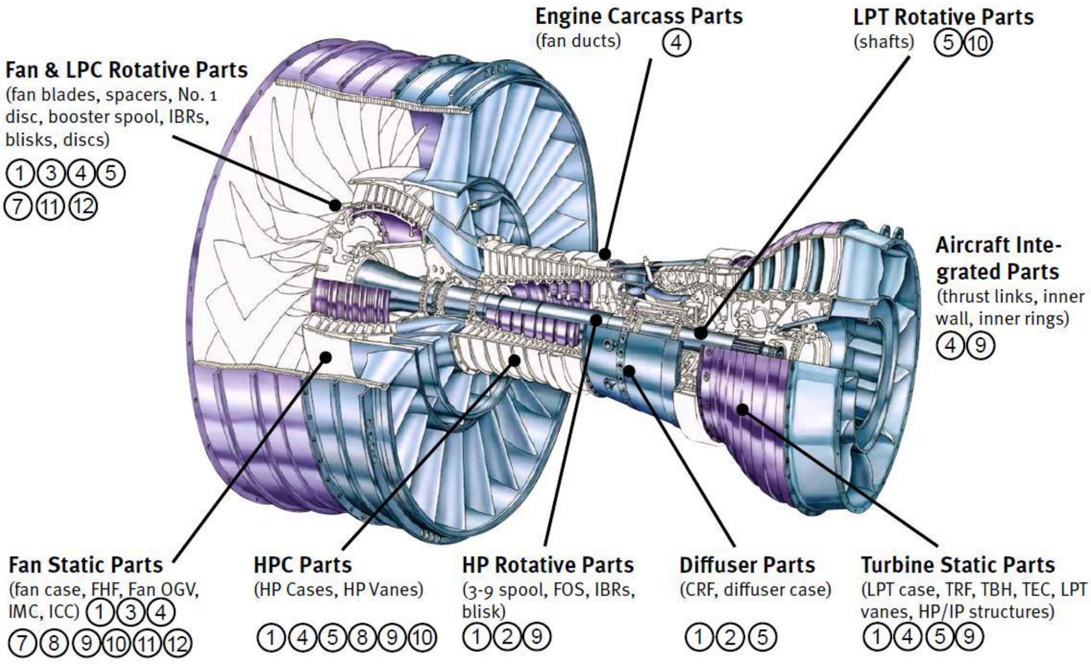

Figure 48: GKN engine product

The production system consists of manual and semi-automatic processes: CNC machining (welding), robotic cells (deburring) and human operations (especially inspection and assembly).
All the data information are then stored in ERP system to fulfill the requirements for traceability.

The goal is to demonstrate more agile production solution, called “micro-flow” concept, designed to be a modular system / platform with a large flexibility potential and be able to be reconfigured for different kinds of processes and products. This cell is an integrated system that can complete a well-defined part of the value adding process chain. Alternatively single processes can be done to serve different parts in a mixed product value stream. The process can be fully automatic and/or supported by manual processing or assistance. Except for the value adding process, cleaning and inspection/measurement is needed to control quality and record process and/or product data. Over time, different kind of process modules can be developed and introduced in the different cell configurations. The principles of the concepts are illustrated in Figure 49.
The goal is also to make it a unit that can easily be moved to another location when needed. This will require integrated tools and solutions to facilitate fast reconfigurations and reduce time and cost for changeovers and moving from one location to another.

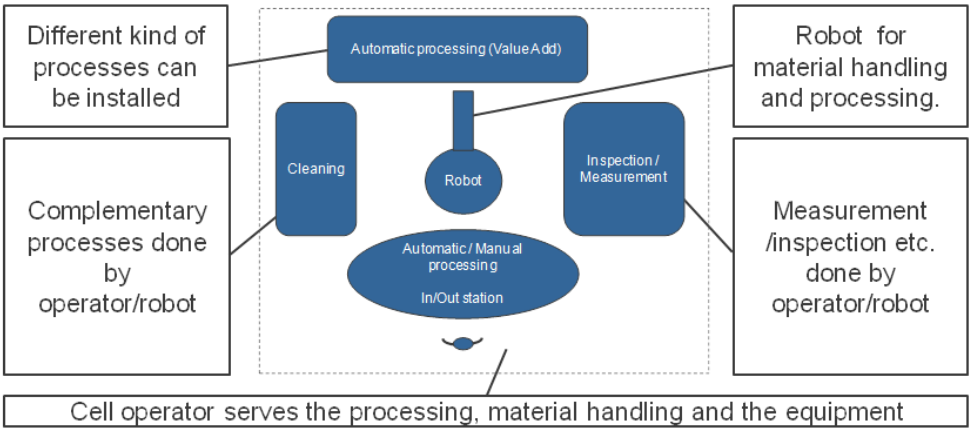

Figure 49: Micro flow concept for the GKN use case

The main involved operative work processes are:

- Manufacturing: brushing, marking, surface measurement and dimensional inspection
- Material handling
- Manufacturing engineering
- Maintenance

Robot automation processes should improve the current low level of automation. A small sequence of processes / assets will be integrated into modular cells with low level of complexity. Also, the integration of human resources and their safety will be an important task.
The layout and production flow will be simplified, yet flexible to adapt to the need of capacity and the localization of the cell and which product it should process: thus, it is possible to set-up the production resources / capacity where it is needed.
The modular system will require a reliable plug and produce solution for the cell components (interfaces / adaptors and middleware for communication), as well as data management and connection to ERP system.

To realize the modular cell concept, for flexibility in making changeover to different products and quick reconfiguration for different tasks the three different kind of interfaces are essential:

- Mechanical interface – to enable a quick change over of equipment / components and good enough defined localization etc.
- Electrical interfaces –to connect different components in a cell architecture in a quick way and support the concept of flexibility / reconfigurability. The adaptors between components and the functionality of components will be a key issue.
- Software interfaces – reliability and simplicity of middleware / protocols to allow the required communication.

The high quality and safety standards and strict requirements on traceability of e.g. materials, process data and inspection and other product data will need special care and attention to make this system qualified and approved for aerospace use.

In the current production floor, many resources and components can be used, given that they are reasonably up to date regarding any control system and software and have the option of being used in an automated process/cell. It should be considered that each component or resource will need more or less adaptation regarding the physical interfaces, media supply and control software.

Adaptors and middleware solutions will be needed anyhow due to the lack of current standards and different suppliers.

Figure 50 sums up the GKN use case:

Figure 50: GKN use case overview

5. PERFoRM Objective

PERFoRM project aims to develop a next generation of agile manufacturing systems that are dynamically reconfigurable and evolvable to cope with smaller lot sizes and shorter lead time and time-to-market, based on plug-and-produce systems concept. The project intends to validate this approach universally for different kinds of industry needs. In order to find a general approach, four industrial use cases will be investigated, covering a wide range of manufacturing systems, different in industry domains, product sizes, production volumes and process types.

The PERFoRM industrial use cases could take several advantages in utilizing flexible and reconfigurable systems based on Cyber-Physical Production System philosophy, albeit they have diverse goals due to the different nature of their products. Figure 51 depicts the focus areas of all the industrial use cases in PERFoRM surrounded by a blue frame.

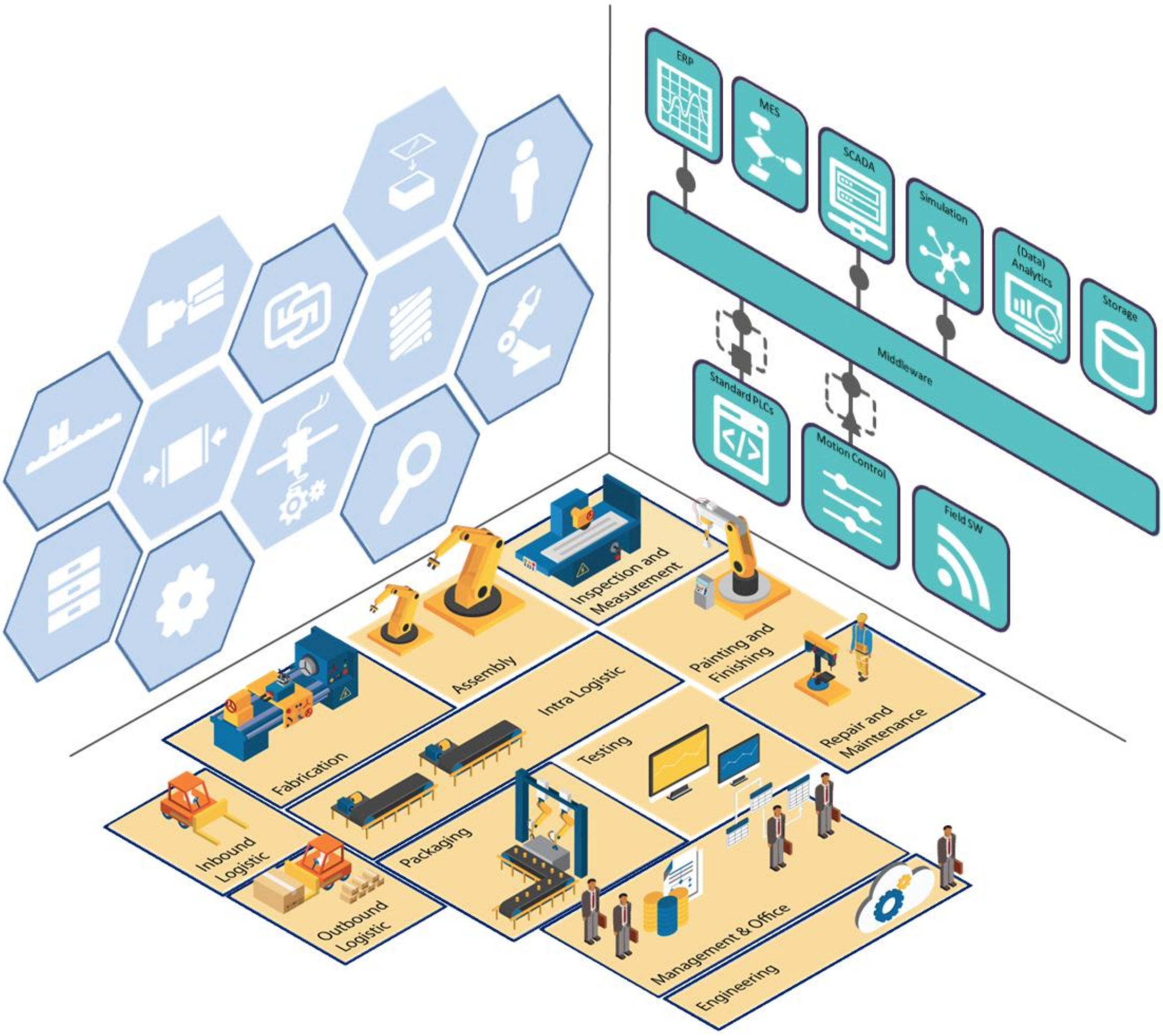

Figure 51: PERFoRM use cases goals

The four following figures (Figures Figure 52Figure 53Figure 54 Figure 55) depict with blue borders the objective of each industrial use case separately. The currently areas covered by the use cases are colored, while the ones that are still missing are depicted in grey.

SIEMENS intends to improve the availability of existing equipment, the quality of products, to avoid waste and streamline the production. PERFoRM will enable its existing production equipment as Cyber-Physical Production System components through being retrofitted with ubiquitous information and communication systems along the whole value chain. The show case intends to demonstrate the potential of using cyber-physical systems to improve prediction strategies, increase productivity and reduce maintenance costs. The implementation of highly flexible production resources with lower changeover times, increase of tool endurance and increased availability of machine tools, will result in significantly reduced delays, interlocks and, therefore, fixed capital, increased delivery reliability and ability to react to changes in customer demands. The high product safety levels and testing & traceability requirements will even be increased by retrofitting existing production to act as decentralized intelligent machines.

Figure 52: SIEMENS use case objective

As depicted in Figure 52, the use case will mainly focus on predictive repair and maintenance in order to have a better maintenance planning. Sensors for physical data acquisition and software to analyze these data are required. It is also needed a middleware that enables the complete integration of maintenance system in ERP/MES systems, and sensor technology with machine control.
Thus, it will be necessary to improve skills of human operators.

The key challenge for IFEVS is to achieve the ability to produce relatively low quantities with high variation while maintaining high-quality standards and minimizing costs. PERFoRM is completely aligned with the IFEVS concept of flexible production systems which eliminate hard tooling and dedicated automation as much as possible and rely on advanced ICT and agile plug-and-produce resources with flexible tooling. By means of high degree of automation systems, it is expected to improve the efficiency and reproducibility of processes and enable highest product qualities, minimizing the variability of manual operation and thus, human errors and manual actions. In addition, the large reduction of the needed upfront investments for the variants of vehicles addressed in PERFoRM will reduce particularly the production costs.

Figure 53: IFEVS use case objective

As no technologies are currently available in IFEVS, the objective of this use case (Figure 53) is to adopt automation solutions for the entire shop floor and office space, except the painting operation that is outsourced. New tools need to be implemented, to improve the adaptability of the production line to different lot sizes, and integrated, to communicate to each other. The shop floor should be enlarged and the competence of operators upgraded.

By implementing automation solutions, the WHIRLPOOL factory would benefit from a different approach, which can definitely lead to a better and more accurate management, increasing productivity, traceability, efficiency, flexibility, reconfigurability and real-time control. Specifically, WHIRLPOOL use case aims to have a faster reaction to market changes in term of volume/mix in order to avoid quality issues that arise from customers and equipment failures or unavailability. It is also desired to have cheaper adaptation costs in front of a new product introduction and product transfer from other production plants.

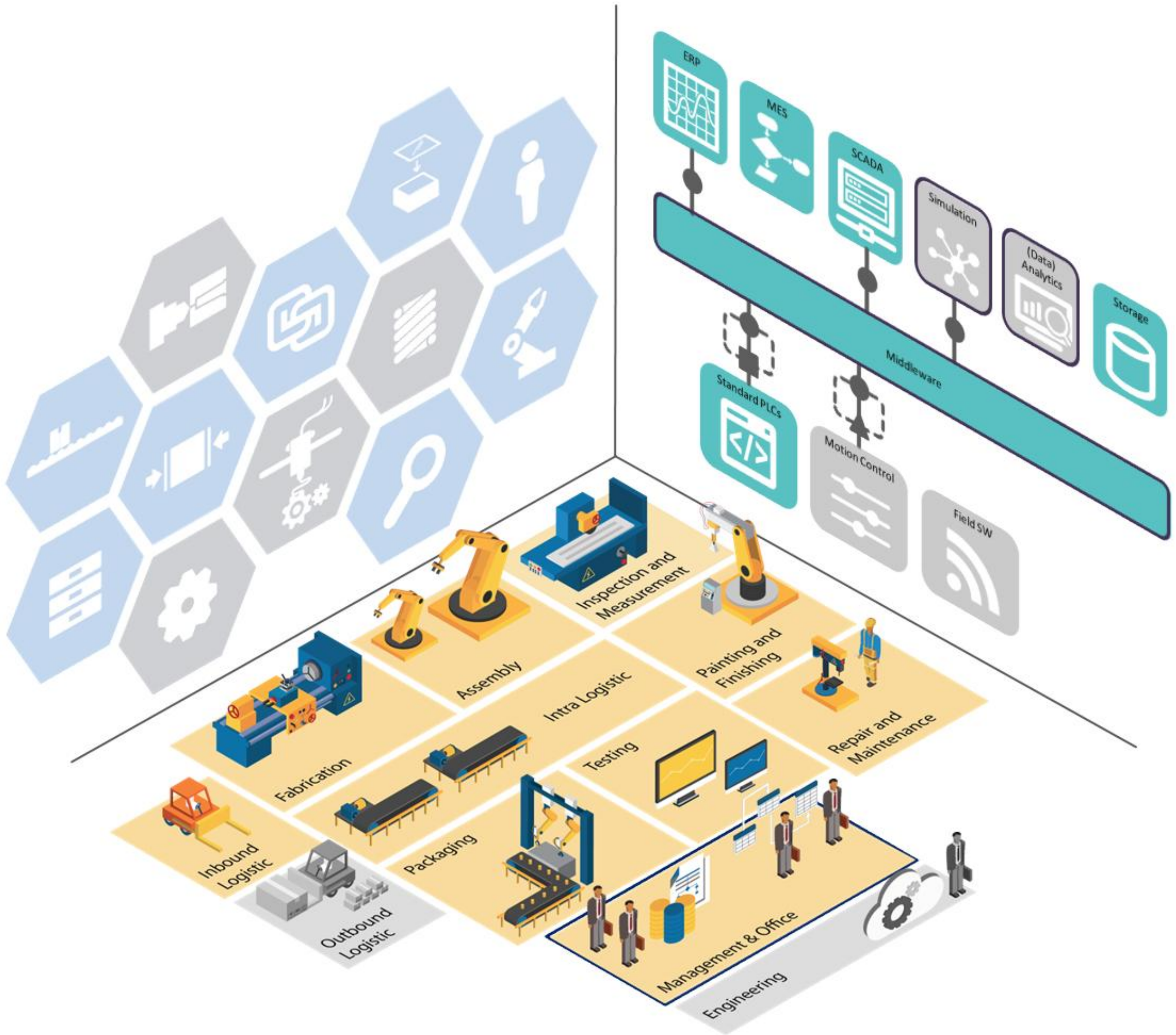

Figure 54: WHIRLPOOL use case objective

Whirlpool use case (Figure 54) focuses on the synchronization of manual assembly, automated bonding and product quality control. PLM software capable to communicate with the entire production system, through ERP/MES, is required.

Lastly, GKN's motivation for the PERFoRM project is to demonstrate more agile production using a new integrated system that can complete a sequence of operations in the value adding process chain. The aerospace use case is looking for a more cost-effective solution for automation of low volume and high mix production reducing investments, product costs and improving process repeatability and quality by reducing variation. Moreover, it would reduce lead-time by integrating several process steps in one cell, "micro-flow cell". Another objective is to increase the utilization of the cell(s) and the production resources/components, being able to adapt capacity to the variation in demand.
The demonstration effort will be to allow different resources and products to be rapidly deployed into this cell and manage their manufacturing process while maintaining high quality.

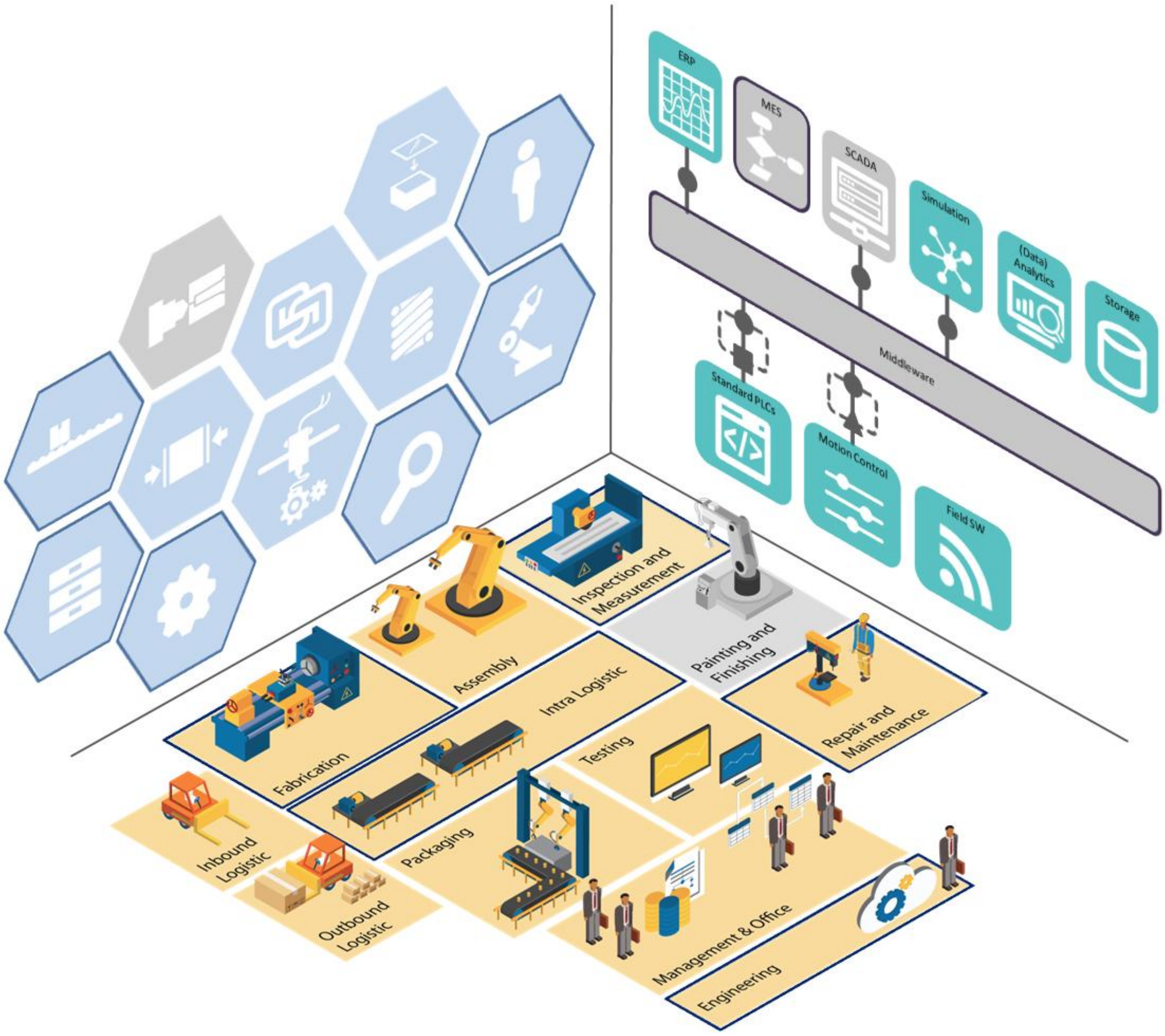

Figure 55: GKN use case objective

This use case (Figure 55) aims to improve the material handling and storage in a production cell, the inspection of surface polish and dimensional measurement and to automate grinding and polishing operations with robots, including deburring, tool handling and part handling. GKN will focus mainly on grinding, polishing and deburring workstations and marking, improving also the dimensional inspection and surface finish. Moreover, it is required a better intra-logistic system that allows the loading and unloading in production cells. The main goal will be the design of new reconfigurable cells and the production / process planning for more flexibility. It is also needed to develop a middleware that enables interfaces between the available systems, including a possible MES system.

6. Summary and conclusion

PERFoRM aims to develop a new generation of agile manufacturing system based on plug-and-produce concept, in order to cope with smaller lot sizes and shorter lead time and time-to-market. There has been already conducted a big volume of research activity on this field. PERFoRM wants to collect the results, methods and tools of the previous relevant EU projects and industrialize them. Each project has found individual solutions on multi-agent systems, standard communication protocols, network of cyber-physical components, etc. but they never applied them into an industrial environment in an integrated form. This project aims to harmonize, standardize and integrate these solutions to facilitate the industrialization of plug-and-produce devices.

In this deliverable, a collection of the PERFoRM partners' knowledge and experience gathered during former research project is provided. Figure 56 depicts a general overview of the developed solution domains in the previous projects in terms of flexibility and reconfigurability of robots and machinery in manufacturing systems.

Figure 56: State-of-the-Art methodologies

This report shows also the current status of the industrial use cases, analyzing their characteristics and their expectations within the project. Comparing Figure 56 with the PERFoRM use cases' goals (Figure 51), it can be said that the work areas of previous projects in their research activities match the focus areas of the industrial use cases within this project.

The developed methodologies of the analyzed previous projects comprehend different solutions that integrate robots and machinery to the operational control and logic domain.

In particular, lot of research has been conducted in the realization of plug-and-produce production systems for flexible products, production volumes and processes. These flexible production systems are based on modular architectures including a middleware that, through service mediators or gateways, allows the communication among components using different communication protocols and standard interfaces for industrial plug-and-produce devices.

Planning systems and control architecture have been realized to improve the integration of process and quality control in factory.

Some projects focused on self-learning and experienced capture for decision support, implementing monitoring and self-adaptation methods. Furthermore, reconfiguration methodologies have been realized, with semantic information models and self-adjustment models.

Monitoring and diagnosis methods have also been implemented together with distributed diagnostic and predictive repair models in order to avoid failures. Maintenance monitoring models can support decisions on real-time adjustments of maintenance parameters.

There is still a lack of solutions that support the integration of casting and molding, forming and coating and laminating assets, but PERFoRM use cases do not focus on these assets (see requirements definition in D1.2).

There are also insufficient results that prove the application of these methodologies in outbound logistic or painting and finishing processes because they were not object of interest in the analyzed research projects. It might also be noted that the outbound logistic can be integrated similarly to the inbound logistic, thus, PERFoRM can implement new integration approaches taking experience from similar integrated processes. At the same time, the industrial use cases have no interest in painting and finishing process (D1.2), for this reason, the project will not concentrate on this issue.

The challenge that PERFoRM wants to address is the industrialization of previous work on agile, smart and evolvable systems. It is evident that the PERFoRM consortium has already a wide knowledge on the state of the art technologies of flexible and reconfigurable manufacturing systems, necessary to overcome the barriers and obstacles in exploiting the developed solutions in industry and to achieve the new generation of cyber-physical production systems.

Contemporary, these emerged paradigms seem to meet the industrial use cases challenge of integrating tools from the shop floor up to the top floor to improve their production flexibility and reconfigurability.

A common reference architecture of the PERFoRM technology platform will result from the integration and harmonization of the available solutions here defined, dealing with the use case goals.

7. References

[1] P. J. Marrón, D. Minder, S. Karnouskos. "The Emerging Domain of Cooperating Objects: Definition and Concepts." Springer, 2012.

[2] Tauseef Aized. "Flexible Manufacturing System: Hardware Requirements, Future Manufacturing Systems." InTech, 2010.

[3] S. Karnuskos, A. W. Colombo, F. Jammes, J. Delsing, T. Bangemann. "Towards an architecture for service-oriented process monitoring and control." *36th Annual Conference of the IEEE Industrial Electronic Society (IECON-2010).* Phoenix, 2010.

[4] H. Wiendahl, J. Reichardt, P. Nyhuis. "Handbook Factory Planning and Design". Springer, 2015.

[5] N. Antzoulatos, E. Castro, D. Scrimieri, S. Ratchev. "A multi-agent architecture for plug and produce on an industrial assembly platform." *Production Engineering*, 2014: 773-781.

[6] A. W. Colombo et al. (eds.). "Industrial Cloud-Based Cyber-Physical Systems." Springer, 2014.

[7] M. Onori, N. Lohse, J. Barata, C. Hanisch. "The IDEAS Project: Plug & Produce at Shop-Floor Level." In *Assembly Automation, vol.32*, 124-134. 2012.

[8] *IMC-AESOP Project.* http://imc-aesop.org.

[9] *SOCRADES.EU.* http://www.socrades.net/.

[10]A. Cannata, M. Gerosa, M. Taisch. "SOCRADES: a framework for developing Intelligent systems in manufacturing." *Industrial Engineering and Engineering Management (IEEM 2008).* Singapore: IEEE, 2008. 1904-1908.

[11]S. Doltsinis, P. Ferreira, N. Lohse. "A Symbiotic Human-Machine Learning Approach for Production Systems Ramp-up", IEEE Transactions on Industrial Informatics (under review).

[12]*ReBorn Innovative Reuse.* http://www.reborn-eu-project.org/.

[13]*EMC2-Factory.* http://www.emc2-factory.eu.

[14]Critical manufacturing. http://www.criticalmanufacturing.com/de/r-d/i-ramp3

[15]I-RAMP³. http://www.i-ramp3.com/iramp3.html

[16]*EMC2-Factory.* http://www.emc2-factory.eu.

Appendix

I. Acronyms

Abbreviation	Explanation
AM	Additive Manufacturing
CAD	Computer-Aided Design
CAM	Computer-Aided Manufacturing
CNC	Computerized Numerical Control
CPS	Cyber-Physical System
DCS	Distributed Control System
DMS	Decentralized Manufacturing System
DSS	Decision Support System
EMS	Energy Management System
ERP	Enterprise Resource Planning
FMS	Flexible Manufacturing System
HMI	Human Machine Interface
KPI	Key Performance Indicator
MAS	Multi-Agent System
MES	Manufacturing Execution System
PLC	Programmable Logical Controller
SCADA	Supervisory Control And Data Acquisition
SOA	Service Oriented Architecture
XML	Extensible Markup Language
WS	Web Service