Chapter 1
Introduction

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Abstract This introductive chapter aims to clarify some of the main research contents that are involved in Manutelligence project and wants to present the objectives of the project and the structure of the Manutelligence IT platform. We briefly describe some fundamental concepts, such as the Product Lifecycle Management (PLM), the Product Service System (PSS), the Internet of Things (IoT) for the smart manufacturing, the Life Cycle Cost and the Life Cycle Assessment (LCC and LCA). All these topics are strictly connected, since Manutelligence project aims at supporting enterprises to design and to develop suitable Product-Service Systems, addressing customers' needs and stakeholders' requirements, collected also through IoT technologies. Furthermore it aims to integrate best in class methodology and tools from research and industry, resulting in a secure, collaborative Product/Service Design and Manufacturing Engineering Platform, able to manage the Product-Service lifecycle and to collect information in order to implement LCC and LCA.

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1.1 Product Lifecycle Management

PLM (Product Lifecycle Management) is an acronym widely used in the current industrial practice. Coined more than 15 years ago, PLM is often seen as an extensive and comprehensive concept, which defines the integration of different kinds of activities performed by engineering staff along the entire lifecycle of industrial products, "from cradle to grave" [1].

In its practical essence, PLM defines the adoption of several software tools and platforms for supporting innovation and engineering processes. According to the main business analysts (e.g. Gartner, CIMdata, Tech Clarity), PLM is a leading global market of IT solutions, mainly segmented in two branches: (i) Authoring and Simulation tools and (ii) Collaborative Product Development platforms and environments. In the first segment, dozens of vendors are globally proposing their solutions for enabling virtual prototyping solutions (from CAD 3D, to Computational Flow Dynamic, from Finite Element Analysis, to Discrete Event Simulation, etc.). The second branch is populated by a plethora of collaborative functionalities supporting, for instance, effective file sharing, document vaulting, work flow automation, team management and on distance working. Most of them are provided in one single, secured environment.

PLM is still a matter of design and engineering tools, and their integration. The industrial practice shows how PLM's real implementation is quite far from its comprehensive "lifecycle" meaning [2].

One product lifecycle framework in production engineering differentiates three main phases, describing the product from the "cradle to grave" [3]:

- **Beginning of Life (BOL)**: processes related to development, production and distribution;
- **Middle of Life (MOL)**: processes related to a product's use, service and repair;
- **End of Life (EOL)**: processes related to reverse logistics like reuse, recycle and disposal.

Approaches, such as closed-loop PLM [4], take a view upon the entire product lifecycle, from product ideation to end-of-life processes. Ideally, the view extends into the beginning of the next lifecycle. This puts forward a paradigm shift from "cradle to grave" to "cradle to cradle" [5]. An example is the refurbishment of components from decommissioned products for use in new ones. The aim of closed-loop PLM is to close information gaps between the phases and processes of the product lifecycle. This can be backwards, for example providing usage data to design processes, or forwards, for example providing production and assembly information to recycling processes. It deals with products as classes or variants, as well as individual product items ("item level").

1.2 Product Service System

The adoption of the service business by manufacturing companies is a common trend in many industrial sectors, especially those offering durable goods. This shift, referred to in literature as servitization process, is defined as "[…] the increased offering of fuller market packages or 'bundles' of customer focused combinations of goods, services, support, self-service and knowledge in order to add value to core product offerings" [6]. Servitization supports companies to strengthen their competitive position thanks to the financial, marketing and strategic benefits led by the integration of services in the companies' offer [6–9].

Differentiation against competitors, hindering competitors to offer similar product-service bundles and the increasing of customer loyalty are the main benefits of servitization. Today, more than ever, servitization is customer driven [10]. A research field that is often associated to the servitization process is the one related to the Product Service-Systems (PSS) [11]. The first definition of a PSS was given in 1999: "A product service-system is a system of products, services, networks of players and supporting infrastructure that continuously strives to be competitive, satisfy customer needs and have a lower environmental impact than traditional business models" [12].

Manzini points out that PSS is an innovation strategy that allows fulfilling specific customer needs [13]. Tukker observes that PSS is capable to enhance customer loyalty and build unique relationships since it follows customer needs better [14]. Another important contribution comes from Sakao and Shimomura that see PSS as a social system that enhances social and economic values for stakeholders [15].

The move towards the PSS entails an organizational change that makes a company shift from a product-oriented culture to a service-oriented one. The transition is quite a complex process that requires several changes and that usually happens in subsequent steps.

Martinez et al. identify the five categories of challenges a company has to deal with when moving along the servitization process, namely embedded product-service culture, delivery of integrated offering, internal processes and capabilities, strategic alignment and supplier relationships [16].

PSS often include value adding services based on ICT contributions, both in terms of enhanced information and knowledge generation/sharing, as well as of additional functionalities [17, 18]. PSS providers need to establish collaboration among specialized companies. In particular, Fisher et al. discussed approaches for service business development on a global scale. They take into account organizational elements, such as customer proximity or behavioral orientation [19].

The closer affiliation of customers and manufacturers/service providers offer potential to generate revenue throughout the entire lifecycle [18, 20]. Moreover, as stated by Baines et al., "… integrated product-service offerings are distinctive, long-lived, and easier to defend from competition based in lower cost economies …" [18]. The potential extension of the lifetime of tangible components of PSS, due to their integration with adding value services, opens interesting perspectives also about environmental sustainability improvements.

The advantages coming from PSS have been demonstrated in literature, yet for many companies efficiently managing the service operations is still a challenge. Best practices and empirical analysis are mainly carried out with a focus on larger companies. Nonetheless, the PSS topic is more and more recognized by SMEs that are looking for innovative business solutions to improve their competitive advantages.

1.3 Internet of Things for Smart Manufacturing

The term "Internet of Things" (IoT) was first used by the Massachusetts Institute of Technology in the year 1999. It was used in the sense of a networked system of autonomously interacting and self-organizing objects and processes, which was expected to lead to a convergence of physical things with the digital world of the Internet [21]. This extrapolates the idea of the Internet—a global, interconnected network of computers—to describe a network of interconnected things, such as everyday objects, products, and environments. At the heart of the concept lies the idea that objects—things—are capable of information processing, communication with each other and with their environment, and autonomous decision making. For instance, Intelligent Products are physical items, which may be transported, processed or used and comprise the ability to act in an intelligent manner. McFarlane et al. [22] define the Intelligent Product as:

> [...] a physical and information based representation of an item [...] which possesses a unique identification, is capable of communicating effectively with its environment, can retain or store data about itself, deploys a language to display its features, production requirements, etc., and is capable of participating in or making decisions relevant to its own destiny.

The degree of intelligence of a product may exhibit variations from simple data processing to complex pro-active behavior. Three dimensions of characterization of an Intelligent Product are suggested by Meyer et al. [23]: Level of Intelligence, Location of Intelligence and Aggregation Level of Intelligence. The first dimension describes whether the Intelligent Product exhibits information handling, problem notification or decisions making capabilities. The second shows whether the intelligence is built into the object, or whether it is located in the network. Finally, the aggregation level describes whether the item itself is intelligent or whether intelligence is aggregated at container level.

More recently Porter states that intelligence and connectivity enable an entirely new set of product functions and capabilities, which can be grouped into four areas: monitoring, control, optimization, and autonomy [24]. A product can potentially incorporate all four. Each capability is valuable in its own right and also sets the stage for the next level. For example, monitoring capabilities are the foundation for product control, optimization, and autonomy. A company must choose the set of capabilities that deliver its customer value and define its competitive positioning.

Smart, connected products have three core elements:

- *Physical* components comprise the product's mechanical and electrical parts. In a car, for example, these include the engine block, tires, and batteries.
- *Smart* components comprise the sensors, microprocessors, data storage, controls, software, and, typically, an embedded operating system and enhanced user interface. In a car, for example, smart components include the engine control unit, antilock braking system, rain-sensing windshields with automated wipers, and touch screen displays.
- *Connectivity* components comprise the ports, antennae, and protocols enabling wired or wireless connections with the product. Connectivity takes three forms, which can be present together:
  - One-to-one: an individual product connects to the user, the manufacturer, or another product through a port or other interface—for example, when a car is hooked up to a diagnostic machine.
  - One-to-many: a central system is continuously or intermittently connected to many products simultaneously. For example, many Tesla automobiles are connected to a single manufacturer system that monitors performance and accomplishes remote service and upgrades.
  - Many-to-many: multiple products connect to many other types of products and often also to external data sources. An array of types of farm equipment is connected to one another, and to geo-location data, to coordinate and optimize the farm system.

Connectivity serves a dual purpose. First, it allows information to be exchanged between the product and its operating environment, its maker, its users, and other products and systems. Second, connectivity enables some functions of the product to exist outside the physical device, in what is known as the product cloud.

Smart, connected products offer exponentially expanding opportunities for new functionality, far greater reliability, much higher product utilization, and capabilities.

These new types of products alter industry structure and the nature of competition, exposing companies to new competitive opportunities and threats. They are reshaping industry boundaries and creating entirely new industries. Smart, connected products have been shown to be applicable to various scenarios and business models. For instance, Kärkkäinen et al. describe the application of the concept to supply network information management problems [25]. Other examples are the application of the Smart Products to supply chain [26], manufacturing control [22, 27], and production, distribution, and warehouse management logistics [28].

Smart connected products are increasingly the focus of research into the collection of item-level product usage data for closed-loop PLM applications, servitization and product avatars [29, 30].

1.4 Life Cycle Cost (LCC) and Life Cycle Assessment (LCA)

Life Cycle Cost (LCC) analysis provides a framework for specifying the estimated total incremental cost of developing, producing, using and retiring a particular item. This methodology is useful to directly provide cost information to designers, in order to reduce the life cycle cost of the products they design [31].

There exist some difficulties in the application of LCC techniques to PSS, which usually includes the necessity of analyze various scenarios for effectively evaluating the impact of risks and uncertainties. These difficulties arise from some specificities of PSS, such as the modification of the role and responsibilities of customers and suppliers in the various PSS life cycle phases, the difficulty to foreseen the timing and overall frequency of use of some services, the lack of availability of life cycle data. The gap about LCC information among the various stakeholders during the PSS design phase can lead to unsatisfactory choices and prevent the full exploitation of PSS benefits [32, 33].

Life Cycle Assessment is "a process to evaluate the environmental burdens associated with a product system, or activity (process) by identifying and quantitatively describing the energy and materials used, and wastes released to the environment, and to assess the impacts of those energy and material uses and releases to the environment" (www.setac.org). To calculate impact ratios, LCA defines four phases that takes place iteratively: the goal/scope definition, the inventory definition and analysis, the impact assessment and the interpretation. Fundamental for the reliability and repeatability of calculating impact ratios is the completeness and quality of data and the transparency of processes and methodology applied.

Although LCA is a well-documented methodology (e.g., LCA handbook, 2010), repeatability is weakened because of the large freedom offered in choosing system boarders, parameter selection, data quantity and calculation methodology, which introduce uncertainties on estimated impact ratios and make difficult their comparisons. Moreover, due to the complexity and the diverse types of uncertainties inherent to LCA, simplifications and by analogy approaches are often required in order to use it [34]. This hinders the comparison of studies even when they address similar situations. The role of LCA in influencing design and more generally decision making towards a sustainability strategy is hindered by its current use, which often takes place as a posteriori side activity after product design fulfillment, as well as by the lack data models and tools able to capture and make transparent the choices and decision process during all the step of product lifecycle. These problems are exacerbated while considering PSS due to some specific challenges, such as:

- Wide difference of PSS typologies implying modifications to the required activities and the involved actors [35];
- Strong influence of the context of application of PSS for determining the encounters and the methodologies to be followed [36],
- Unsatisfactory integration of sustainability issues in current PSS design methodologies.

1.5 The Manutelligence Project

The Manutelligence Project aims at supporting enterprises to design and to develop suitable Product-Service Systems, addressing customers' needs and stakeholders' requirements. Manutelligence aims to integrate best in class methodologies and tools from research and industry, resulting in a secure, collaborative Product/Service Design and Manufacturing Engineering Platform.

The Manutelligence consortium consists of a group of highly qualified industrial and academic research organizations that has been specifically affiliated to meet the challenges of the project.

All the involved RTD partners have a strong experience in publicly funded projects, both at a European and a national level, with high innovative and application capabilities. The RTD partners have the core competences and expertises required to cover the knowledge domains of this project (information and communication technologies, product lifecycle management, product & service innovation management, data and knowledge management, etc.). The application partners are concentrated on the industry-driven implementation and evaluation, to prove the resulting research concepts.

The partners are divided as follow:

- 4 Research partners broken down as follows:
  - 2 Universities: Politecnico di Milano and Supsi.
  - 2 Research Institutes: VTT and BIBA.
- 3 ICT Industrial partners: Dassault Systèmes, Holonix and Balance.
- 5 Industrial Companies: Ferrari, Mayer Turku, Lindbäcks Bygg, Fundacio Privada Centre CIM, Rina Consulting.

Concerning the geographical distribution of the consortium partners, Manutelligence gathers partners form seven different countries: Finland, France, Germany, Italy, Spain, Sweden, and Switzerland.

1.5.1 Manutelligence Research Objectives

The main research topics addressed during the projects have been:

- Improve efficiency and develop new methodology for the PSS design process, with a specific focus on the integration of IoT technologies (Chap. 2).
- Achieve a complete integration of Product Lifecycle Management and Service Lifecycle Management, developing concepts, methodologies and tools to support PSS development (Chap. 2).
- Adapt and integrate existing design, data analysis and life cycle assessment tools to realize closed-loop PLM for PSS (Chap. 2).
- Enable designers and engineers access data from the traditional enterprise IT systems, but also from the IoT enabled systems. The objective is to manage all data,

information and knowledge related to the P-S and its lifecycle in manufacturing. (Chap. 3).

- Extract feedback from P-S customers, analyzing data coming from IoT systems, in order to speed up the design of P-S, and to decrease the costs and to better understand customer needs (Chap. 3).
- Extend and improve the use of Manufacturing and Service Execution Simulation and optimize it through comparisons with test bench and real usage data (Chaps. 3 and 4).
- Measure and simulate costs and sustainability issues, through Life Cycle Cost (LCC) and Life Cycle Assessment (LCA), collecting data from both traditional sources and smart connected products. The combined use of various tools allows effectively sharing LCC and LCA information to all the stakeholders in a simple way, supporting their decision making processes (Chap. 5).

1.5.2 The Manutelligence IT Platform

To achieve the described objectives, Manutelligence aims to integrate best-in-class methodology and tools from research and industry, resulting in a secure, collaborative Manufacturing Engineering Platform. This platform enables designers and engineers to access data from both the traditional enterprise IT systems (CAD, CAX, PLM, MES, etc.) and from smart, connected products. In Table 1.1, the architecture of the Manutelligence platform is presented.

The platform consists of the integration of different tools components, which will be exhaustively described in Chap. 4.

The core technical achievements of Manutelligence are:

- Inclusion of tools for the process design and manufacturing execution. These tools are intrinsically integrated with the PSS design phase and can leverage on the IoT information coming from the operations.
- Access information through a 3D interface representing the digital representation of the product, containing both information from the digital product model stored in the PLM and those coming from Intelligent Products (IoT technologies).

Table 1.1 Manutelligence's tools integration

Partner tool name	Brief description of component	Provided by partner
3DEXPERIENCE	Managing the Product Service Design and Manufacturing processes	Dassault Systemes
I-Like	Managing the Internet Of Things (IoT) data gathering and elaboration	Holonix
MaGA	Managing the environmental impact analysis	SUPSI
LCPA	Managing the Product Service life cycle cost analysis	BALANCE

- Support the interaction between the engineering and the environmental (LCA) or business (LCC) analysts, as well as to provide tools and methods to enable iterative calculation and optimization of these aspects. The platform results a suitable tool to collect, share data and information helping analysts to retrieve data and to define boundaries of the analysis.
- Features of the platform can be applied in many different industrial cases, improving the manufacturing efficiency and quality, addressing the needs captured from the products usage by the end users.

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