# D7.2: WHITE PAPER

## Manufacturing change management based on a holistic approach.

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# 1. Executive Summary

**FoFdation introduces a new paradigm to the manufacturing change management based on a holistic approach.**

Today's increasing volatile economy, mass customization requirements and versatile large-scale production require careful planning of the production, flexible manufacturing and continual optimization of the manufacturing process. Modern manufacturing enterprises need for simultaneously tackling quality, productivity and sustainability issues and all manufacturers know that it is often not possible to perform the final production process as defined by the original plan. In order to reach the goals set in terms of quality, energy and resource efficiency, cost effectiveness and time required, the plan must be constantly adapted to the reality, through iterative process requiring agreements and decisions of numerous participants at different levels of the enterprise.

Currently, in the factory, dynamic changes caused by internal and external turbulences like a machine breakdown or an order fluctuation might not be taken into account because of multiple non-compatible information systems and lack of data interoperability and integration.

There is a real need to work together, in order to

1. simulate and optimize the machining process whereas providing more smart IT tools for managing the manufacturing change process at the shop-floor level and to deliver the best part quality and manufacturing flexibility according to the customer's constraints and requirements
2. monitor the production process, improve synchronization between production planning and the manufacturing operations and optimize sustainable implementation of the manufacturing macro-planning
3. manage global cooperation with multiple supply chain partners. In order to enable management to make the right decisions at the right time, real-time visibility through a holistic dashboard throughout the whole manufacturing process and the direct implementation of decision support tools are indispensable.

There is also a need for a universal manufacturing information system based on a standardized data definition that enables information sharing seamlessly in an interoperable way. Whilst doing all of the above, factories must continue to meet the highest standards of lean, agile, flexible and sustainable production while ensuring traceability and security.

Figure 1.1: Information must flow…

This white paper has two goals:

4. To introduce the breakthrough results and outcomes of the FoFdation project as new innovation stone or development kernel to support the smart factory of the future and manufacturing change management.
5. To propose an exploitation plan through the living Lab that could encourage the market acceptance through pragmatic demonstrations and recommendations based on meaningful and helpful proof-of-concepts use cases.

## 2. Top-down integration: direct engineering-to-shopfloor control

The manufacturing paradigm is envisioned to drastically evolve from the mechanic-based system to the computer-assisted system driven by knowledge. The end-to-end process integration towards the virtual factory could be realized if only based on a fully digital factory model composed by Product, Process, Resource and Plant and their live characterization throughout their lifecycle.

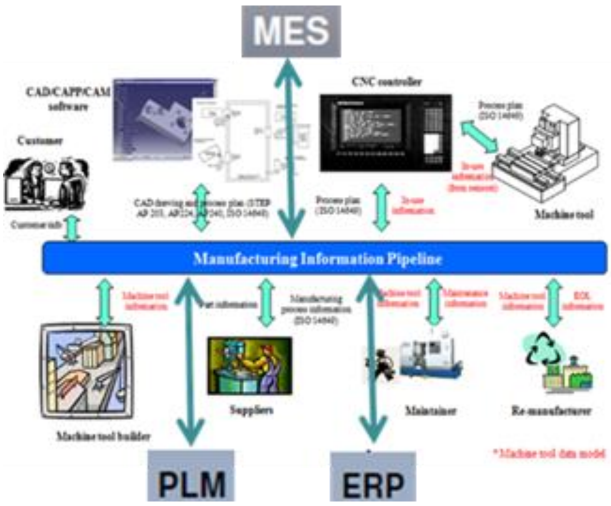


Figure 2.1: MIP backbone

In FoFdation, the consortium proposes a Manufacturing Information Pipeline (MIP), based on STEP and STEP-NC to demonstrate a proof of concept of the manufacturing shift that consists of fully integrating the Design-Manufacturing process (Fig.3).

The FoFdation project envisions a 'Smart Factory' architecture and implementation which has the potential to achieve significant benefits in earlier visibility of manufacturing issues, faster production ramp-up time, faster time-to-volume production and subsequently shorter time-to-market, reduced manufacturing costs, improved product quality, as well as sustainability objectives like reduced energy consumption and waste reduction.

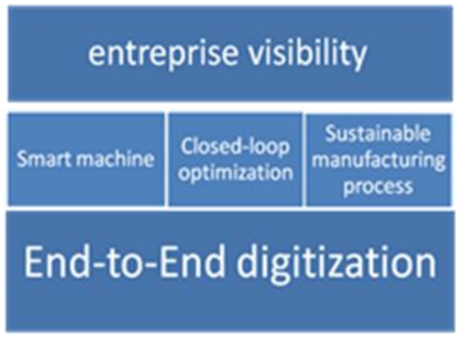


Figure 2.2: FoF building blocks

Realizing the objectives of the project requires that several pieces are integrated with each other. At the center of these pieces is the **Smart Machine tool Controller** (SMC). The original vision in FoFdation for the SMC is to implement an advanced machine controller based on an open-architecture, standard enabling data access and data visualization application. Additionally, an extended STEP standard will be seamlessly integrated to bring CAD-CAM data down to the shop floor level, thus enabling intelligent and self-learning manufacturing process. The key proposition is that the Smart Manufacturing Controller (SMC) is tightly coupled with the Smart Manufacturing Optimizer (SMO): this combined SMC-SMO controller will exploit interoperability enabled by MIP, as a modern Master Model, between PLM-CAD systems and machine-tool while being able to optimize the cutting process in real-time, based on the closed loop assistance of the Smart Manufacturing Optimizer.

## 2.1 Airbus Use case 1: concept and methodology for smart machining

**This UC addresses the issues: “how to make a part better” and “how to manage the supplier qualification”**

Today, the factory manufacturing control and management still rely on disparate systems:

- Product Lifecycle Management (PLM) for innovation and product development
- Shop floor planning and programming system for the allocation of NC jobs and machine-tool
- And a multitude of middleware applications and Enterprise Resource Planning (ERP) to synchronize the information between the internal and external worlds at the management level.

The current manufacturing approach has multiple problems that require better solutions:

Firstly, the existing CAD/CAM-CNC data chain has one way information flow, broken at post-processing stage with little/no feed-back. The data formats for tool path control is outdated leading to legacy problems.

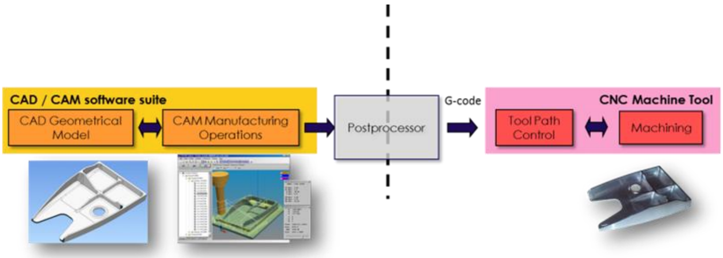


Figure 2.1.1: existing CAD-CAM-CNC chain

Secondly, there is limited flexibility. Design changes have to get through the whole data chain leading to loss of time, material and resources. Shop floor modifications are difficult to handle and to feed back to enterprise business systems.

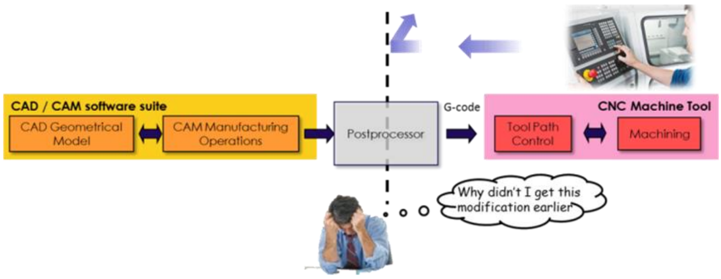


Figure 2.1.2: Lack of flexibility of the current process

Thirdly, there is limited adaptability. It is highly difficult to switch from one machine to another. In case of change of machines or factory, product re-planning is complicated leaving very little room for flexible planning.

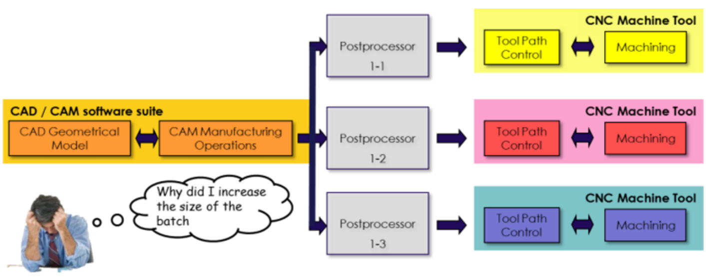


Figure 2.1.3: Lack of adaptability of the current process

Moreover, there is no compensation of the condition changes during the manufacturing process. The process analysis has limited scope due to unavailability of online/offline data sources. There is

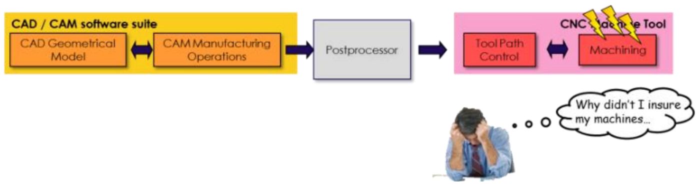


Figure 2.1.4: Limited adaptivity and adaptability, thus lack of productivity

also no secure ground for process documentation for traceability.

Fourthly, there is limited productivity. Process simulations are based on "perfect" machines using programmed feed rates. There is no real way of setting optimal process parameters to take the machine wear and tear into account. In most of the instances, the calculated lead times cannot be trusted

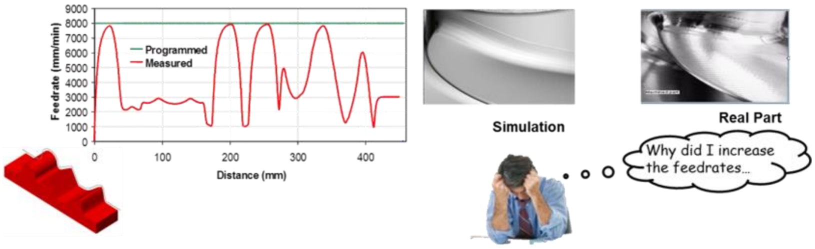


Figure 2.1.5: Lack of quality control

- **Direct machining through Smart Machining Controller (SMC-Step-NC compliant)**

At present, machine-tool is still classified as an automatic machine: after once being set, it operates automatically and blindly follows the machining code provided and it is up to an operator to detect if a crash is about to occur, and to manually abort the cutting process. Indeed, any unforeseen condition cannot be met, and any hazard event may cause machine crash or failure, and harmful damage to the equipment and operator, despite collision detection through sensors or limiting switches that equip some modern machines.

In the Factory of the future, knowledge is essential and could or must be accessible everywhere, as the digital convergence will be also affecting manufacturing and allowing an interconnected web of information and production. Smart machines will collaborate with each other, with intelligent software, with tech-savvy workers, with customers, with managers all across the supply chain. Machine-tool then can be augmented with new capabilities such as global awareness of human goals, perception of sensory and contextual information and decision for self-optimization capability.

A smart machine is defined as a machine equipped with an advanced controller that knows the capabilities of the machine to be driven. Such a machine is able to define the most efficient method to produce 'first part correct' every time. It will do this all whilst monitoring itself and utilizing data that closes the gap between the designer, manufacturing engineer, and the shop floor, whilst allowing high level production management and supervision.

To accomplish the above SMC characteristics, a generalized architecture has been developed in order to enable both progressive and breakthrough innovations for industry. Therefore the innovation of the SMC is not just a product in the conventional sense but it is an architectural framework that can be further extended with new features and implemented on several platforms.

The progressive innovation must be based on defined components that are compatible with legacy systems, thus supporting the industry's transformation by introducing more IT-assisted technologies into conventional and existing manufacturing chains for better optimization of the manufacturing process. This condition is necessary to support the transformation of prevalent brand name controllers (FIDIA, SIEMENS, etc.) mostly based on ISO G&M code into STEP-NC compliant controllers, thereby allowing companies to increase their production performance without heavily investing in new expensive machines and time-consuming training. Implementations developed need to be usable in the short term by industry to show immediate benefits and encourage commitment and investments from machine tool industry.

Breakthrough innovation is based on a STEP-NC SMC interface for part programming tightly integrated with the optimization module, thus looking at creating the perfect model of the imperfect machining process, right from conceptual design through to development and evaluation. For example, feed rate has been identified as a key parameter and therefore needs to form part of the machine tool simulation signature. The controller will be able to generate cutter trajectory and optimize the cutting strategy in real-time. This is possible with an embedded STEP-NC SMC interface including its own tool-path generator, e.g. for surface milling.

- **Machining optimization for ensuring part quality based on CADPM monitoring technology**

What are the aims? First, the very "high-fidelity" simulation of the manufacturing process to predict time and surface quality beforehand and second, to extend machining with process monitoring to allow corrective actions and safeguard the manufacturing traceability and optitimized conditions. Also in case of production disturbances, record the disturbance and machine settings and make the data available via the Manufacturing Information Pipeline (MIP) to the other components and higher management through a Smart Enterprise Content Management (SECM).

Practically, the platform for the simulation and verification tools was the PowerMILL™ CAM system where the actual feedrate model was developed to drive the simulation tools. Key components are the accelerations and jerk rates of the machine. Experimental work has resulted in validation of the model by comparing simulated and real feedrate profiles on different geometrical parts. Using this model, the time estimation for machining operations is much more realistic, allowing better production planning and cost estimation. The same model is also able to drive the ViewMILL™ simulation and thereby able to better predict the surface quality of a part before cutting and avoid scrap. The achieved results satisfy the goals of the task.

A stand-alone simulator was also developed, which can be exploited separately and can be used with any other platform.

In the end, a prototype for intelligent process monitoring was implemented, based on CTM™ process monitoring solution methodology to monitor the machine and the machining process. From all R&D sub-tasks, prototypes were developed and each of them has been installed at one or more of the machining centres for demonstration. Process monitoring allows the comparison of the actual situation on a machine with a target situation. Traditionally it is done by

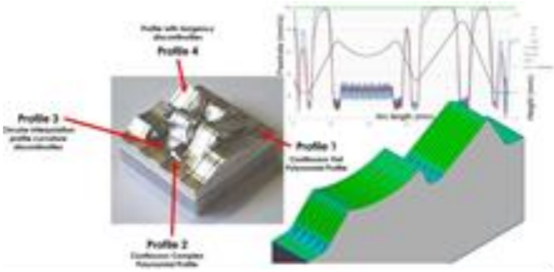


Figure 2.1.6: Feedrate predictions verified on "4wawes" test

monitoring only the spindle torque signal which is a very rough indicator of the actual process condition. Results achieved include new monitoring strategies based on teachless monitoring and a combination of several key dynamic properties for more accurate and reliable process monitoring.

Typical scenarios include collision, tool missing, tool breakage, tool wear and over- and underload. To set up process monitoring **CADPM** technology has been developed. For the first time it is now possible to configure thresholds, alarm reactions or additional process information to the monitoring system with the help of CADCAM. For each deviation corrective actions have been developed and implemented into demonstration setups. The second major topic was the communication of the detected deviation and corrective actions taken to the overall MIP for closing the loop. Validation experiments of the developed hard- and software solutions were performed, e.g. at CRF for "tool wear monitoring" with preventive corrective action taken accordingly. The results show use of the prototypes and prove the successful development of the intelligent adaptive and sustainable approach, enabling two main information bridges; Design to Production and Production to High Level Management.

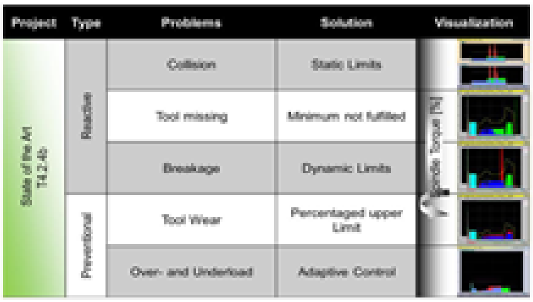


Figure 2.1.7: Overview of typical production problems and corrective actions

The FoFdation SMC-SMO integrated solution makes a big step ahead:

• The system learns from experience and future performance is improved based on stored knowledge and science based simulation;
• Machining conditions are automatically selected to produce parts of the desired quality with maximum efficiency;
• Models and sensors work synergistically to improve both the machining process and the accuracy of the models themselves through on-line calibration;
• A high level language is used to communicate the part requirements, control the machining process, describe the physical components and store the history.

Taken together, these qualities allow the system to produce parts of the **desired quality with the first part produced and every subsequent part**.

# 3. Bottom-up integration: live data aggregation for manufacturing operation management

Many IT technologies are expected to help managers and knowledge workers tackle overall management and planning tasks, by helping them aware of the manufacturing diagnosis through real-time information. The daily visibility of the factory shop floor health and the comprehensive awareness of the whole manufacturing eco-system (including customers and suppliers) are also primordial to the top management for taking the right decision at right time within a global context, thus meeting the triple-bottom line objectives and requirements. Nevertheless, the bottom-up feedback process of data from the factory operational ground is still in the infancy stage today although many technologies are claimed to be the cornerstone for such innovating process like complex event processing, data pattern mining, or big data analytics… And at the data collection level, many commercial stand-alone solutions are existing on the market and can be classified into three categories:

- Dedicated data collection tools
- MES based tools
- Specialized systems for quality tracking or energy monitoring.

As a consequence of the analysis performed in FoFdation, our consortium has selected a MES system as a basis to our general monitoring solution and sustainability assessment. The data collection module (FoF-EMon) is proposed as a new feature of the extended MES (called Smart MES) which will be adapted to form a comprehensive approach for energy and resource monitoring, controlling and assessment. Such a combination leads to an improved awareness of the manufacturing operations performance through a configurable set of sustainability key performance indicators (KPIs).

The present approach is a pragmatic proposition to address a dedicated solution need: energy management or quality tracking. This might be not sufficient to address a general, real-time and permanent diagnosis in order to permanently watch after the manufacturing operations which generate huge data streams, but this could efficiently support engineering approaches towards product, process and resource characterizations that are needed to improve the optimization process reliability and correctness based on the fine-tuning of its validity scope.

## 3.1 Fiat Use Case: concept and methodology for sustainability management

**This UC addresses the issue: "how to produce greener and leaner"**

- **An extended MES for sustainability management**

Companies face the challenge of demonstrating their actual contribution to sustainable development. Common management theory and practice concentrates on economic performance. Environmental and social performance has traditionally been excluded from the equation. This is because it is measured and represented differently from economic performance. Certain approaches, e.g. the Sustainable Value, allow the environmental and social performances to be measured and reported in the same way as their economic performance: value-oriented and in tune modern management practice.

The FIAT Use Case focuses on production management: planning, sequencing and execution through Triple Bottom Line (TBL) sustainability optimization within manufacturing operations, resource usage optimization, e.g. through idle-time reduction, quality throughput improvement through increased awareness, and support on decision making. It highlights the limitations that the current procedure related to sustainability within these phases, e.g. lack of standardized method for assessment, only few sustainability aspects considered, more awareness required on the shop floor, limited control of consumption at the machine tool, and improvements in resources consumption.

KPIs are first established at machine, production line and factory levels. Then, the data collection mechanism is implemented in order to obtain the required measured values to calculate the sustainability KPIs, related to production execution, including resource consumption information and micro-optimization at machine level. Third, with the collected data, an optimization mechanism is implemented in order to obtain best schedules that lead to maximize sustainability of the manufacturing operations which considers the three aspects, economic, environmental and social, of the Triple Bottom Line (TBL). Finally, the analysis of data within a dashboard supports managers for decision making, with tools that allow predicting the evolution of sustainability KPIs and looking into the factors that lead KPIs to undesired limits.

The main achievements and impact of the work that has been performed are:

- sustainability measurement KPIs aligned with the company's strategy and support for the data collection strategy to be implemented;
- easy to install data collection mechanism;
- improved and detailed control of the energy consumption of the machine and support for energy consumption reduction and optimization;
- improved production awareness through KPIs to support decision making for performance improvement at shop floor level and factory level;
- enhanced interoperability with enterprise solutions and devices;
- multi-criteria optimization through work order scheduling including social and environmental aspects (TBL); and
- Reduction of waiting/idle time energy consumption.

  According to theoretical calculations, the impact of the achievements here exposed lead us to considering **reduction of CO2 emissions by 10%** and **non-machining energy consumption by over 35%**, whereas the **reduction of idle-time could be up to 20%.**

- **Green Manufacturing Viewer**

**Data acquisition, monitoring and sustainability assessment in the manufacturing plant**

Manufacturing optimization based on the Triple Bottom Line (economic, environmental & social) requires starting with the sustainability measurement criteria and the acquisition of necessary data on the manufacturing shop floor. In order to achieve that, FoFdation proposes (1) a method that leads to define sustainability assessment through KPIs aligned with company's strategy and (2) the implementation of a data collection mechanism to obtain the required measured values related to resource consumption and production execution to calculate such KPIs.

FoFdation gives good support to companies on the adequate selection of indicators for the assessment of sustainability at the manufacturing site based on its strategic goals and the sector and process the company belongs to. It helps not only in the selection process but also in its definition, i.e. application, owner, target, etc. And it also supports on the establishment of the proper data collection mechanisms to obtain sustainability assessment through KPIs within the manufacturing context taking into account existing systems.

FoFdation also proposes a data collection mechanism within the SMES (Smart Manufacturing Execution System) on the execution of manufacturing operations and the resources consumed by the equipment carrying out the corresponding processes.

FoF-EMon, built by ETHZ, is an easy to install system that is capable of obtaining any kind of consumptions from the machine with internal and external sensors (mainly energy but also compressed air). It enhances awareness on the machine by monitoring its behaviour categorized by a standardized approach (ISO 14955). It also offers the capability for micro-optimization by suggesting actions to minimize the level of certain consumptions at the machine when it is in stand-by mode.

The data collection for the execution of the production is performed by a Manufacturing Execution System (MES) developed by IK4-TEKNIKER. It is an adaptable and easy to install MES with capability for production sequencing, data collection, production monitoring and support for workers. Its standardized interfaces (B2MML, OPC UA) allow interoperable connectivity with ERP systems and devices at the shop floor (including NC and PLCs) which facilitates the integration with the 'things' at the factory and improves awareness on the shop floor with high visibility on the manufacturing operations.

Major benefits of these outcomes are, first, bringing to companies the ability for sustainability assessment and improvement in the production lines through not only economic KPIs, but also environmental and social indicators, and, second, enhanced visibility and awareness at machine and shop floor levels to support decision making on consumption and production efficiency.

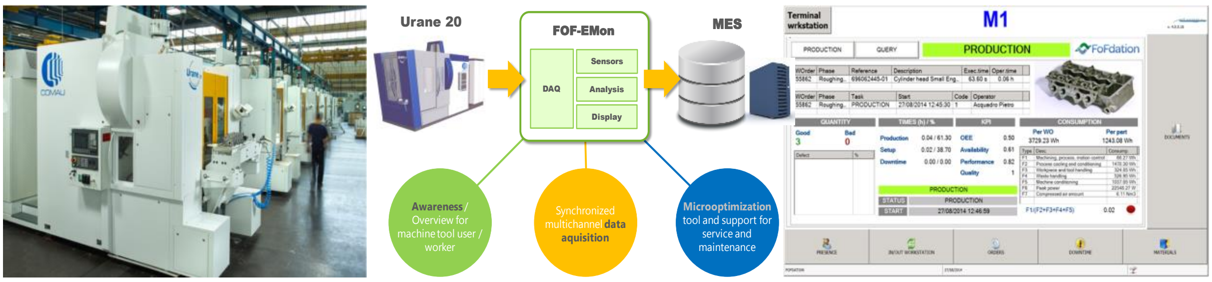


Figure 3.1.1 Data acquisition for sustainability assessment in the manufacturing plant

- **Optimizing the production line toward triple bottom line sustainability**

Once KPIs have been selected and the relevant data are monitored the Production Optimization and execution service (PROPTIM), is applied to generate production schedules with optimal TBL sustainability indices.

PROPTIM, developed by PARAGON, is based on the modular web-service tool SSO (Smart Sustainability Optimization) that contains two principal components, the Shop-Floor

Simulator and the Multi-Criteria Optimizer (based on evolutionary algorithms) and is adjustable to any KPI set and/or production line. The SF simulator reproduces the shop-floor functionality and calculates in detail all resource utilizations and all relevant KPIs (full production simulation down to 1 sec). From the optimization process the optimal TBL sustainability schedule is produced and idle times are identified for low-power machine-state implementation. Through its web-service design, PROPTIM provides open connectivity to MES systems.

Factories and managers will benefit by applying PROPTIM as an enhanced managerial tool to their production lines through the easy and quick generation of analytic optimal TBL sustainability production schedules that can also be revised in case of machine failures. Corporate responsibility, legislation compliance and employee satisfaction will improve at the same time.

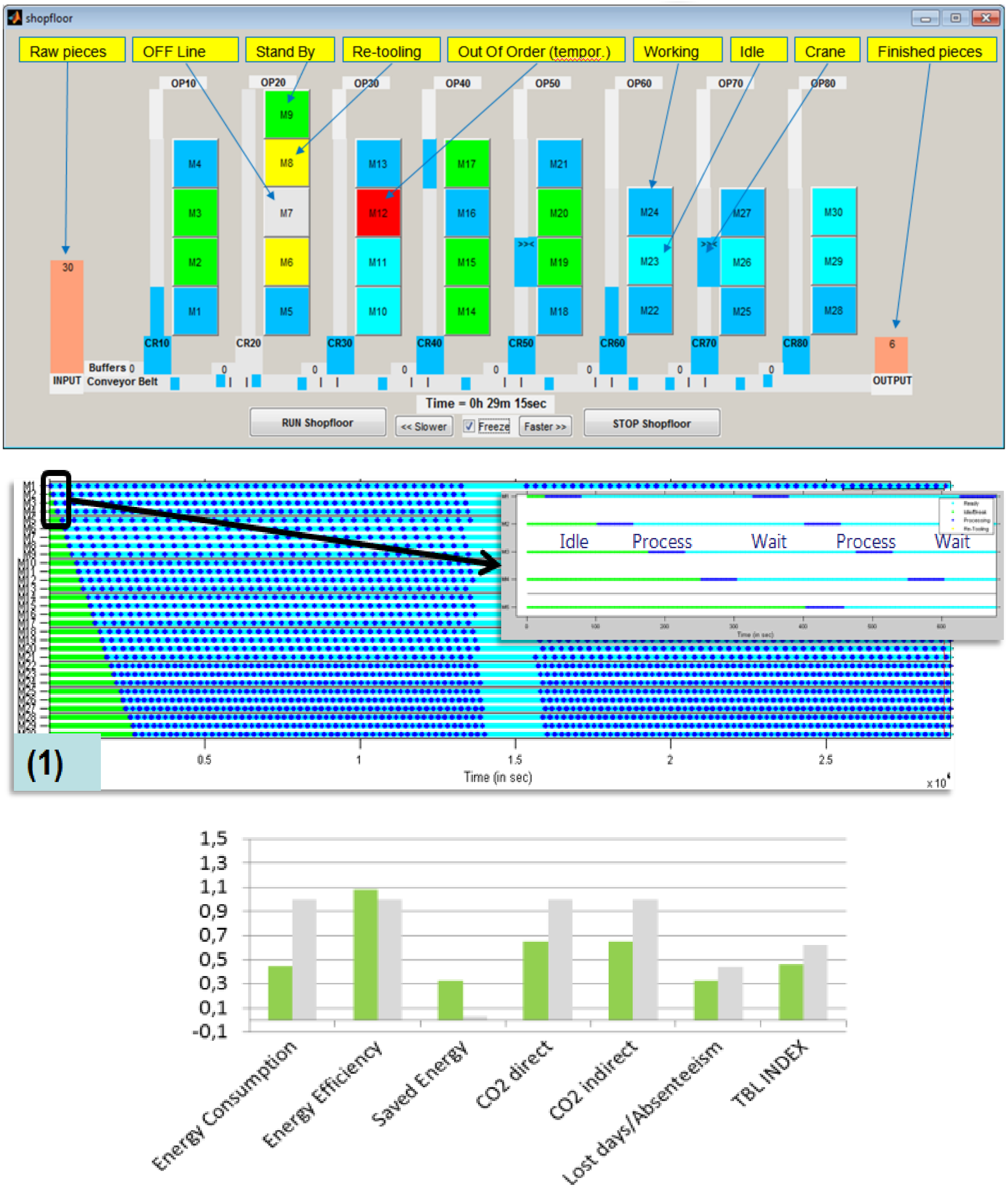


Figure 3.1.2: PROPTIM, SF simulator (top), resource utilization (middle) & KPI performance outputs tool

➢ **Dashboard for sustainability visibility and analysis: The Analysis Tool Case**

The process and production data collected on the shop floor is analyzed by managers through a dashboard that is developed by LMS. This management-level tool is related to predicting values of Key Performance Indicators (KPI) and foreseeing the trend of the production. Also, decision support through error root cause identification has been made. Such an approach is to give a boost at decision making, as actions of the production manager will not be based purely on his experience, but he can have an auxiliary tool. In the figure below, the applicability on an industrial case of the tool is shown using the Overall Equipment Effectiveness (OEE) as a KPI.

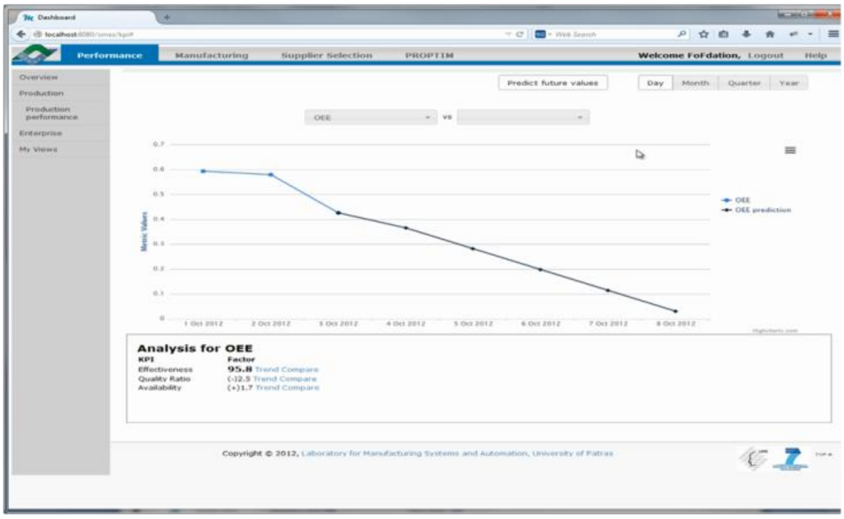

Figure 3.1.3: Trend Analysis of Overall Equipment Effectiveness (OEE) and its Analysis: Effectiveness causes the drop in OEE by 96%.

Characteristics of the Applicability (illustrated in the figure below):

- Once a KPI is found to exceed its threshold value, the involved KPIs have to be examined to determine which one(s) are responsible for this fact.
- A manager has the chance to work with the Analysis Tool at any time. If everything works well according to the prediction, he has to do nothing. But if a single KPI seems to exceed some threshold in the near or further future (yellow circle in Figure 2.4), then he has to run the Analysis Tool and see which lower level KPI is the reason for this fact.
- He then may repeat the process for the new KPI, as many times he desires, until of course he reaches a (directly) Measured Value.

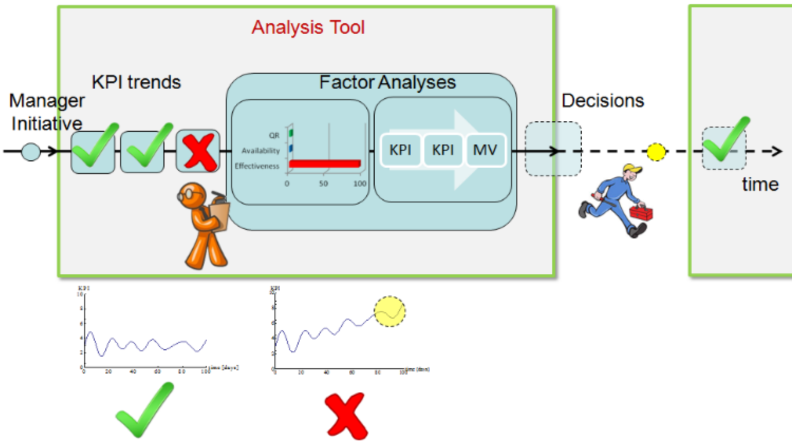


Figure 3.1.4: Analysis

## 3.2 Airbus Use Case 2 for Smart manufacturing management

Manufacturing context in a corporate OEM company: in order to secure its "make or buy" strategy, large OEMs such as Airbus used to perform "calls for tender" for contracting the manufacturing of a dedicated part to its "preferred suppliers" who have been usually pre-qualified through a strict procedure. The suppliers quotes are then analysed through a complex bidding process which must support the OEM to take the right decision based on multi-criteria.


Figure 3.2.1: Airbus Use Case context

The FoFdation concept consists in integrating all the relevant information related to the **extended manufacturing enterprise** through a collaborative technology data integration environment based on an integrated **manufacturing information pipeline** (MIP) that describes over the product data all the needed resources and processes to be managed efficiently.

The MIP concept will allow supporting bi-lateral and quick communication and synchronization between Airbus and its suppliers:

- From **Airbus to the suppliers**: suppliers upload to the MIP files describing the "to be delivered" part.
- From **suppliers to Airbus**: suppliers give feedback for decisions making on costs, simulated machining process scenarios, the expected "as-delivered" part quality in digital format and the energy-efficiency class of its production system.
- From **Airbus to the suppliers**: the company can virtually check and control the expected "as-delivered" part, select the right partner and upload slight modifications of the part.

The suppliers can concurrently optimize the machining process based on the self-learning performances of their machine from on-line MIP data.

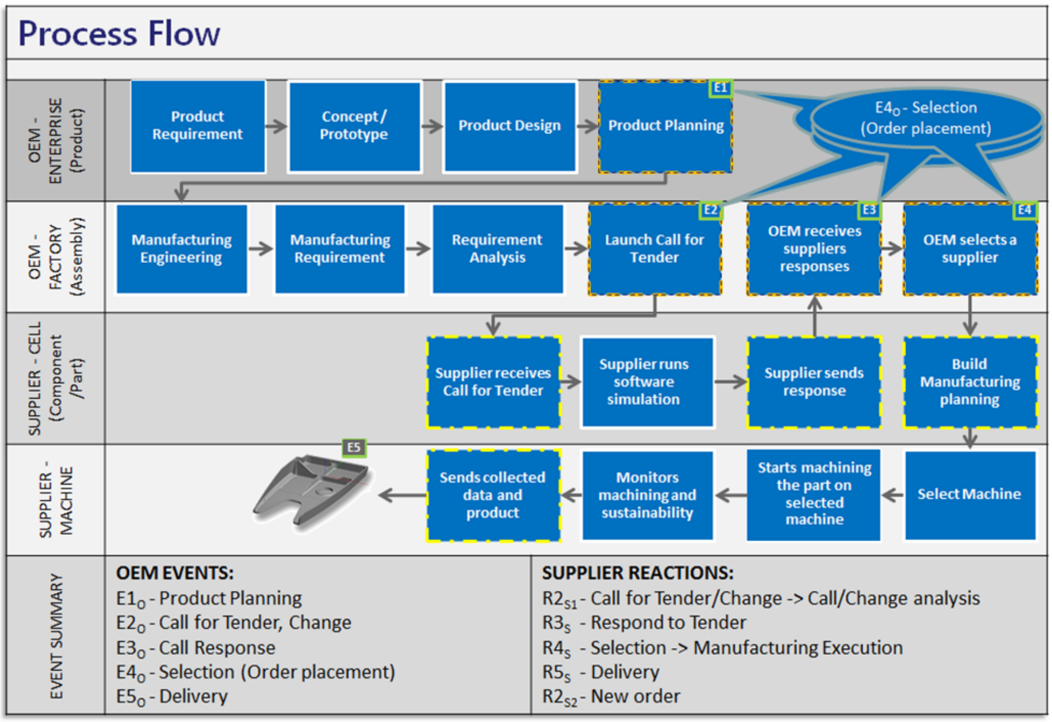


Figure 3.2.2: Process flow of the Airbus Use case

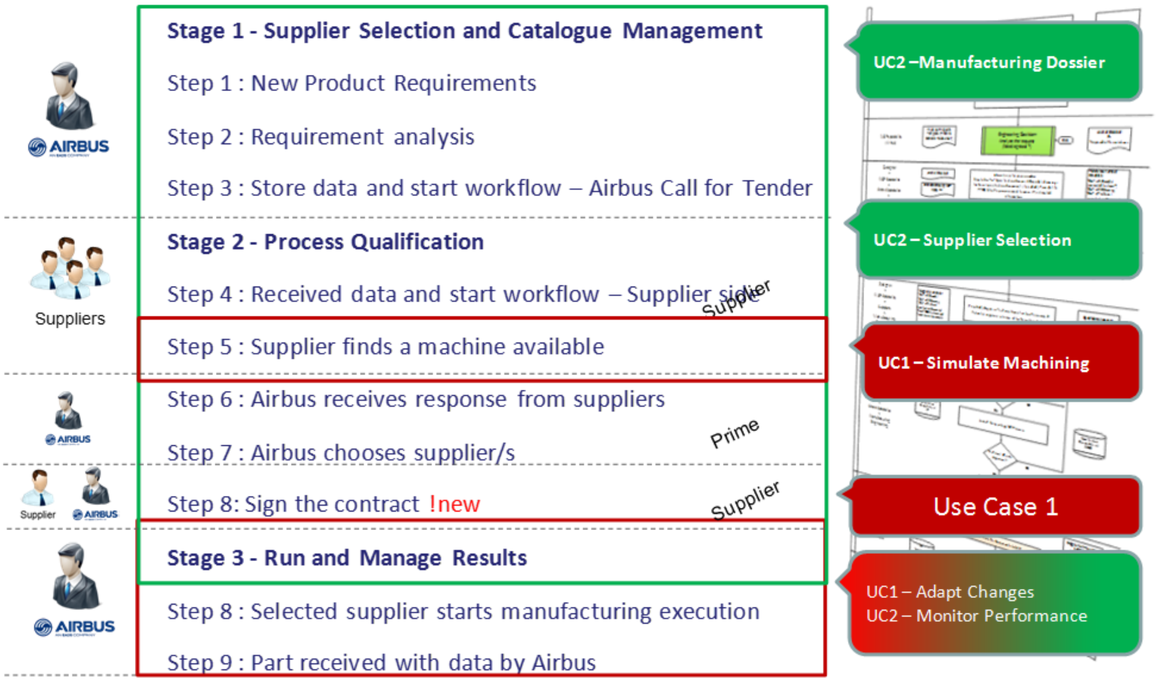


Figure 3.2.3: Airbus integrated Call for tender and supplier validation use case

➢ **Supplier Selection within the (stand-alone) FoFdation Dashboard**

FoFdation addresses the problem of supplier selection within the framework of the extended business. A network of suppliers can thus be used to enhance many aspects of flexibility, such as:

- ➢ Demand
- ➢ Manufacturing Process
- ➢ Transport
- ➢ Criteria
- ➢ Variants of the part

The Dashboard is used to this end, as it is a management-level tool. The sequence of actions one has to do is simple:

- ✓ Define suppliers (illustrated in Figure XXX1X)
- ✓ Define resources
- ✓ Define the product and its requirements

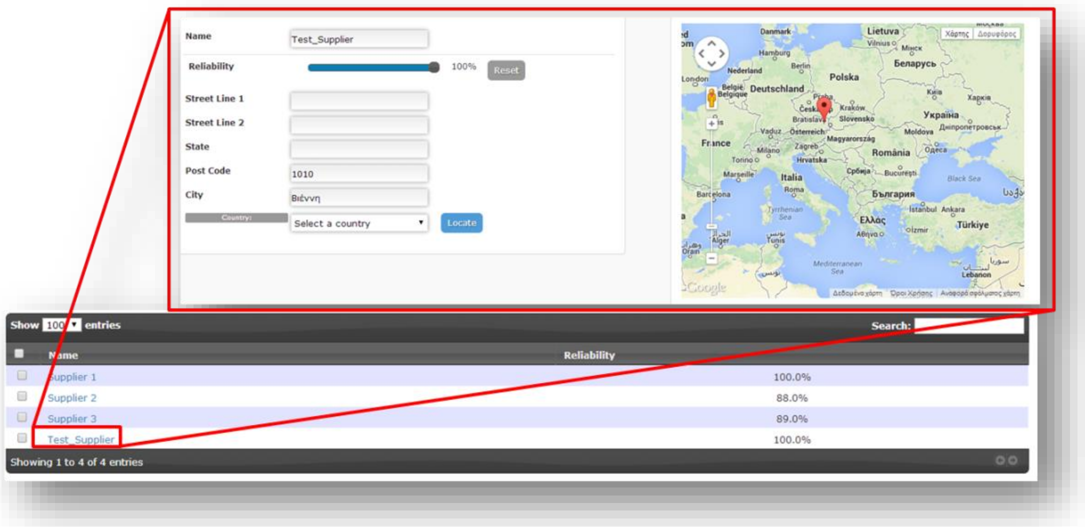


Figure 3.2.4: Setting up a supplier in Austria

Figure 3.2.5 Graphical Representation of the criteria

The next step is to choose what requirements / criteria they want to use in the supplier selection process:

- Part Quality
- Sustainability
    - Production Cost & Transport Cost
    - $CO_2$ Emissions
    - Electrical consumption
    - Corporate Social Responsibility

- Capacity (maximum quantity the suppliers can provide)

The Dashboard then, in an automated way chooses the best supplier(s), as below.

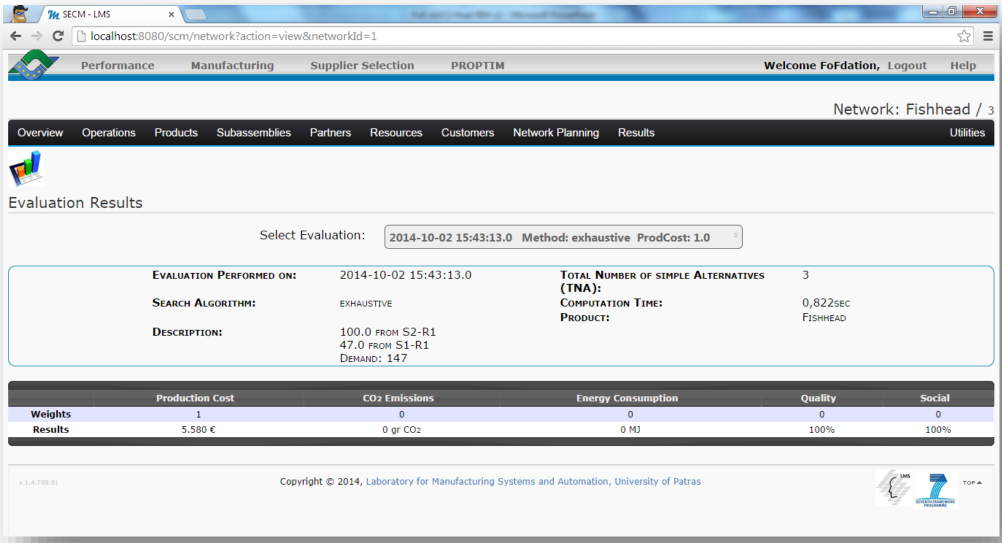


Figure 3.2.6: Supplier Selection Result

The dashboard, with its Supplier Selection Functionality Area, in combination to the MIP implementation in Teamcenter, succeed in achieving:

- ✓ Centralized Communication
- ✓ Increase of visibility & Progress Awareness
- ✓ Workflow & Execution Automation
- ✓ Increase Production-to-Enterprise Input
- ✓ Paper-less communication
- ✓ Data Exchange & Awareness
- ✓ PLM Capabilities Integration

- **PLM integration and mobile applications**

Moreover, the Workflow driven Schedule Task can be generated and safeguarded within the MIP and attached to the "master model" via a PLM platform.

Another benefit from having a PLM platform with a modern architecture is the possibility to use mobile PLM platforms to review MIP data including 2D and 3D information, browse product structures, mark-up documents and adding input to workflows. This allows always-on access anytime and anywhere to manufacturing information.

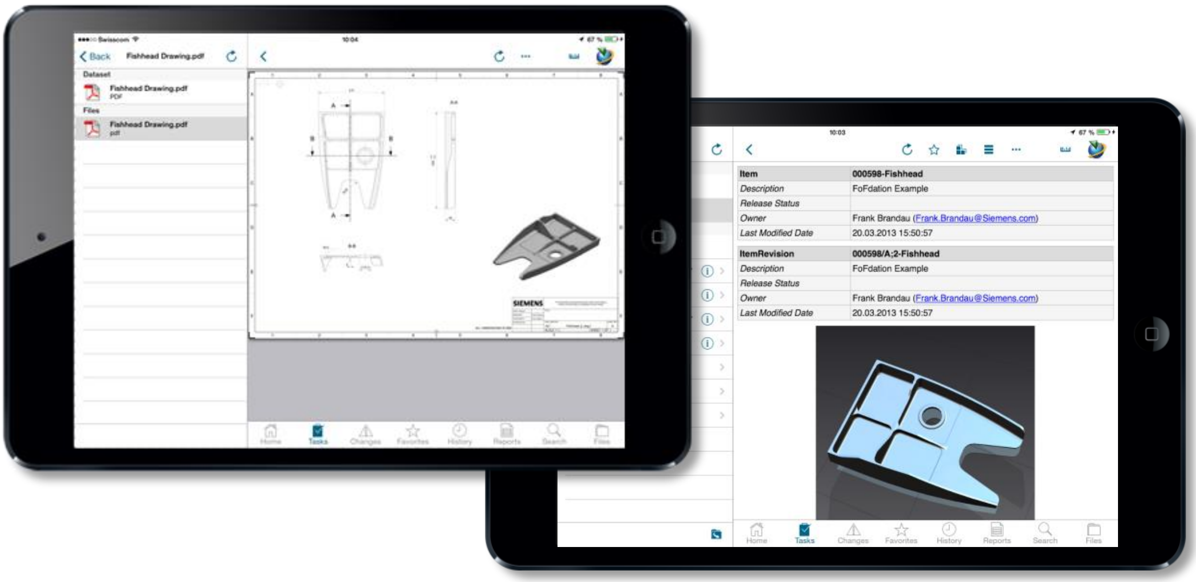


Figure 3.2.7: Teamcenter Mobility displaying Schedule Task based on MIP reference

# 4. FOFdation for EDM, a non-conventional process

➢ **Direct wire-cutting through Step-NC compliant controller**

In general the main challenge of competitive manufacturing is to produce high quality products, with costs as low as possible and with a sustainable process. These goals are the same when cutting parts with the Electric Discharge Machining (EDM) machining process. To reach these objectives, it is necessary to close the loop of the machining process data flow, starting for the CAD model, through the process planning to the production of the part, and feeding back the information coming from the process tracking, the energy monitoring and the final part inspection (Figure 4.1).

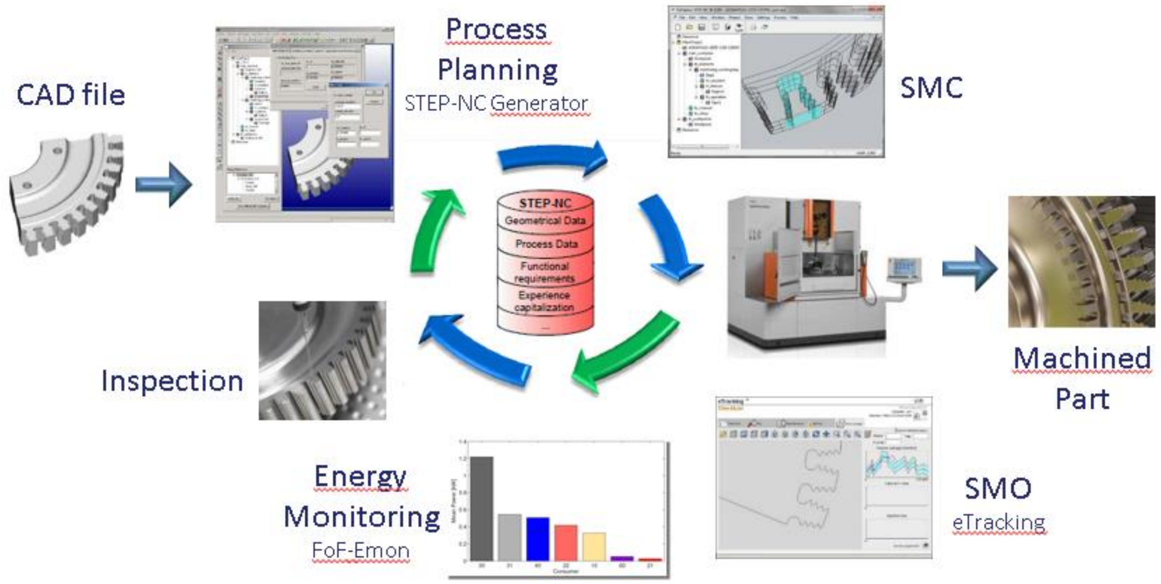


Figure 4.1: Closed the data loop for the Wire EDM process

The original vision in FoFdation for the Smart Machine tool Controller (SMC) is to implement an advanced machine controller enabling data access and data visualization application. The use of the STEP-NC standard will be seamlessly integrated to bring CAD-CAM data down to the shop floor level, thus enabling intelligent and self-learning manufacturing process. The central data model is based on ISO 14649-13 (STEP-NC) Process Data for Wire EDM standard (Figure 4.2). The data model contains the following main elements:

- Process plan (working steps, operations, strategies, …)
- Geometry of the final part
- Technology parameters, machine functions, wire information, etc.

The main advantage of using a STEP-NC data model is to have an integrated CAD/CAM/CNC data chain which is interoperable and generic, allows bi-directional data exchanges (e.g. feedback from process monitoring) and consequently has no loss of information.
Another benefit is the possibility to have the final part geometry (manufacturing_feature) defined as ruled surfaces. Currently the programming of the machining creates 2D

trajectories in the upper and the lower planes of the workpiece. The offset calculation is done in these two planes, which method gives not accurate results for certain parts.

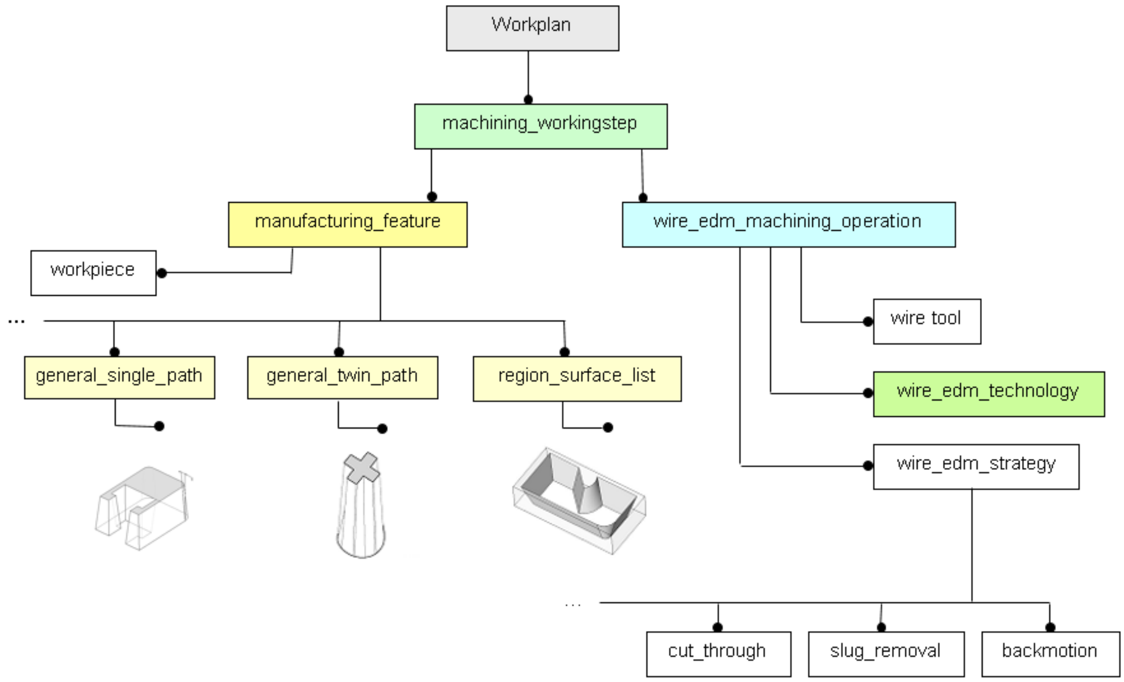


Figure 4.2: STEP-NC Data structure for Wire EDM (ISO 14649, part 13)

Figure 4.3 depicts a complex cutting example where correct path calculation requires varying the offset in 3D based on surfaces rather than planar contours.

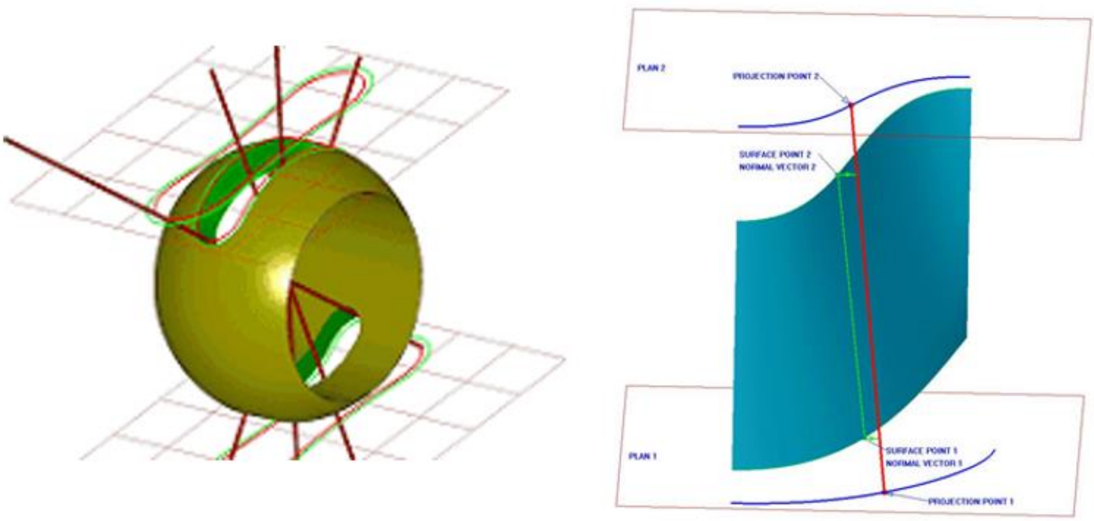


Figure 4.3: High accuracy in cutting complex parts thanks to 3D offset calculation

In FoFdation project a Smart Manufacturing Control (SMC) was developed for wire EDM machines for bringing higher information at controller level in order to (i) use new algorithms to drive the wire, e.g. by using 3D offset calculation, (ii) feedback and store information from the process monitoring for optimizing the machining parameters.

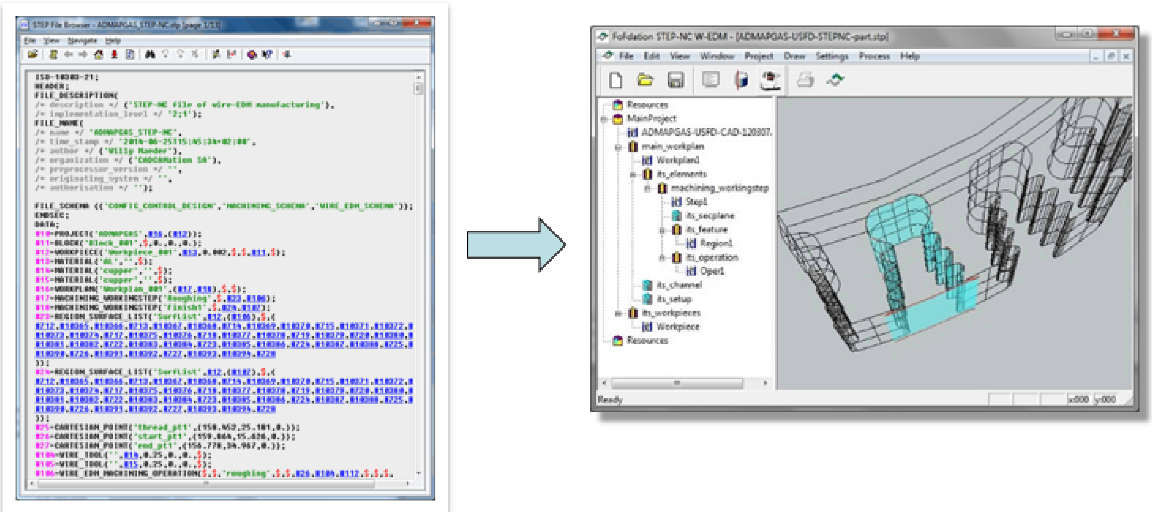

Figure 4.4: The STEP-NC file and its representation with the SMC interface

Figure 4.4 shows a typical wire EDM STEP-NC file. After reading this file, the SMC interface displays the data structure and the part geometry. Interactive functions allow checking and editing the data, setting technology parameters, calculating the wire trajectories and generating machine code.

Advantages of STEP-NC data model:

- An integrated CAD/CAM/CNC data chain
  - Interoperable and generic
  - Bi-directional data exchanges
  - No information loss
- Brings rich information to SMC/CNC level
  - Process plan (working steps, operations, strategies, …)
  - Geometry of the final part (e.g. 3D data)
  - Technology parameters (incl. feedback of experience)

- **Data monitoring, quality indicators tracking and direct optimization**

One of the main goals in FoFdation is to address sustainability at the factory shopfloor, and on the machine tool and to supervise the productivity and sustainability indicators to meet the triple bottom line corporate objectives- economic, environmental and social.
Optimization activities are based on real- time manufacturing data. This data must be further handled and analyzed in order to reveal indication for optimizations.

In addition to the conventional manufacturing, an important application of the Fofdation project concept (integration through MIP) and outcomes (SMC, EMon…) has been achieved for non-conventional processes like EDM (Electric Discharge Machining) by GF Machining Solutions by using the extensive information available from this cutting technology due to its full-electronic nature and advanced CNC features, in order to define a Smart Manufacturing and Communication system. The architecture of such a system is shown in figure 4.6.

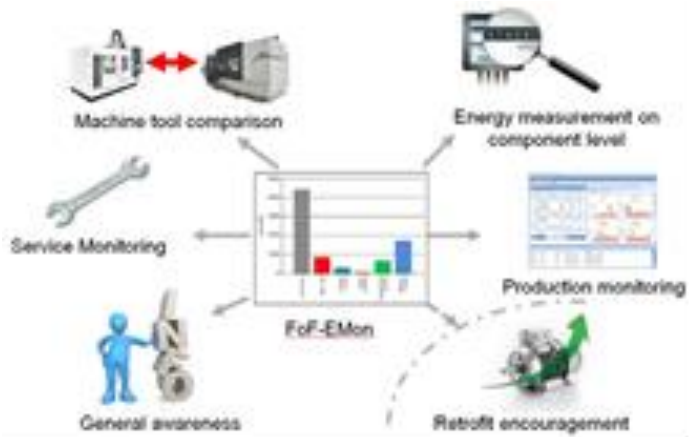


Figure 4.5: Machine monitoring and different Use cases

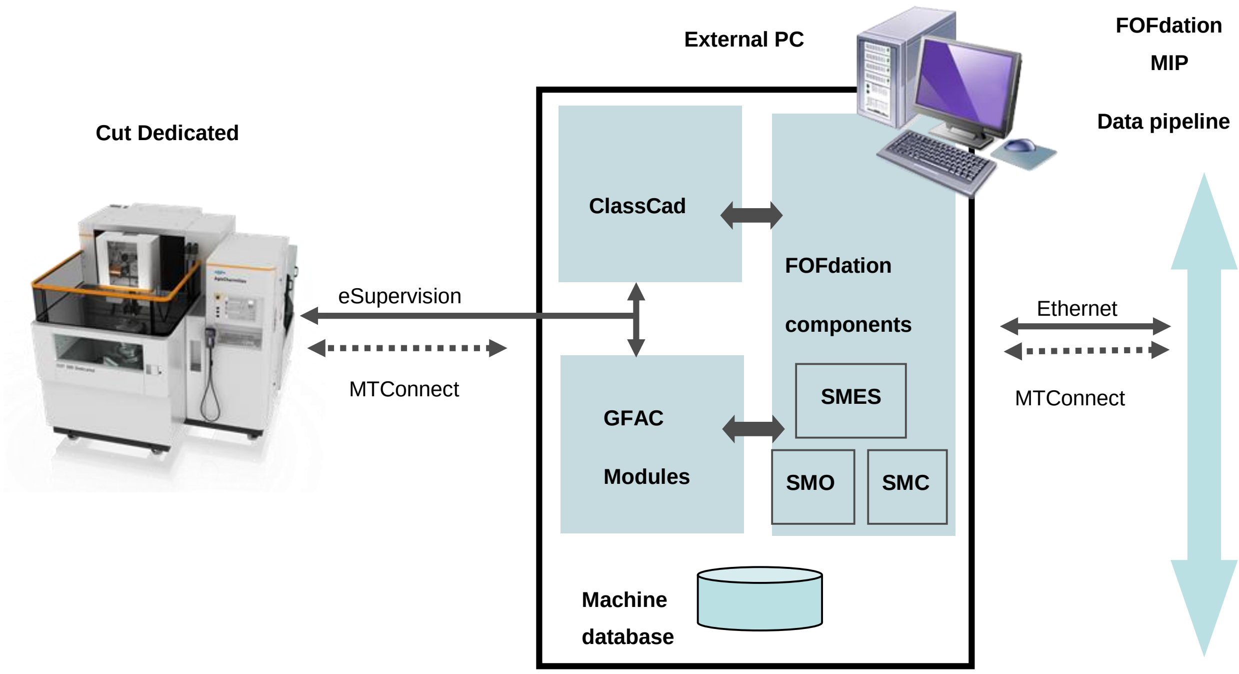


Figure 4.6: A smart management and communication system for EDM machines dedicated to aerospace component manufacturing, using ClassCad™ visualisation, Smart Machining Control and Optimiser structures and Smart Manufacturing Execution systems concepts

Previous wire EDM platforms had the possibility to connect to remote control units and supervise at distance the machining process. The Fofdation project has provided a structure and specific components that builds on these connectivity features a Smart management and process monitoring system which has been adapted specifically for applications where quality control are vital as in aerospace and medical component manufacturing.

- **Higher level management: Workshop supervision with a Smart Manufacturing Execution concept**

The system can now be integrated into a higher level management system defining a workshop supervisor, which can gathers information at the level of each machine. The architecture of such a smart manufacturing and monitoring systems for wire EDM is described in figure 4.7.

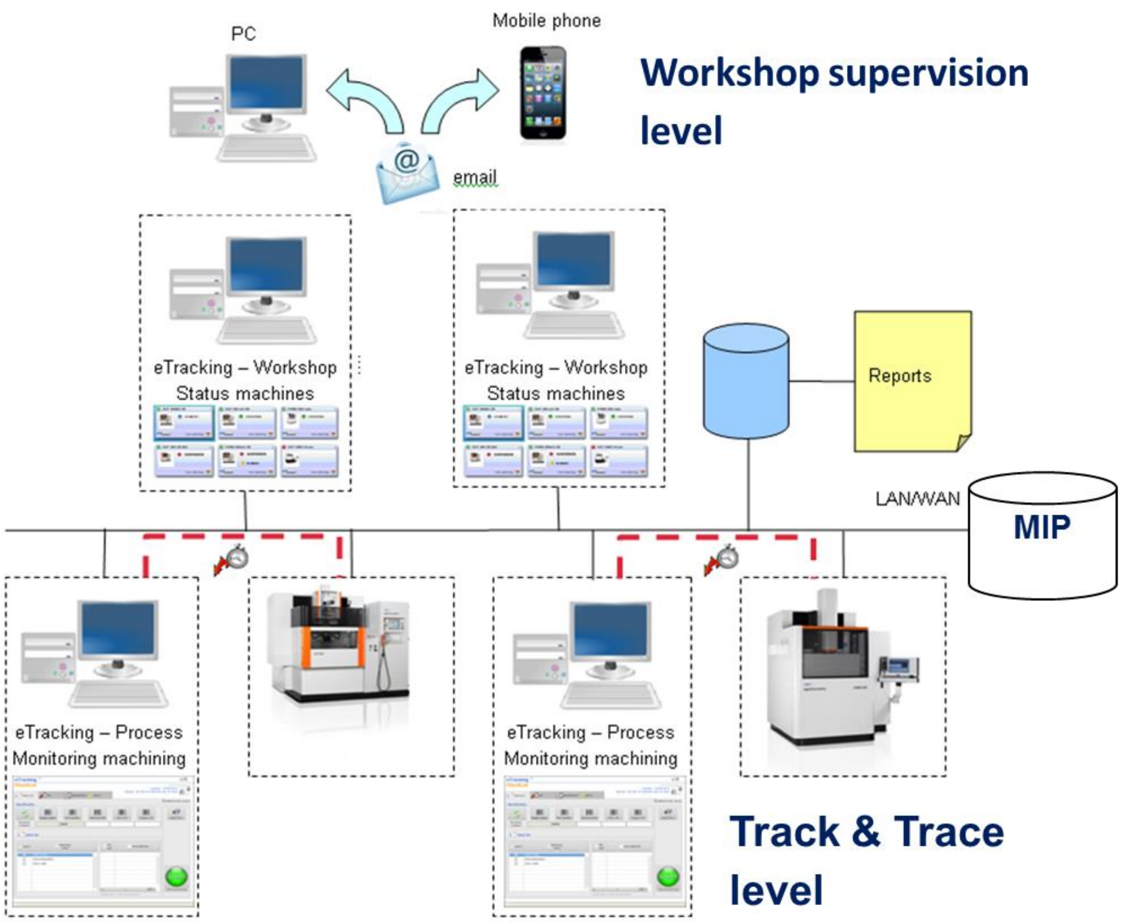


Figure 4.7: FoFdation Smart Management System for a complete manufacturing cell

At the workshop supervision level the status of the operation workflow can be monitored in detail. Every step of the set-up process for each device can be logged and traced and the following information coming from a local smart system can be raised; abnormal events, consumable status, key process indicators and process reports. These are elaborated at the machine level; the track and trace or e-tracking level, where afterwards the detailed follow-up of the machining process is performed (figure 4.8)

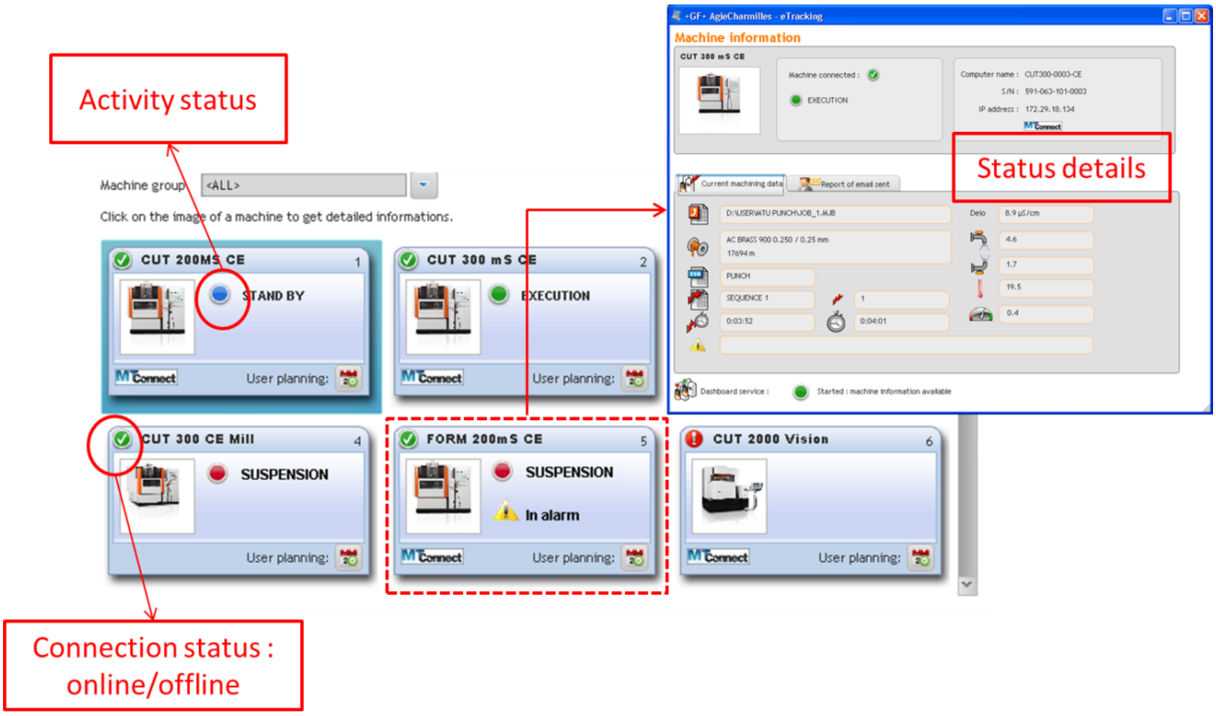


Figure 4.8: Example of machine information retrieved by the e-tracking system, showing follow up the cell status and machine level of consumables (wire, filters, etc), dielectric, injection and general process status.

## ➢ Smart process optimiser: the microscopic digital quality control

As we go down into the process control, the FoFdation concept defines a link with the micro-process level in order to define quality targets for key process indicators, the part signature, and follows up the associated signals in order to indicate accurately any out-of-tolerance event so to make this information available to the supervision level. The e-tracking software helps therefore first to define the quality signature of key process indicators with a reference part, during a

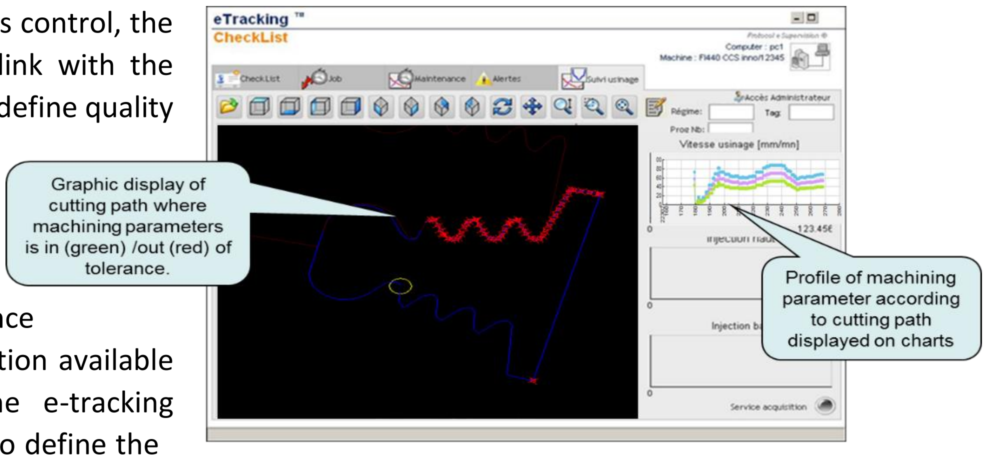


Figure 4.9: Follow up of key process signals on the machining paths and representation of key process values with reference to the part quality signature and

homologation phase. This is part of the process validation at the customer level. Secondly, and during the process, e-tracking follows up the key process signals, represents them graphically and indicates abnormal events on the tool path and the signal scale graph, as shown in figure 4.9

Full traceability is therefore ensured by the e-tracking system, which generates detailed reports from the process follow-up and provides to the management a quality certificate or, in case of abnormal events, an accurate indication on the position and the nature of the defect in order to allow actions for a detailed analysis or, in a following development stage, the implementation of a closed-loop or smart defect correction at the machine control level.

- **A strategic development for entering new markets**

The developed system defines a key result for GF Machining Solutions for addressing the needs of strategic market segments as aerospace, energy and medical component manufacturing. The EDM technology has been traditionally used in moulds, dies and general tool manufacturing, but the capabilities acquired through the Fofdation concept, namely end-to-end digitisation, remote control and interaction of macro and micro-production levels, traceability, productivity and sustainability of a complete production process gives the technology the means to respond to current challenges of these industries and opens new perspectives for the commercial development of GFMS

# 5. Strategic vision about ubiquitous Factory and manufacturing change management

To cope with today's industrial demands requiring (1) coverage of the whole product life cycle, (2) environmentally conscious manufacturing, (3) competitive sustainability manufacturing, etc., a new manufacturing paradigm should be developed. A conceptual framework for a new paradigm called ubiquitous factory (u-Factory) by applying ubiquitous computing technology to the manufacturing system is proposed based on the end-to-end digital MIP as proposed FoFdation. Following paradigms like Ubiquitous Computing and "Internet of Things", modern factories are developing into intelligent environments in which the gulf between the real and digital world is becoming smaller and smaller. The "Internet of Things" in everyday environment is developing into a vision of the "Factory of Things" for the ubiquitous factory environment.

Figure 5.1: U-Factory based on FoT-IT layers

The u-Factory is based on our previously developed paradigm, called UbiDMR, meaning product design, manufacturing, and recycling via ubiquitous computing technology. The essence of u-Factory can be represented by three key phrases: (1) information transparency, (2) autonomous control, and (3) sustainable manufacturing.

Ubiquitous Factory (u-Factory) is an innovative factory combining ubiquitous computing technology as an enabler for solving problems on the shop floor with existing components. U-Factory can be defined as a factory system in which autonomous and sustainable production takes place by gathering, exchanging and using information transparently anywhere anytime with networked interaction between man, machine, materials and systems, based on ubiquitous technology and manufacturing technology. This section describe how u-Factory concept could be derived and related issues including ubiquitous technology, problem analysis and design consideration.

Ubiquitous technology follows the idea of Mark Weiser; i.e., many kinds of pervasive and intelligent networked computers embedded in objects and environments will make human life easier and more comfortable. Since it was introduced in the early 1980s, ubiquitous technology has been mostly applied to human life, such as u-Home, u-City, u-Health, mainly by using RFID (Radio Frequency Identification) and USN (Ubiquitous Sensor Network) technology. In particular, material handing is the most widely applied area in the name of u-Logistics and u-SCM by replacing conventional bar- codes. This trend will rapidly increase in industry and eventually almost all the industries will adopt RFID-based material handling systems.

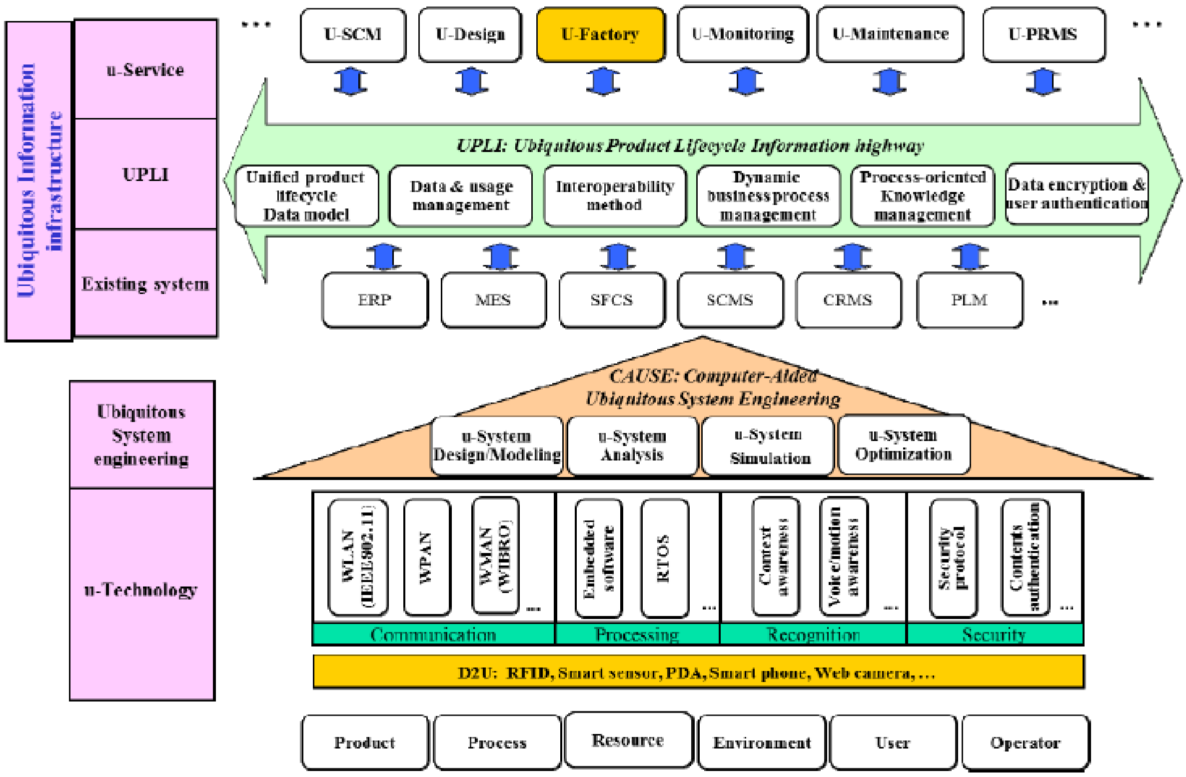


Figure 5.2: U-Factory in the frame of UbiDMR concept (Postech)

It is worth pointing out that the u-factory should not just be an application of ubiquitous computing technology (UT or ICT) in manufacturing systems, which would end up with just another type of automaton. In other words, the u-factory must be approached from the total system perspective based on vision and philosophy, rather than a solution means to solve local problems on the shop floor. In view of this, a new manufacturing paradigm called UbiDMR (Design, Manufacturing, and Recycling via Ubiquitous Computing Technology) has been proposed as introduced in D1.1. The main issue of UbiDMR is the utilization of the entire product lifecycle information via UT for product design, manufacturing, and recycling as shown in Figure 1. As indicated in Figure 1, u-Factory is one of the innovative services (namely u-Services) including u-SCM, u-Design, u-Factory, u-Monitoring, u- Maintenance, and u-PRMS. POSTECH Centre for Ubiquitous Manufacturing developed conceptual framework and architecture for u-Factory, u-PRMS, UPLS, CAUSE, etc. [*-*]. This research is concerned with u-Factory dotted in Figure 5.1.

u-Factory is an innovative factory combining ubiquitous computing technology as an enabler for solving problems on the shop floor with existing components. Therefore, u-Factory can be defined as a factory system in which autonomous and sustainable production takes place by gathering, exchanging and using information transparently anywhere anytime with networked interaction between man, machine, materials and systems, based on ubiquitous technology and manufacturing technology. Eventually, achievement of a transparent, an autonomous and a sustainable factory is the vision of a u-Factory. As shown in Figure 2, u-Factory aims at autonomous factory from the perspective of process control and sustainable factory from the perspective of manufacturing environment based on transparent factory from the perspective of information flow.

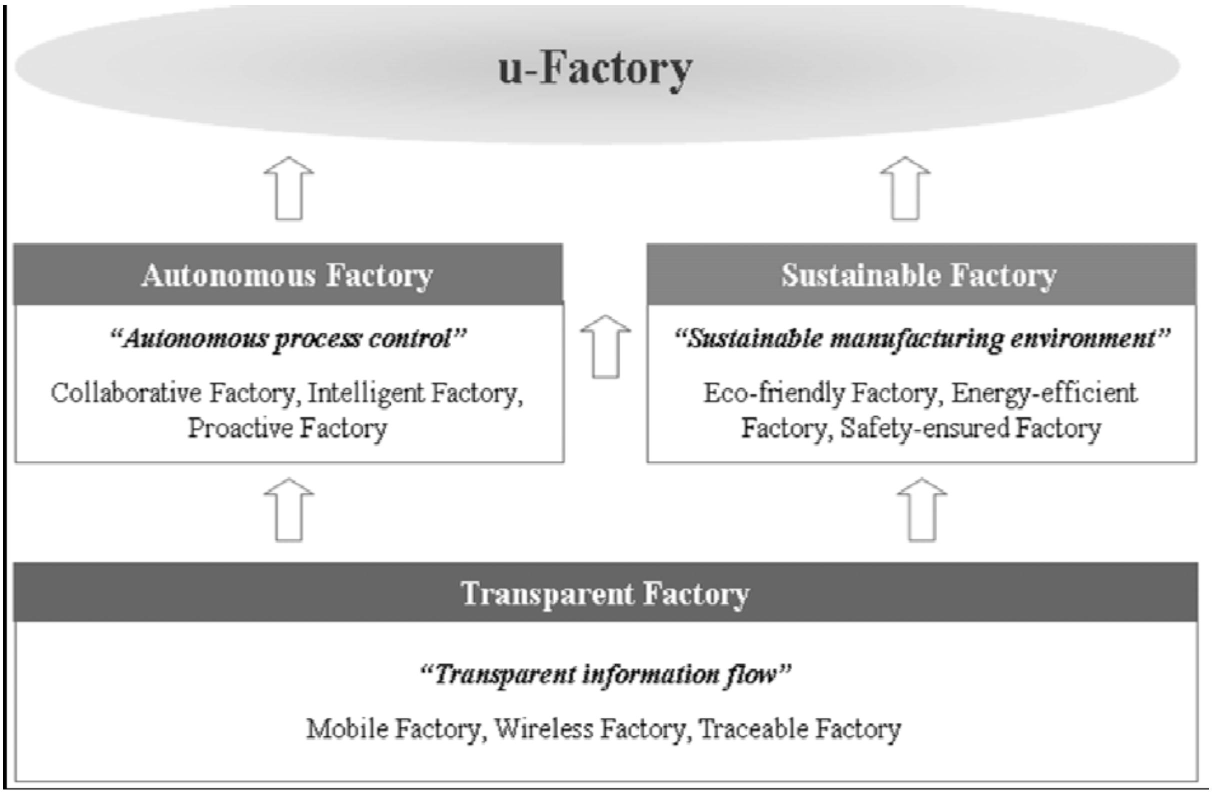


Figure 5.3: Vision of U-Factory enabled by FoFdation

- **Adapting MIP for u-Factory**

Manufacturing Information Pipeline in FoFdation define manufacturing information data model for process, product, and resource (from WP2). Also MIP is expected to perform various functions to enable smooth data exchange in addition to provide information data model (From WP6). From the perspective of UbiDMR, Ubiquitous Product Lifecycle Information highway (UPLI) plays a role as MIP as shown in Figure 3.
In order to realize u-Factory for FoFdation, MIP should perform data transfer, data integration, data expression and user authentication in addition to play a role as an information model and data repository. Thus Horizontal Information Infrastructure of UbiDMR should support Smart Service such as Smart SCM, Smart Design, Smart Monitoring, and also specific MIP functions such as Dashboard and KPI and Data encryption & user authentication as shown in Figure 3.

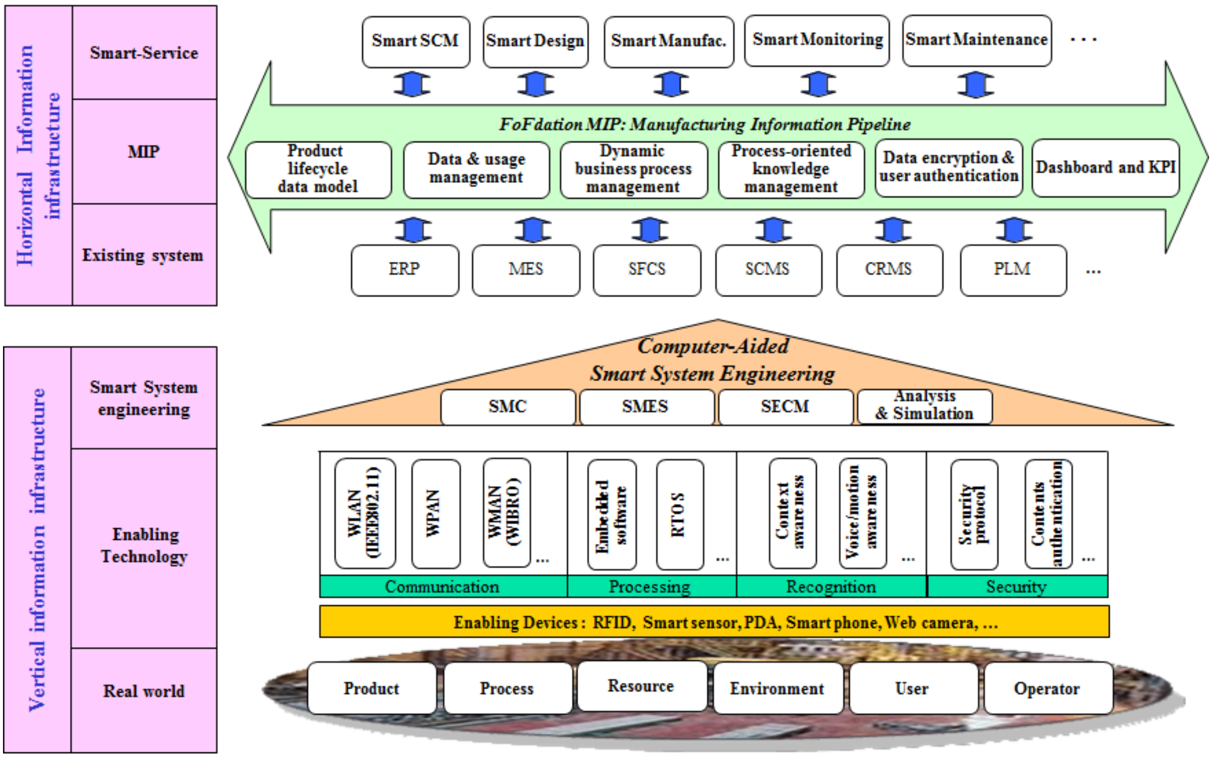


Figure 5.4: Ubi-DMR adapted to FoFdation

Information Infrastructure of UbiDMR for FoFdation consists of Vertical Information Infrastructure and Horizontal Information Infrastructure. Vertical Information Infrastructure represents the manufacturing information framework that collects and refines various raw data generated from manufacturing process and transports to higher system. In Real world layer, representing manufacturing field, objects of information collecting such as Product, Process, Resource Environment, User and Operator take place. Information generated from these objects are transported to higher system by ‘enabling technology’ which make it possible to vertical information exchange using Communication technology, Processing technology, Recognition technology and Security technology. ‘Enabling technology’ can be adapted to manufacturing filed through enabling device such as RFID, Smart Sensor, PDA and Smart Phone.

Smart System Engineering Layer builds and utilizes the system which use vertically transported information. SMC, SMES, SECM and Analysis & Simulation system are the target system of Smart System Engineering layer, and they are constructed as Computer-Aided Smart System Engineering which is an information system using IT technology.
Vertical Information Infrastructure enables information exchange between lifecycle application systems in order to provide various Smart-Services. Vertical Information Infrastructure consists of existing System layer, MIP and Smart Service. In Existing System Layer, there are existing systems in manufacturing field and information system such as ERP, MES, SCMS and PLM. MIP gets manufacturing information from those systems, stores and manages information, and transport to other system. Also MIP provide Smart-Service by manipulating received information. Smart-Service is an automatic/autonomous manufacturing activity according to status of manufacturing environment and process, and examples of Smart-Service are Smart Design and Smart Manufacturing.

By considering expected features and characteristics of MIP in u-Factory, it is required to do following functions MIP should perform in u-Factory:

- ✓ To collect manufacturing field information
- ✓ To transport required information to manufacturing field
- ✓ To transport required information to Smart-service
- ✓ To internal function such as Product Lifecycle Data Model, Dynamic Business Process
- ✓ Manager, Data Encryption & user authentication, Dashboard and KPI
- ✓ To communicate with SMES and SECM
- ✓ To communicate with external system

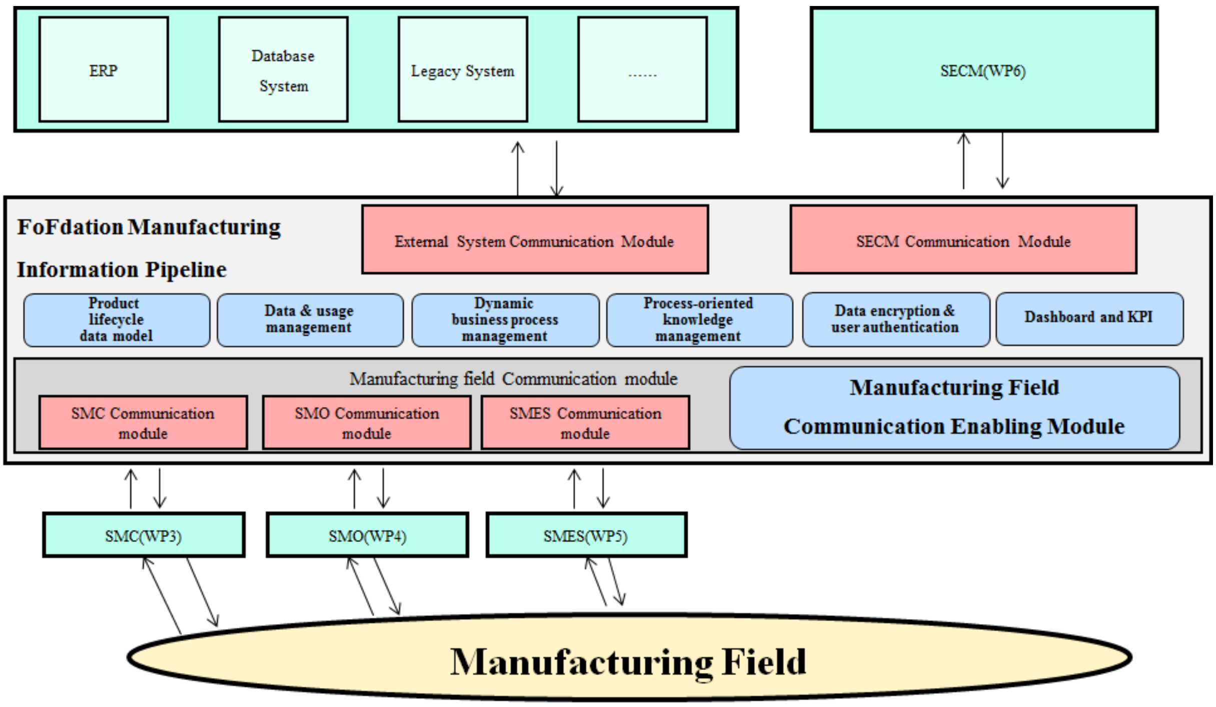


Figure 6.1: U-Factory based on MIP

## 6. The Living LAB for advanced manufacturing: bringing research to life

According to Wikipedia definition:

"A living lab is a user-centred, open-innovation ecosystem, often operating in a territorial context (e.g. city, agglomeration, and region), integrating concurrent research and innovation processes within a public-private-people partnership.

The concept is based on a systematic user co-creation approach integrating research and innovation processes…

The living lab process which integrates both user-centred research and open innovation, is based on a maturity spiral concurrently involving a multidisciplinary team in the following four main activities:

*Co-creation:* bring together technology push and application pull into a diversity of views, constraints and knowledge sharing that sustains the ideation of new scenarios, concepts and related artefacts.

*Exploration:* engage all stakeholders, especially user communities, at the earlier stage of the co-creation process for discovering emerging scenarios, usages and behaviours through live scenarios in real or virtual environments

*Experimentation:* implement the proper level of technological artefacts to experience live scenarios with a large number of users while collecting data which will be analysed in their context during the evaluation activity.

*Evaluation:* assess new ideas and innovative concepts as well as related technological artefacts in real life situations through various dimensions such as socio-ergonomic, socio-cognitive and socio-economic aspects; make observations on the potentiality of a viral adoption of new concepts and related technological artefacts through a confrontation with users' value models."

- **Why do we need a living LAB for FoFdation? …Breaking the barrier towards efficient exploitation of the project outcomes**

In our project FOFdation, in addition to the technical objective, we pursue the exploitation development through a network of living Labs to "bringing research to life".

Many initiatives about the livingLAB concept already existed worldwide, but our living Lab is specifically characterized by the following features:

- Totally private initiative (association as legal body, and hosted by a company GFMS)
- Very oriented to SMEs (many sub-associations of SMEs are members of our living LAB)
- European implementation and networked management (all projects partners are instantly invited to become member)

The objectives are very pragmatic and focusing on bridging the Technological Valley of Death, beyond the European R&D programme, as many projects outcomes at the end of the EC funding period are abandoned on the paper tray or in the secret drawer. We need to achieve our research mission towards an exploitable product!

All innovators know that two distinct and proven barriers impede the innovation lifecycle for the implementation of breakthrough technologies and paradigm shift: the Technological

Valley of Death and the Commercialization Valley of Death, both of which are depicted in the graphic above.

The Technological Valley of Death stands between the first and second stages and even till the mid of the third stage of technological development, as researchers seek further capital to develop an exploitable prototype from the proof-of-concept, and prove its basic market viability through intensive demonstration in real application scale (live demo).

The Commercialization Valley of Death occurs later in a technology's development, as entrepreneurs seek capital to fund first-of-a-kind commercial-scale projects or manufacturing facilities.

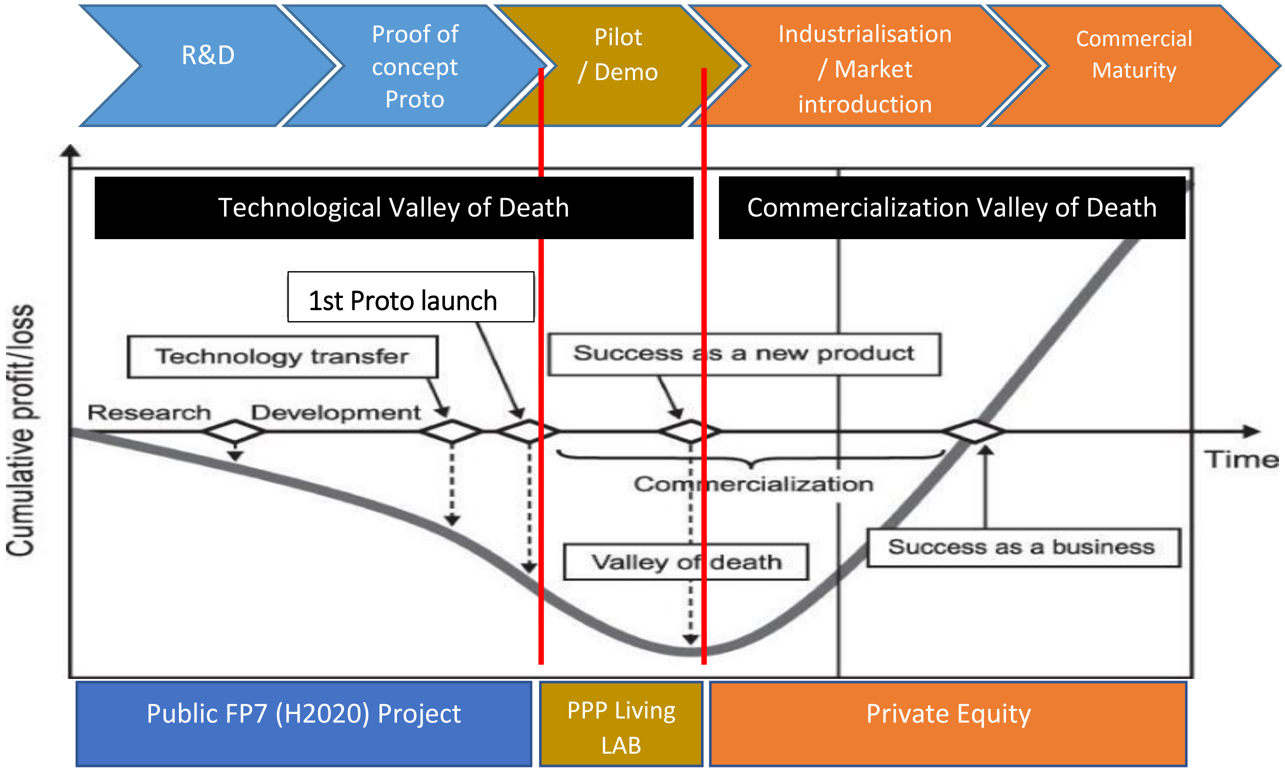


Figure 6.1: Living LAB for closing the technological Death Valley

Moreover, the actual innovation landscape is rather dominated by public or academic initiatives: most living LABs have been set up within the universities and higher schools campus, sometimes with the support of large corporate companies. Many innovation strategic initiatives were rather focusing on the set-up of supporting and administrative tasks like networking-clustering activities, entrepreneurship assistance and information desk about R&D funding policies than the concrete achievement of real industrial research and development activities. Recently new trends like FabLABs that emerge from the disruptive 3D-printing paradigm were proposed everywhere thanks to the very accessibility of this technology and its "self-creativity enabling" perception by the public!

Nevertheless, the reality on the ground is still far from consistent with these initiatives and programmes with regard to the real manufacturing environment mainly in SMEs.

In FoFdation, we believe that our industry-centric Living Lab is strategically necessary to make the differences for promoting the Collaborative Economy and enabling Value Creation within Companies:

- On the one hand, turn ideas into reality or research results into exploitable products-services in the manufacturing research context, by overcoming at least the Technological Death Valley, beyond the project duration and framework. Moreover customers often say: "We are pleased about innovative and high-quality products – but we don't always buy the best available on the market. We will procure the products which cover our demand most economically. Even if competitors' products are not equal to your product, they might fulfil our requirements better and possibly even cheaper".
- On the other hand, transfer advanced knowledge to SMEs, and enable the acceptance of new technology by smaller firms. Address SMEs and support them to tackle efficiently the integration of advanced technology into suitable and right solutions that fit their needs. Customers need rather solutions than products! And solution is often based on the adequate integration of new or legacy products from different brands.

Then our living LAB goal is support our research partners to offer adequate solutions that could be built upon innovative and high quality products delivered by the R&D projects!
To summarize, our living Lab practically pursues two main objectives:

- Knowledge capitalization from projects results: the living LAB is an appropriate platform to gather former partners in order to explore new project ideas based on previous outcomes.
- Proof-of-Concept demonstrations: many "FoFdation components" can be on-going presented and demonstrated (SMC smart controller, SMO-CADPM for machine monitoring and optimization, FoF-EMon energy monitoring and Green Manufacturing Viewer, SSO Smart Sustainability optimizer, FoFdation Dashboard etc…). They can offer today "point" solutions thus addressing the local factory issues or practical problems that need concrete and downsized products for the short-term while being compatible with the long-term integration perspective. Research projects tends to deliver the ideal solution outcome while in practice new technology implementation was usually achieved step by step. The living Lab is aiming at downsizing the overall solution into practical "point solution" products to meet earlier practical needs.

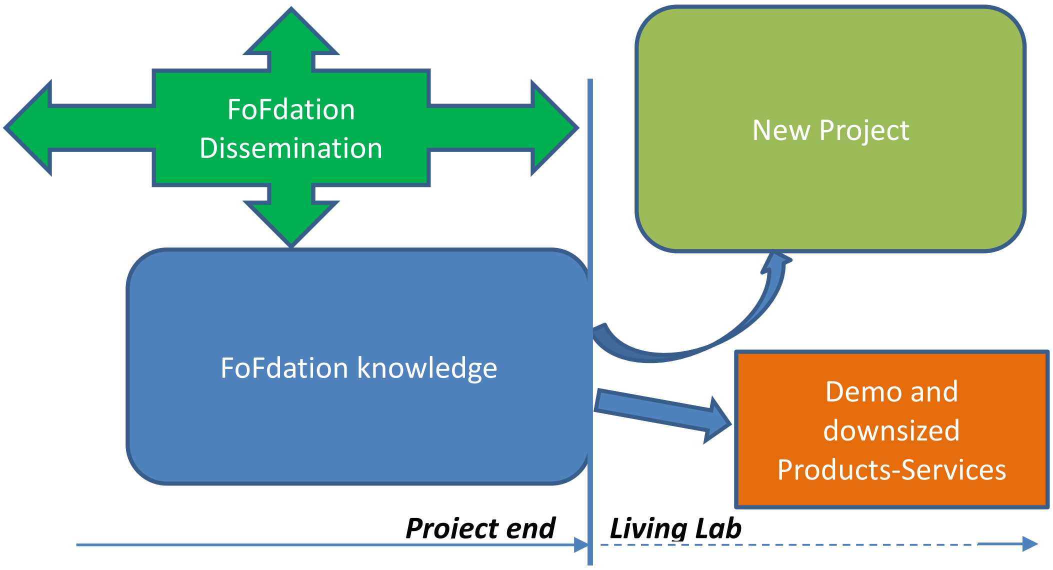


Figure 6.2: FoFdation Living LAB missions

## 7. Conclusion

Digital data is at the heart of competitive manufacturing mainly of highly complex products.

- Interoperability of data/information (versus compatibility) and robustness (application scope is dynamic and will continuously change as business and technology requirements change over time)
- Integration platform for different temporal-decision scale data (realtime, neartime, anytime) and multiple data sources
- Integration of the real and the virtual data-information towards a predictive model for manufacturing

FoFdation is directly contributing towards increasing the competitiveness of European manufacturing by developing an end-to-end and interoperable digital manufacturing model to enable the future CPS (Cyber Physical system implementation) that can be adapted from and adapted to anywhere, to lead to a predictive factory. Decision making at the field level (real-time), the factory plant level (near-time), and the corporate management level are much more informed and can be made much more easily. The Management Information Pipeline (MIP), currently being developed within the project will combine these four innovative elements:

- Smart Manufacturing Controller (SMC)
- Smart Manufacturing Optimizer (SMO)
- Smart Enterprise Content Management (SECM)
- Smart Manufacturing Execution System (SMES)

Inter-linking to ensure a complete dashboard of accurate and up-to-date information.