POLITECNICO
MILANO 1863

SCUOLA DI INGEGNERIA INDUSTRIALE
E DELL'INFORMAZIONE

A Business Model For The Customization Of Advanced Maintenance Through Microservices

TESI DI LAUREA MAGISTRALE IN
MANAGEMENT ENGINEERING
INGEGNERIA GESTIONALE

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Academic Year: 2021-22

Abstract

This thesis has, in its scope of work, the interest and goal to understand what characteristics of industry 4.0 can be embedded in advanced maintenance, especially looking at the potential of micro-services to develop advanced maintenance as business opportunity and foundation of a new business model. Microservice architecture is a way to arrange an application as an ensemble of small, independent, loosely-coupled services which communicate each other and are potentially able to confer flexibility and scalability to modern applications.

After having analysed the state-of-art (in quantitative and qualitative dimensions) for each concept embedded in this thesis (from advanced maintenance to servitization to micro-servitization) and having deeply analysed to what extent the association of micro-servitization to advanced maintenance was explored in literature, the most important gaps have been brought to light, in order to give a direction to the desirable research fulfilments. In particular the most relevant gap found in literature was the lack of a structured business model able to fulfil the need of customization of advanced maintenance solutions.

Starting from identified gaps, this thesis tried to give its own contribution to literature by providing a business model able to put the basis for the development of advanced maintenance solutions through micro-services. Such business model, in fact, confers to advanced maintenance a certain degree of customization expressed especially in terms of flexibility and scalability increase. As the solution has been designed as business model Canvas, each building block was deeply described and some practical examples of value proposition provided to the reader for a more comprehensive understanding of advantages enabled by micro-services.

Finally, the business model idea was tested through an innovative validated procedure proposed by A. Osterwalder in 2021, interviewing mainly two companies operating in two different contexts and providing two different points of view: one from costumer side and one from supplier side.

As result, sufficient evidences were provided to support and validate the proposed business idea, with the precious contribution of some additional insights that could be used as starting point for future developments of the presented business model and its application in real use cases.

Key-words: advanced maintenance, micro-servitization, smart maintenance, e-maintenance, micro-services, flexible maintenance, customization

Abstract in italiano

Questa tesi l'interesse e l'obiettivo di comprendere quali caratteristiche dell'industria 4.0 possono essere incorporate nella manutenzione avanzata, in particolare guardando al potenziale dei micro-servizi per sviluppare la manutenzione avanzata come opportunità e fondamento di un nuovo modello di business. L'architettura di microservizi è un modo per organizzare un'applicazione come un insieme di servizi piccoli, indipendenti e isolati che comunicano tra loro e sono potenzialmente in grado di conferire flessibilità e scalabilità alle applicazioni moderne.

Dopo aver analizzato lo stato dell'arte (nelle sue dimensioni quantitativa e qualitativa) per ogni concetto incorporato in questa tesi (dalla manutenzione avanzata alla servitizzazione alla micro-servitizzazione) e aver analizzato a fondo fino a che punto l'associazione tra micro-servitizzazione e manutenzione avanzata è stata esplorata in letteratura, le lacune più importanti sono state portate alla luce, al fine di dare una direzione agli auspicabili adempimenti della ricerca.

In particolare, la lacuna più rilevante riscontrata in letteratura è stata la mancanza di un modello di business strutturato in grado di soddisfare l'esigenza di personalizzazione di soluzioni di manutenzione avanzate.

Partendo dalle lacune individuate, questa tesi ha cercato di dare il proprio contributo alla letteratura fornendo un modello di business in grado di porre le basi per lo sviluppo di soluzioni di manutenzione avanzate attraverso micro-servizi. Tale modello di business, infatti, conferisce alla manutenzione avanzata un certo grado di personalizzazione espresso soprattutto in termini di flessibilità e aumento della scalabilità. Poiché la soluzione è stata progettata come modello di business Canvas, ogni elemento costitutivo è stato descritto in modo approfondito e alcuni esempi pratici di proposta di valore sono stati forniti al lettore per una comprensione più completa dei vantaggi abilitati dai micro-servizi.

Infine, l'idea del modello di business è stata testata seguendo un'innovativa procedura validata proposta da A. Osterwalder, nel 2021, intervistando principalmente due aziende che operano in due contesti diversi e forniscono due diversi punti di vista: uno lato cliente e uno lato fornitore. Di conseguenza, sono state fornite evidenze sufficienti per supportare e validare l'idea proposta con, in aggiunta, un prezioso contributo di alcuni ulteriori approfondimenti che potrebbero essere utilizzati come punto di partenza per sviluppi futuri del modello di business presentato e applicazioni reali.

Parole chiave: manutenzione avanzata, micro-servitizzazione, manutenzione intelligente, e-maintenance, micro-servizi, manutenzione flessibile, personalizzazione

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1 Introduction

1.1. Overview

Maintenance was historically considered as a not value adding activity, more specifically the cost derived from the repair of the asset and time needed to achieve the restoration. Over the years, maintenance has assumed a relevant role in strategical activities of the company, due to a progressive amplification of its objectives, moving from the concept of maintenance as group of activities to repair an asset and restore its degraded status, to maintenance as key aspect to increase performances. This "evolutive" dimension of maintenance affects also the maintenance techniques which tend to follow and encourage an evolution of the system of assets, based on the experience that is made on it and on new requirements from markets and business [1].

Moreover, starting from '90s, the maintenance culture radically changed due to the emergence of new business dynamics and the rapid increase of production volumes, pushing organizations to invest in an effective maintenance management in order to increase availability and reliability of machines, increase productivity and ensure safety dimension [2]. This prosperity contributed to the development of new maintenance paradigms and it started to be object of study of many industries and universities in the world, thanks also to an increasing interest of B2B companies, which see in the new requirements fulfillment some business opportunities [3].

The arrival of the fourth industrial revolution also known as "Industry 4.0" and the emergence of new technologies change radically the industrial panorama in terms of maintenance paradigm. Sensor-embedded machines are able to collect real-time data together with new digital technologies, with the consequence to make data always available and system interconnected (such as IoT) [4]. The increasing usage of sensors has marked the shift from selling simply products to sell solutions in which products are integrated with services increasing the value of the product itself. This stays on the basis of the concept of "servitization".

With the evolution of such technologies, especially the technologies related to application and software development, the era of micro-servitization begun. Microservice architecture is a way to arrange an application as an ensemble of small, independent, loosely-coupled services which communicate each other to the aim to provide a specific final service [5]. Contrarily to what is commonly thought, micro-services are not strictly related to application and IT field, but they have the potentiality to escalate a business organization from a centralized model to a distributed one.

The idea of this thesis is trying to detach the topic from the IT perspective and elevate it at business level, exploiting literature to discover hidden opportunities about their application to smart maintenance.

This introductory chapter consists of an introduction of general concepts inside the topics of smart maintenance and Industry 4.0, as well as an overview on the characteristics of demand that pose as a challenge for manufacturing system.

1.2. Manufacturing Transformation and Industry 4.0

This section's aim is to contextualize the environment and the field on which this thesis is focused, with particular reference to manufacturing sector. Manufacturing is, in fact, responsible for more than 80% of R&D investments and the 15% of Italian national economy comes from manufacturing [6].

Starting from 60's, customers are becoming more pressing and more mature, this brought machine producers to increase their market shares starting to fight with the competitors, for these reasons **differentiation and cost reduction** became important [7].

During the 70's the **make or buy** strategy was applied. The level of automation was important, the first automated machines have became available during the third industrial revolution. Between 1960s and 1970s, Japan developed a new manufacturing paradigm called "Just-In-Time production" that is also referred to Toyota Production Systems (TPS). The idea behind this business model was to deliver to costumer exactly what he needed avoiding stocks.

From the second half of the '80s, the relative importance of "competitive variables" has changed significantly. Companies passed from **internal efficiency** (we are looking for cost reduction) to **external efficiency**: manufacturing customer started to look at quality and time of products and not on price.

The industrial model during 90's changed again and was characterized by an increase in product range and variety and in processes speed. The business model adopted in that context was called "lean manufacturing", came again from TPS and was mainly a philosophy based on the elimination of the so-called "7-wastes of production": transportation, inventory, motion, waiting, over-processing, over-production defects [8].

Nowadays companies are involved in big transformation that brings digital innovation inside companies' value chain: the era of "digital transformation" has begun. It is a matter of exploiting the opportunity to have smart products interconnected and able to reveal important business information, but also the possibility to experiment new production logics and build-up a network between companies, products and customers. Digital transformation means also to continuously looking for new competitiveness opportunities thanks to innovation, that is faster with respect to past years for which technological advancements were only incremental, if compared to the breakthroughs of this last century [9].

The ongoing transformation has happened in the context of the fourth industrial revolution also called "Industry 4.0". The key aspect of this revolution are the so-called "cyber-physical systems", e.g. systems able to interact each other and collaborate. The nine pillars of industry 4.0 are [10]:

a) Big Data & Analytics: they were made possible thanks to the arrival of sensors, which allow to collect huge volumes of data (Big Data) that after been elaborated and analysed, can support decision making process providing useful information to take decisions.
b) Autonomous Robots: used to perform complex tasks in environments that could be dangerous for humans. Robots can interact each other and work safely with humans, learning from them.
c) Simulation: it a technology that leverages real-time data to re-create a virtual world from the physical one, on which is possible to test, optimize and setup machines before transferring the same configurations in the real production environment, to minimize machines setup times and increasing quality
d) Horizontal And Vertical System Integration: with industry 4.0 paradigm integration does not invest only horizontal level (for example all the actors of production floor), but is also vertically developed. This means that all the business units of an enterprise are fully integrated through data networks enabling automated value chains.
e) Industrial Internet of Things (IIOT): is referred to the network of machines, sensors, devices characterized by embedded computing and able to share information each other. In particular, information are shared with particular devices called "controllers" with the aim to automatically monitor production processes and act on systems real-time to improve productivity.
f) Cybersecurity: is a fundamental topic for industry 4.0 since the high number of interconnected systems exchanging data and the consequent increase of vulnerabilities in the communication, brought to the need of a set of rules and tools needed to establish secure and reliable communications as well as correct access management for users, machines and devices.
g) The Cloud: it is considered an enabler for analytics, thanks to the fast response and reaction times capabilities. Machine data and functionalities can be then deployed on cloud, enabling more data-driven services for production systems.
h) Additive Manufacturing: such technology helps in produce small customized products that usually have very complex design with the aims to reduce time-to-market and stock on hand.

i) Augmented Reality: it is used to provides workers real-time information to improve training process, to help in taking decisions and to facilitate working procedures.

Industry 4.0 market has huge impact: according to Business Wire's research [11], the global industry 4.0 market is expected to reach 264.89 billion dollars in 2027. And according with BCG, industry 4.0 is considered "*the future of productivity and growth for manufacturing industries*".

1.3. Servitization 4.0 and Micro-servitization

Servitization is a strategy emerged in the last years that consists in offering to clients high value-adding services related to the sold products. This business model was born from Sandra Vandermerwe e Juan Rada in 1988 with an article entitled "Servitization of Business: adding Value by adding Services" [12]. Servitization is not a totally new concept, since the first evidences started during 70s' with Rolls-Royce and its "pay-per-flying-hour contacts" until 90's with pay-per-use services for copy machines ideated to IBM [13] .

Servitization becomes innovative if dropped into the context of industry 4.0. In this case we can speak about "servitization 4.0" and is a strategy that exploit the opportunities of the new enabling technologies for offering services that are more and more adapted to the product itself and "tailored" on specific costumers' need [14] .

Servitization fulfils the need to maintain a relation between customer and supplier and to differentiate products from other competitors. Many manufacturing companies, in fact, leverage on servitization to offer services linked to products to increase margins and thanks to the information and data flow connected to those services, can receive feedbacks on the same services and products solved, optimizing products. In this context, big data and analytics play a very important role, enabling new maintenance paradigms like predictive maintenance that will be analysed in the following section. Under a business model perspective, servitization can be deployed via per-per-use services or to services more customer-centric leveraging on applications or software.

Servitization 4.0 is enabled by ICT: the higher is the level of ICT the higher is the level of services that we are able to provide. The evolution of ICT has generated new technical ways to build applications that, at the same time, created new business opportunities innovating the existing business models [15].

This is the case of distributed architectures, based on **micro-services.** Distributed systems are characterized by different nodes that are connected to others and share data. Similarly, micro-services in distributed systems are single isolated, autonomous entities that perform specific tasks and communicate with other micro-services in order to provide the overall functionality. Micro-services can provide to modern application following advantages [16]:

1) Easy scaling: the possibility to isolate components and act separately on each of them, allow to do modifications without taking down the system and deploying it again
2) Improved fault tolerance: Applications within microservices can keep working even if one service fails. This thanks to loose coupling between the services. Failure of one microservice does not affect the working of others and be easily replaced
3) Better code understanding: reading codes is easier and also acting on it, since each micro-service provides one single functionality and it is easier to re-design a module keeping in mind the functionality provided uniquely by that specific module, moreover codes are smaller and quick to deploy.
4) Independent deployment: when a module is modified, the rest of the application does not notice the change, facilitating continuous delivery and continuous deployment minimizes the unavailability of the service
5) Possibility to experiment: the high flexibility provided by micro-services allows to follow technological evolution and to experiment new technologies while creating new services.

Obviously, this architecture presents also many drawbacks mainly related to a relatively complex development of such application. Micro-services, in fact, must be integrated and put in communication each other, that is difficult especially when functionalities required result from a process characterized by huge number of dependencies. Also, coordination between multiple services must be considered, that's why micro-services are usually not built at once, but the deployment process is mainly characterized by release: small pieces of code added progressively like pieces of a puzzle. Although, these pain points, micro-service architectures are considered "the architectural emerging patter for the big modern application" [17].

Micro-servitization even if related more to IT perspective, can be leveraged on business level thanks to the business opportunities that can be generated, for which an example is provided in this thesis.

1.4. The Evolution of Maintenance Paradigm

Maintenance is defined as the ensemble of activities including functional checks, repairs, etc. to preserve machines, tools and equipment by deterioration. Today maintenance is one of the most important activities to run the business, since it allows to ensure productivity of the company [18] .

Reference [19] proposes an interesting historical overview of changes in maintenance management strategies caused by each industrial evolutions. Until second industrial revolution, maintenance was mainly an activity performed by operators and it was mainly **corrective maintenance**: restoration activities started after the failure occurred.

With the arrival of the second industrial revolution and the phenomena of mass production, maintenance model started to change: the high demand for products, especially in car production field, required to maximise the production to follow demand and for this reason a new maintenance approach was implemented: **cyclic preventive maintenance.** With this approach, interventions were programmed anticipating failures, but due to cyclicity of this approach, pieces substitutions happened even before their useful life increasing the maintenance costs.

In 1960, the adopted approach was **condition-based maintenance**, with the earlier introduction of techniques based on studies about product life cycle and reliability of equipment.

During 80's, the concept of lean manufacturing was developed: the objective was the one to minimize waste and not value-adding activities. This change of culture was reflected also in the maintenance model adopted: **total productive maintenance (TPM)** [2]**.** The main objectives were:

1) Reduction of unplanned maintenance interventions
2) Reduction of machines downtimes obtained by increasing preventive maintenance interventions
3) Production costs reduction
4) Increase of safety in workplace
5) Resource optimization

In these last years, in the era of industry 4.0, also maintenance approach has been impacted and today we speak about "Maintenance 4.0" or "Smart maintenance" or "advanced maintenance". With this new concept, maintenance, until now seen as a cost to face in order to extend assets useful life, became more and more a service that could be sell to costumers in order to increase margins. Maintenance 4.0, in fact, exploits the main technologies of industry 4.0 (sensors, IIoT, Big data, Artificial Intelligence…) to identify failures before they occur.

The main protagonist of this new concept are the so-called "**prognostics and health management (PHM) systems**", they are systems that allow to detect real-time when the operating conditions of an industrial component or a group of components is deviating from its normal operating conditions, with the aim to increase the availability of machines, reduce downtimes, improve safety and quality and have a positive impact on productivity, by eliminating the hidden costs of unscheduled maintenance activities .

The increasing of available technologies, especially the huge amount of data generated by sensors to deal with, creates the need to elaborate data, process them in order to extract useful insights. This increase in data availability has pushed towards the development of new techniques for data analytics such us machine learning (ML) and deep learning (DL) [20]. Thanks to these new methodologies diffusion of analytics systems and in general, advanced maintenance applications are being boosted remarkably.

1.5. Prognostics and Health Management (PHM)

The main smart maintenance strategies rely on the classical maintenance types, that can be adopted. In the reminder, a short description is provided for those types [21]:

1) Preventive maintenance: it is the same approach mentioned before and historically already implemented, but the main difference that today is not cyclic but based on the study of components' failure behaviour and the maintenance activity is scheduled accordingly. The main advantages is to significantly reduce the unplanned downtime to minimize impacts on productivity, on the other hand, there is an high risk of maintenance costs increase due to maintenance interventions' number higher than the required one or on the contrary, too low with respect to the optimum, bringing the risk to unseen malfunctions.
2) Condition based maintenance: it is considered an intermediated approach between preventive and predictive maintenance, since it better balance maintenance costs leverage on interventions frequency. In this case some analytics techniques are used to detect the fault and intervention is scheduled immediately after the detection time. This approach is usually implemented through control charts and other tools of monitoring, often linked to an alerting system based mainly on statistical analysis.
3) Predictive maintenance: in this case, differently from the previous approach, analytics techniques are used to predict failures in advance and some specific thresholds are fixed, in order to find the optimum moment for planning the repair that minimize the number of interventions (maximising productivity and component life), while avoiding downtimes risks.

The PHM process is mainly a pipeline process for which some specific steps must be follow in order to support inspection and condition monitoring.

The very first step is **Data Acquisition** that consists in the purchasing of sensors and smart devices able to collect data. Also database and the related infrastructure must be built in order to start to collect all the data needed for further step. In this phase, it is also important to decide the communication protocols to be used (the most used ones considered standards for industry 4.0 are OPC-UA and MQTT) and where data must be stored (if sent in cloud via MQTT or stored on-premise).

Once data are available, they can be manipulated on two different steps: data pre-processing and data processing. The second step is called **Data pre-processing** and is needed since it can happen that, due to bad connection-related issues, data are lost for some instants or on the contrary, are redundant. In this case the procedure consists in outliers removals where outliers are anomalous values that are far from a normal observation. In same case could be necessary also to change data format, since the high variety of data that coming from different sources and reduce the noise. Data pre-processing can be considered as a "cleaning" step in which data are prepared for being analysed.

When data are cleaned, they are ready to be processed. Due to the high sampling frequency and to variety of data that it is possible to acquire, dealing with big data is not an easy task. To simplify the process, it is needed to reduce the volume of data and preserve the most interesting data trends. For this reason, the third step, called **"feature engineering" or "data processing",** is needed in this process. In this phase data are aggregated using statistical methods in order to discover hidden path and to select specific meaningful information. The objective is to find a specific health condition indicator on which base the model and the further studies.

Next step is **condition-based maintenance (CBM)** that consists of two main elements: **state detection** and **diagnosis.** State detection is the analysis of operating conditions over time of the selected item for the critical component under exam. Each "state" of the machine is collected until to identify the failure state, e.g. the instant in which failure occurs. When found, it is possible to move to the diagnosis phase consisting in an health assessment of the system: faulty component and faulty state of the component for a specific indicator are isolated and data are associated to a specific health state and then categorized in degradation levels accordingly with their severity from the normal condition to the degraded condition (usually from green to red). On this categorization is then built an alerting system for real-time monitoring helping the decision making process.

The information extracted until this step can be furtherly exploited at the predictive maintenance level going on in the process. Last step in fact is called "**fault prognosis**" and is the basis for predictive maintenance. In this seps some ML/AI techniques are put in place in order to determine the Remaining Useful Life (RUL) and the probability of failures (POF) of a certain machine component to understand how long the machine will be operative even if degradation process has already started [22].

1.6. Area of investigation, overarching goal and structure of the research

This thesis has, in its scope of work, the interest and goal to understand what characteristics of industry 4.0 can be embedded in advanced maintenance, especially looking at the potential of micro-services to develop advanced maintenance as business opportunity and foundation of a new business model.

Before going on, it is needed a clarification on the concept of "advanced maintenance" widely used in this thesis. In this work, "advanced maintenance" refers to what is better known as "predictive maintenance" (as elective application area) or other equivalent terms such as "maintenance 4.0" or "smart maintenance" or "e-maintenance" (as paradigmatic terms), all treated by considering a wider scope. Advanced maintenance, in fact, identifies the new digital maintenance paradigm including also other digital services more related to analytics field (e.g. dashboards, visualization tools, reporting, etc.).

This overarching objective can then be broken down into the following sub-objectives:

1. To point out what are the strengths and areas of improvement of the solutions found in the literature for what concern advanced maintenance;
2. To discover new business opportunities related to advanced maintenance and enabled by micro-servitization;
3. To understand how advanced maintenance tools and techniques can assist in increasing the flexibility of manufacturing systems;
4. To propose a business model for advanced maintenance conferring more value to the existing e-maintenance one.

This work is divided in three main parts:

1. PART I: presents the systematic literature review, where the queries chosen as well as inclusion/exclusion criteria are discussed. Articles are then classified according to the topics presented and some of the solutions in the literature are discussed in greater depth. In this part, more specific topics of advanced maintenance, such as control architectures are also introduced, to allow greater comprehension of the solutions presented.

2. PART II: This part consists of the contributions to the literature by this work. First, a business model for customized advanced maintenance based on micro-services is presented and explained in each part of it. Then, a methodology for testing ideas is explained and then applied to the business model in order to validate the correctness of the assumptions done

3. PART III: Finally, after summarizing the main achievements of the thesis, the limitations of this work are shown as an opportunity for future development in the area.

2 Literature Review

In order to explore problems relevant for the scientific sphere, as well as related to impact for practitioners through the investigation over new business opportunities and future trends, it occurs to understand the state of art of a certain argument. Even if a specific topic has not been explored yet, an accurate analysis of embryonic scientific papers can help to discover criticalities and eliminate them, pushing research to a higher level.

For these reasons, in this thesis, a systematic literature review has been carried out with the following main objectives:

a. To examine the state of art of advanced maintenance, servitization and micro-servitization in literature;
b. To investigate if and to what extent the juxtaposition of these topics have been explored in literature;
c. To search for eventual gaps in literature that need to be filled in order to contribute with a starting point for future studies.

The followings sections will provide the description of the research methodology and the research results.

2.1. Overview of the Methodology

The methodology used in this work for systematic literature review, with a certain level of customization required for the peculiarities of such thesis (the investigated theme is not unique, but the juxtaposition of different and complementary topics) is the one proposed in [23], in which some specific examples of the way in which literature review is performed in software engineering field are proposed. Considering that the application field is in line with the topics covered in this thesis, the choice of the framework presented in this particular reference was very useful to develop the whole analysis, since it allowed eliminate subjective point of view during the research.

Similarly, to the reference document, in this thesis the review was divided into two different sections:

1. Primary studies: it refers to the collection of all research papers performed following a specific framework in order to provide a statistical analysis aimed at revealing **interesting trends**. Such kind of studies in this work will be called "**quantitative analysis**".
2. Secondary studies: it consists in the review itself and passes through an accurate reading of the most relevant papers present in literature with the aim to

discover the state of art of analyzed topics and the main gaps in literature. It is fundamental since it provides different information that will be then transformed into "**insights**". In this thesis, this part will be called "**qualitative analysis**".

More details on the methodology are provided hereafter.

Quantitative analysis was performed by taking as reference the previous mentioned paper [23] , that illustrated a framework developed into three main phases showed in figure 1:

1. Plan Review: phase in which research questions are specified and the review protocol is developed and validated;
2. Conduct Review: in this phase of the research quantitative analysis is performed, in particular, data are extracted and furtherly synthesized;
3. Document Review: this corresponds to the last task of the research, consisting in writing the review report and discuss the result.

Phase 3 is clearly entering in a qualitative analysis as it requires more insights from the papers, to validate the evidence from the literature findings, with more detailed analysis.

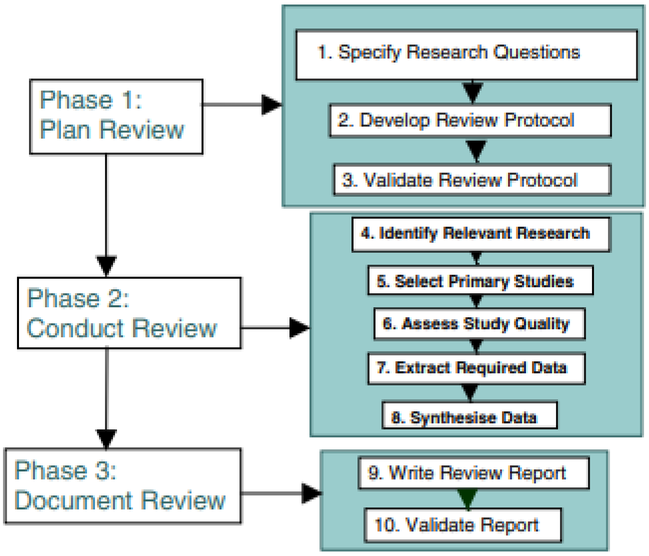

Figure 1 - Literature review procedure schema

For simplicity and consistency of discussion, n this thesis, after presenting the research questions and review protocol (section 2.2.) more details on the findings from other phases, phases 2 and 3, are subsequently illustrated (section 2.3 and section 2.4), before providing an overall summary with the literature findings.

2.2. Research Questions and Review protocol

Quantitative analysis followed a 3-layered approach aimed to evaluate the results given by the intersection of 3 different topics. In particular, level 0 was aimed to analyze the number of outputs about the topics of predictive maintenance, servitization and micro-servitization considered as singular argument; research at level 1 was aimed, instead, to cross predictive maintenance and servitization from one side and servitization and micro-servitization on the other side; level 2, finally, represented the most important research part since allowed to address one of the most important research objective of the review, that is also the core-topic of this work: to understand if in literature the possibility to apply micro-servitization to advanced maintenance has ever been explored.

The below picture shows a schema of the previous described 3-layered approach used during the review:

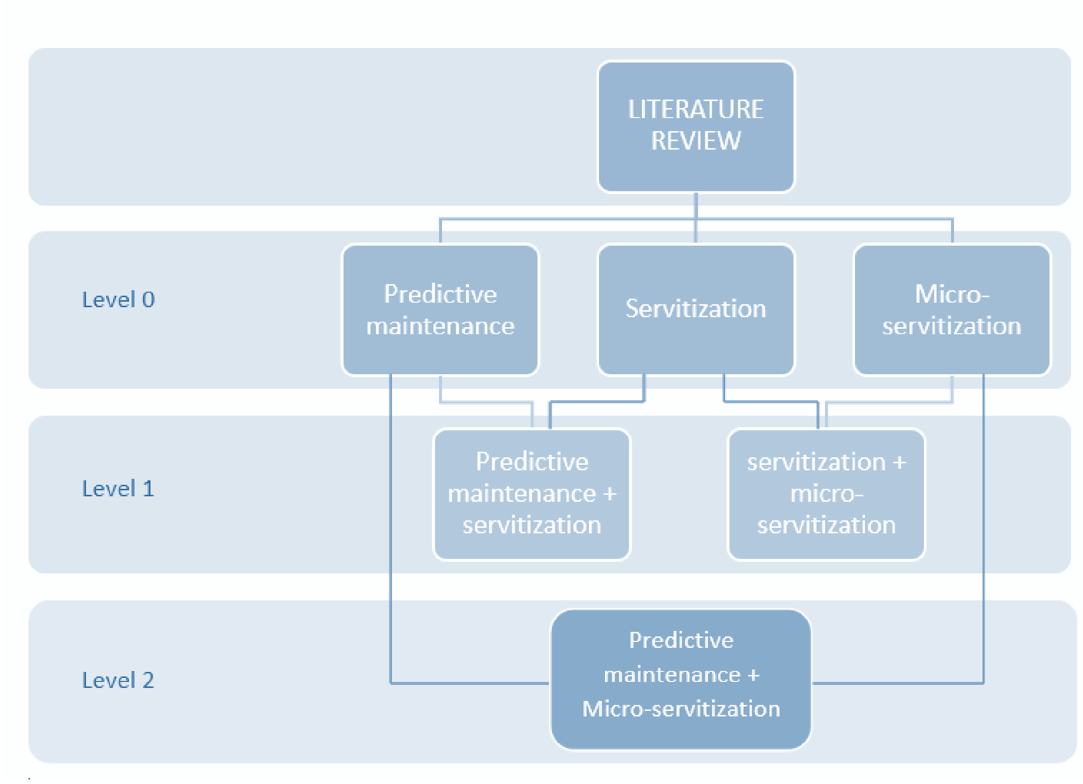

Figure 2 - Quantitative Analysis Process schema

Research for all the layers has been performed using different data sources initially, but finally it was preferred using repositories that allowed to filter results in a detailed way and that ensured highest quality technical literature in engineering and technology. To this scope, the selected data sources were: Scopus and IEEE Xplore (IEEEX).

Research protocol applied was basically an iterative process that, for each research, at the first iteration output all the results for a specific queried keyword or group of keywords; at the second iteration, output results with specific filters applied depending on the research question to be addressed.

2.3. Quantitative Analysis Results

LEVEL 0

Quantitative analysis at level 0 started investigating the number of papers generated for predictive maintenance topic. In particular, the statistical analysis performed was aimed to:

1. Understand which is the main investigation area of predictive maintenance;
2. Understand how the interest on this topic has evolved over time.

To this aim, queries used were described in the below table:

smart	AND	maintenance
predictive	AND	maintenance
E AND -	AND	maintenance
e-maintenance	OR	emaintenance
Advanced	AND	maintenance

Table 1 - Research queries for level 0 analysis

The output of this first research was a gross total of **17.408 papers** between journal papers, conference papers, book chapters, industrial documents, etc. (no eligibility criteria specified for type of paper). Among them, there were papers containing predictive maintenance business cases related to various application field. The results of this first analysis were synthetized in the graphs below (Figure 3):

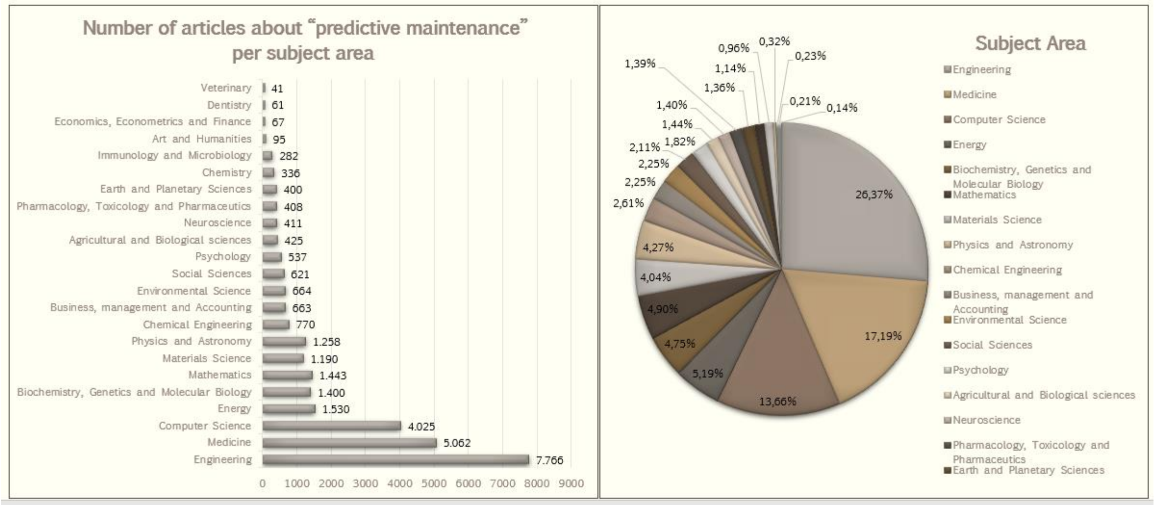

Figure 3 - Number of articles found about "predictive maintenance" per subject area

It can be easily noticed how the majority of the papers (7.766) refers to engineering (in this category falls "industrial and manufacturing engineering", which is the context of this thesis). The second application field is "medicine" and the third one is "computer science". The three areas together represent more than 50% of the total output related to predictive maintenance and this first analysis reveals a first important evidence: **advanced maintenance is studied by different disciplines**, but scientific research has focused mainly on industrial and manufacturing applications.

The second step of this first research consisted in providing a trend over time of the results, in order to see some correlations with specific time periods. To reduce the scope of the research and provide statistical analysis, it was applied a filter aimed to limit the research only to **industrial and manufacturing field.** This second iteration output 7.766 results distributed over years as showed in the following graph (for simplicity of visualization, will be showed only data from 2010 on):

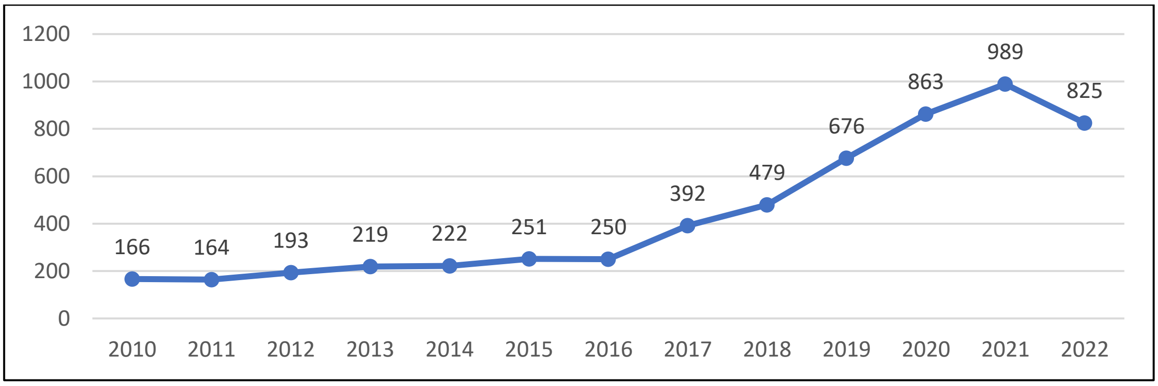

Figure 4 - Interest trend in "predictive maintenance" over time

Predictive maintenance interest in industrial field, started to increase from 2016 and maintained an overall increasing trend over following years. Considering that

2022 is not concluded, it makes sense assuming that this increasing trend will be confirmed also at the end of the year.

The same analysis (from a methodological point of view) was applied to analyze the topic of servitization. In this case, the man research objectives are:

1. Understand which is the main area of interest in which servitization-based business models are studied;
2. Analyze how the interest on servitization evolves over time;
3. Identify Italy's position in terms of study on this field.

The overall result (3151 papers) was extracted querying the single keyword "servitization". Here the graphs:

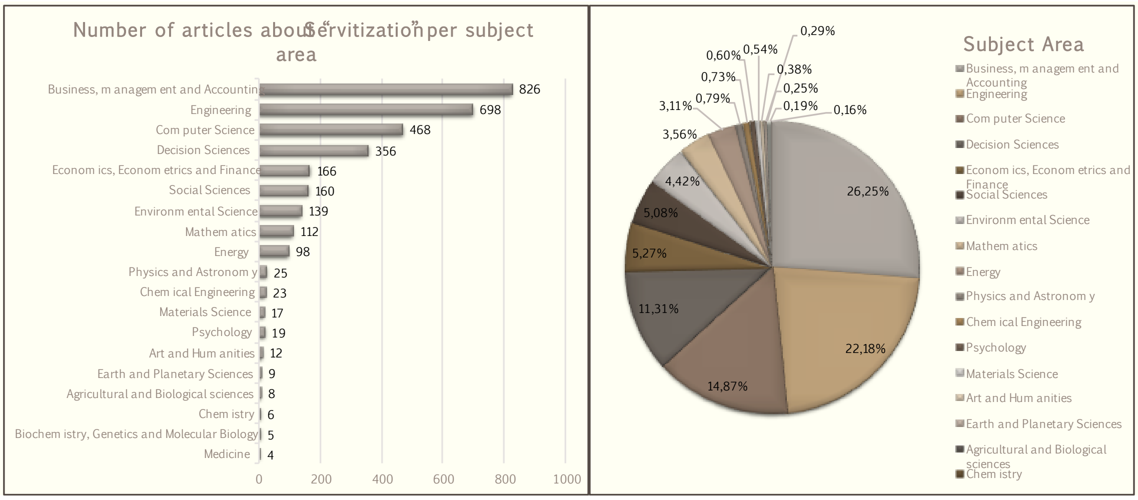

Figure 5 - Number of articles found about "Servitization" per subject area

What can be immediately noticed from such graphs, is that servitization impacts mainly 4 subject areas: Business, management and accounting, Engineering, Computer Science, Decision Sciences. It is possible to understand that servitization has been mainly explored in business area (we can assume that the business models is an interest in this area) but also appears frequently in other areas of investigation related to industrial field, computer science and decision science (wherein it can be expected to find applications of servitization).

In other words, data from literature review confirmed that **interest on the topic is going more and more in the direction of service-oriented paradigms**, especially in industrial and manufacturing field. Servitization interest in industrial field has, in fact, unexpectedly overcame businesses like decision science, economics, energy that by definition are more service-oriented than manufacturing.

To address the objective b. and c. of this analysis, results have been reduced limiting the research to the Engineering subject area using following query:

TITLE-ABS-KEY (servitization) AND LIMIT-TO (SUBJAREA , "ENGI")

This second iteration confirmed a positive increasing trend of interest on this topic over time:

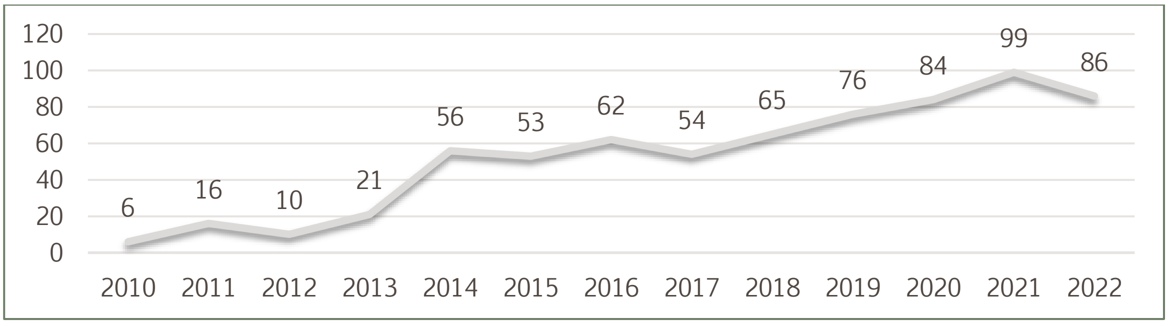

Figure 6 - Servitization Interest Trend Over Time in Industrial Field

The distribution of papers from a geographical perspective reveals that Italy is the second nation in terms of articles and papers produced on this topic, as showed in the below picture:

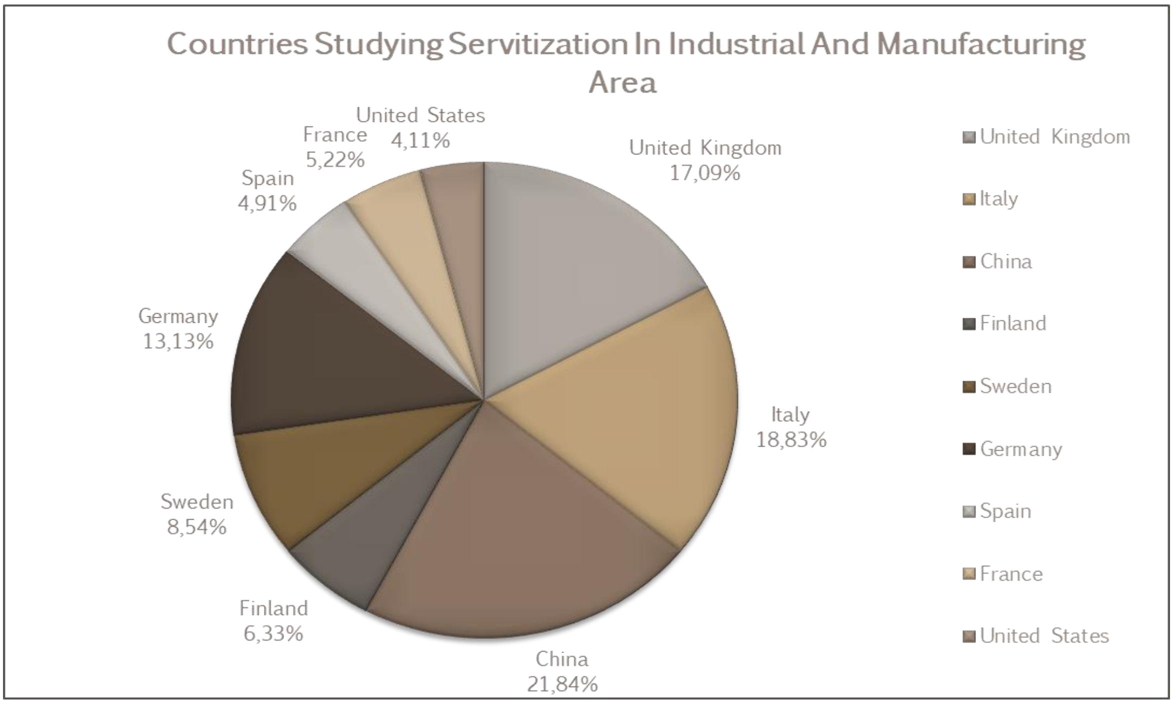

Figure 7 - Countries interest on servitization in the industrial and manufacturing field

Moving further in the review, the last item that was analyzed is micro-servitization. Considering that micro-service is a topic concerning IT and computer science mainly, it was decided to include the investigation to all the fields outside computer science area, in order to verify if this topic found some other applications in literature. The query used for the overall result is the following and output a gross total of 403 documents:

TITLE-ABS-KEY ((microservitization OR micro-service OR microservice OR micro-servitization)) AND (EXCLUDE (SUBJAREA , "COMP"))

Also in this case, the majority of the papers were oriented on engineering subject area, but what is very interesting is the number of articles speaking of micro-servitization in terms of "business" or "decision science". Surprisingly, in fact, as showed in the picture below, only the 2,85% of papers presented the topic from a business perspective ("Business, management & accounting field"), while the 29,17% of the results was about servitization under IT perspective, so from a more "technical" point of view (figure 8).

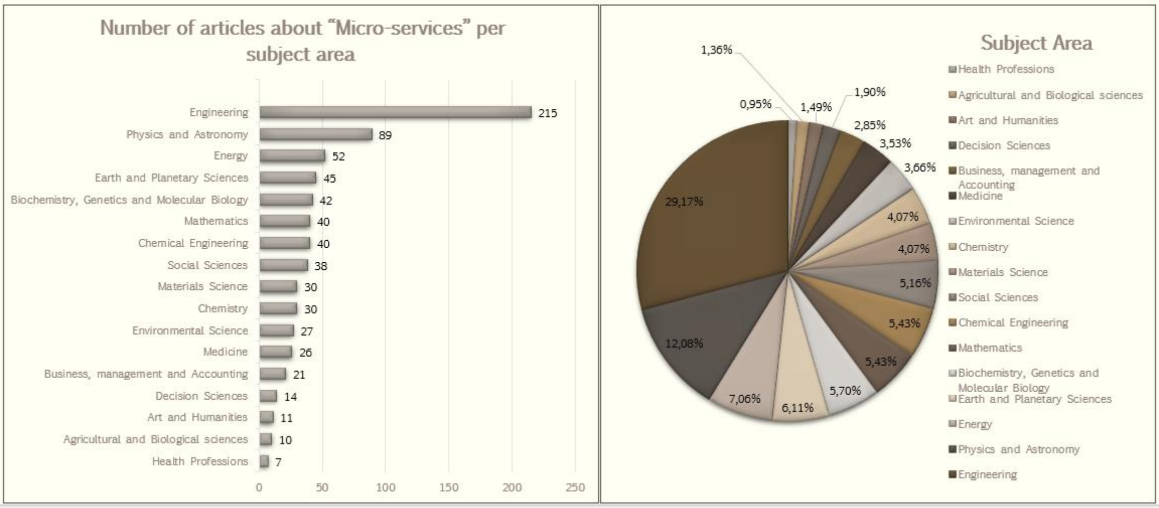

Figure 8 - Number of articles found about "Micro-Services" per subject area

To conclude the first analysis at level 0, brought following conclusions:

a) Predictive maintenance is a deeply explored topic in literature, the area of interest is mainly industrial one, but research is expanding the scope to other areas;
b) Statistical analysis confirmed that literature is increasing its scientific interest in service-oriented perspective, with a totally new and unexpected segment of application: research about servitization in manufacturing and industrial field is increasing and in particular, the country that is demonstrating more interest about the topic is Italy;
c) Micro-servitization is much more related to computer science and applied mainly in IT area, it has not been explored yet as a business opportunity.

LEVEL 1

Quantitative analysis at level 1 was aimed to address the following research questions:

1. To what extent the intersection between predictive maintenance and servitization has been explored in literature?
2. Is there any correlation between servitization and micro-servitization?

To address the first research objective, the protocol used was to juxtapose all the possible keywords referred to predictive maintenance with keywords related to servitization (such as "service"), without limiting the research to any specific area.

The output result was 1758 papers containing the previous defined combinations. This number can be interpreted as the number of papers in which predictive maintenance is presented as "As-a-Service" paradigm. Also in this case, the main application field was engineering and the overall trend is generally increasing. In particular, moving from 2016 to 2018 the number of papers exploring this intersection doubled (figure 9). Considering the high number of results and considering the positive trend, it is possible to deduce that the servitization business model is applied mainly in manufacturing and industrial field and amongst the areas under development, predictive maintenance plays an important role. Moreover, it is possible to assess that this intersection has been explored in literature and has kept still object of study.

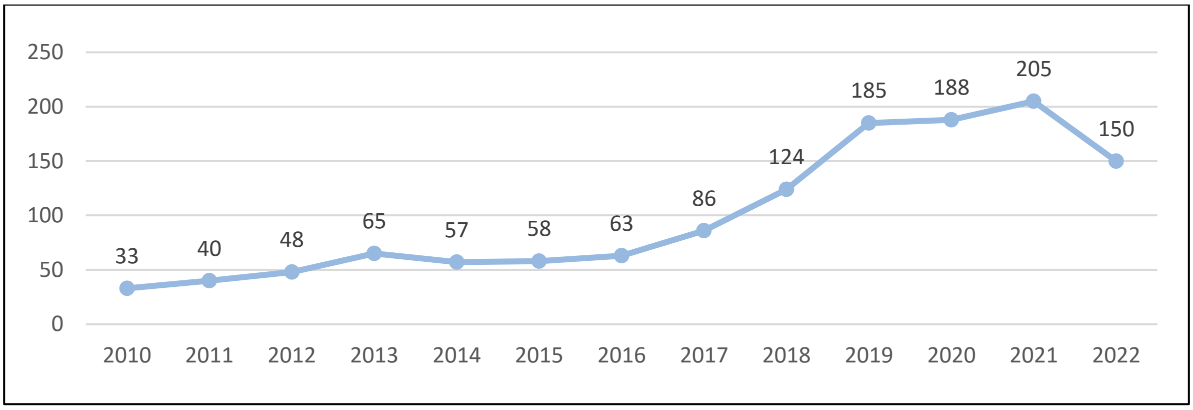

Figure 9 - Interest trend on servitization applied to predictive maintenance

In order to investigate the correlation between servitization and micro-servitization, the data coming from the separated analysis have been overlapped. In particular, in following graphs were compared the trends of produced papers over years for servitization and for micro-servitization limited to engineering field (figure 10):

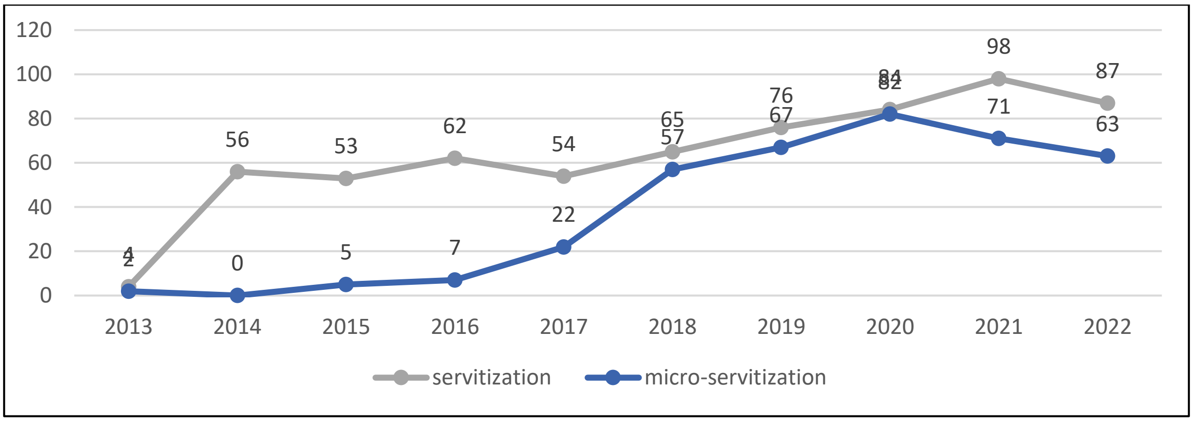

Figure 10 - Interest Trend On Servitization and micro-servitization Over Time

The interesting aspect emerged by the overlapping was the huge gap between the two trends until 2018. Starting from 2018 the two trends converged for 3 consecutive years until reaching the crossroads in year 2021. This rapid growth started in 2018 could be pushed by the creation of the "International Conference on Microservices" created in 2017 that was a forum for the discussion of all aspects of microservices: their design, programming, and operations. This event that happens every year from 2017 contributed to spread knowledge about micro-servitization.

Moreover, a final research was performed in order to find correlation between micro-servitization and servitization itself, by combining related keywords and using following query:

TITLE-ABS-KEY (microservitization OR micro-service OR microservice OR micro-servitization AND servitization)

The result was only 6 papers found that matched both topics and only 2 of them could be considered useful to the review purposes. An interesting point of view useful to understand the correlation between the two topics is presented in [24]. In this paper is explored how **micro-services can add value to digital servitization**, improving the co-creation relationship between a manufacturing firm and its client and facilitating product & services customization process.

LEVEL 2

The quantitative analysis was concluded with the review of literature at the last level, that represents the most interesting level of analysis for the scope of this thesis: the application of micro-services to e-maintenance/advanced maintenance. In particular, the research objective in this case was to understand if in literature there existed any paper or document on micro-servitization applied to e-maintenance. To investigate this topic, the protocol used at this level consisted in multiple research which combined keywords referring to micro-services and keywords related to predictive maintenance and similar.

Input query was the following:

TITLE-ABS-KEY ((microservitization OR micro-service OR microservice OR micro-servitization) AND (predictive AND maintenance OR emaintenance OR advanced AND maintenance OR e-maintenance))

The interesting result was that this first research output only four significative results only from year 2019 on.

The same analysis was performed also by entering keywords mainly referred to main characteristics of micro-services rather than using the keyword "micro-services" itself, for example using following combinations:

QUERY	NUMBER OF RESULTS
TITLE-ABS-KEY (predictive AND maintenance AND microservices)	1
TITLE-ABS-KEY (flexible AND predictive AND maintenance)	10
TITLE-ABS-KEY (modular AND predictive AND maintenance AND service)	19

Table 2 - Research queries for level 2 analysis

Research implemented using keywords more related to the effects provided by the usage of micro-services, produced more results than before. This could suggest that the possibility to confer modularity and flexibility to the existing e-maintenance business models has considered interesting and for this reason to some extent explored, but it has not been strictly related to micro-servitization yet. Despite this consideration, it is a matter of the fact that, differently from the reviews performed at the other levels, the third level of analysis highlighted an important **first gap in literature**: **the application of micro-services in predictive maintenance was not explored** although the single topics, taken alone, have been widely explored.

In order to understand the reason behind this gap emerged, in the next chapter a qualitative analysis (secondary studies) will be performed by screening the results and going deeper in the reading of the most relevant papers provided by literature.

2.4. Qualitative Analysis Results

This level of analysis, from a methodological point of view, was performed by selecting some specific papers judged adapt to address the new research questions came out by the gap emerged from the quantitative analysis and their deeper examination.

In particular, the main research question to be addressed in this part of the review is stated as reported in the reminder: *considering that, from literature, predictive maintenance has been widely studied, in conjunction with advanced maintenance concept and service-oriented perspective, and considering also the relevance that micro-services have achieved during the last years thanks to their capability to add more and more value to provided services, WHY micro-servitization in the smart maintenance paradigm has not been investigated neither considered as a new possible business opportunity yet?*

To facilitate the research of a possible answers to the previous question, three main hypothesis were formulated:

1. **Gains Distrust Barrier Hypothesis**: No interest on the topic since there is no significant improvement provided by the application of micro-services to predictive maintenance;
2. **Feasibility Barrier Hypothesis**: The usage of micro-services in advance maintenance creates value but there are not enabling technologies to realize it or there are some possible barriers in isolating each phase of PHM process;
3. **Value-transfer Barrier Hypothesis**: Micro-servitized advanced maintenance can add value to actual a-maintenance solutions and there are enabling technologies to realize it, but there is a lack of knowledge in understanding how to deploy such innovative business model and position it in costumers 'mind (what do make it desirable and innovative for costumer? Where is the value?).

In next sections, research will be focused in the validation of one or more of the presented hypothesis using insights provided from literature review.

Gains Distrust Barrier Hypothesis

One of the most probable reasons behind the low number of studies on predictive maintenance solutions developed with a distributed architecture could be the lack of benefits provided by micro-services when applied to e-maintenance/advanced maintenance.

To confute this distrust, a case study provided [25] was taken as reference. In this case micro-servitization was applied to a whole predictive analytics software and the benefits of this architecture were measured. In particular, the work illustrated an architecture based on micro-services in which each of them fulfills specific tasks and requests in an isolated manner. Micro-services are orchestrated to provide specific functionalities and their tasks include preprocessing, feature extraction, model selection and validation, semantic feature extraction and selection, and visualization. The paper discussed also some specific uses cases and possible implementations, not only in the industrial field but also in smart health scenarios. One of the most interesting insights emerged from this paper is that **micro-services can help to solve some typical challenges of predictive analytics**: it is assessed, in fact, that the application of micro-services can help in **management of heterogenous IoT data** coming from different sources, since each of them can be specialized in the processing of one specific type of data, improving the efficiency. Moreover, one of the most challenging aspects related to analytics is the difficulty to efficiently analyze the well-known Big Data coming from sensors. According with the authors, thanks to the **high scalability** provided by micro-services, it is measured an **increase of efficiency** in the analysis of this data, since working with modular services enables the system to scale well with analytic features and **reduce the workload**.

Another important aspect underlined in the document is that micro-servitization allows to have an automatic choice of the most accurate machine learning model and a consequent **reduction of time** needed to compare performances of the different models applied to each case. Moreover, classification learner seems to require less time with respect to monolithic architectures to classify data, since distributed systems allow to **process multiple prediction requests simultaneously.**

Furthermore, it is reported that in case of distributed architectures, **code is easier to understand** and to maintain because each service has isolated responsibilities. Reliability and availability in this case increase thanks to the possibility to **isolate issues** and **avoid a "domino" effect.** On the other hand, it is highlighted an higher cost of maintenance to keep the project active on an always-on service business model (strictly required for e-maintenance/advanced maintenance and other analytics applications).

In [26], is proposed a microservice-based architecture able to respond real-time with some actions based on predictive processing of data. Since from the abstract, authors highlighted how the application of micro-services to such case study improved its maintenance and evolution. With particular reference to this last point, in the paper emerges an interesting concept related to the evolution of predictive maintenance systems: authors assessed that "*a prediction microservice adaptable to different models, enables to **evolve and extend the architecture** without costs of evolution and **satisfying the new needs**".*

In the same paper is also mentioned that splitting the system into independent units of software with a clearly defined functionality as well as being able to send messages, makes such units **easy to replace.** On the other side, the same document signals an increase of the complexity of predictive analytics application, given by multiple distributed independent components for one unique application.

To conclude, in literature there were different references speaking about the potentialities and the advantages provided by micro-services in the application field, as already seen, their usage in analytics field contributed to solve typical challenges of predictive maintenance. For this reason it is possible to guess that the lack of benefits provided cannot be the cause for a so poor interest on the topic.

Feasibility Barrier Hypothesis

In the hypothesis that the lack of papers related to the topic depends on a technical feasibility barrier, two possible elements have been considered:

1. Lack of enabling technologies
2. Impossibility to "componentize" the PHM process (strictly required when speaking about distributed architectures built through micro-services).

This analysis has the aim to research in literature information about the technical feasibility of building application based on micro-services for predictive maintenance.

From a technological point of view, in [27] a scalable system for health prognostics was presented. The work was an anticipation of the modern micro-services architecture, but it was relevant from a technological point of view since it proposed a platform able to develop innovative prognostics algorithms to predict and prevent machine failures. The platform under exam was a **Watchdog Agent®-based Real-time Remote Machinery Prognostics and Health Management (R2M-PHM) platform** being developed by the IMS Center. The Watchdog Agent is defined as toolbox consisting of many different embedded algorithms able to predict degradation of devices and machines. It is important to underline that, as already said, this tool can be considered as an anticipation of the modern distributed architectures: in this document, in fact, embedded algorithms of the Watchdog Agent are not called "micro-services" but "modules". Authors talked about communication module, command analysis module, task module, an algorithm module, function module, and DAQ module, each of them is described as independent and responsible to provide specific functionalities. This paper demonstrated the technological feasibility of developing e-maintenance/advanced maintenance solutions through distributed architectures since 2008 and opened the way to the innovative possibility to build up e-maintenance/advanced maintenance tools in a platform ecosystem.

Another example is provided in [28], where a flexible and modular platform for smart maintenance is discussed. The paper presented also a case study in which the platform called SERENA is then applied to predict robot failures at COMAU premises. In general, the provided functionalities of this solution are:

1. adaptive maintenance scheduling,
2. driven from the prediction results;
3. predictive analytics;
4. visualisations tools.

In this specific case, enabling technologies are not only micro-services but also virtualization, that is a key-technology for distributed systems. In this paper is assessed that micro-services have been included in the design of the solution to allow the requirement of flexibility and scalability in terms of deployment and use of technologies (means the capability of the system to be improved by substituting components and technologies over time without compromising the main functionality).

The interesting elements of this document are, among the others, the long list of technologies used to realize smart maintenance solutions through micro-services. In particular, following enabling technologies were used for the scope:

1. Virtualization: it is a technology allowing to scale easily infrastructure. "To virtualize physical machines" is a matter of virtually duplicating resources connected to the same physical resource in order to improve efficiency of the whole application;
2. Docker Containers: they are the most important technology to implement SERENA's service. They are isolated "containers" encapsulating micro-services, each container provides different functions and confers an easy scalability and flexibility to the solution;
3. Apache Spark: it is a monitoring system able to ensure optimal performances, identify issues causing application latency or downtimes, control application health.

Another element to discuss in order to assess the technical feasibility, from a literature point of view, is the possibility to componentize PHM process, that by definition is a pipeline process characterized by strong dependencies, into single and isolated services.

Always in reference [25], a deeper analysis of PHM process was done in order to deploy it through micro-services: each feature of predictive analytics was identified, isolated and then studied in its dependencies, then it was isolated and made autonomous. The result was composed by different module (micro-services) aimed to achieve specific analytics tasks in an autonomous way composed and orchestrated with other microservices to achieve services objectives.

In any case, there many documents in literature in which it is possible to find specific guidelines about how decouple pipeline processes and how behave with distributed systems. For example, in [29] it was proposed and explained a 4-steps systematic dataflow-driven approach to decompose monolithic applications into microservice-oriented ones. Similarly, in [30], some best practises for micro-services decomposition are suggested.

An example of how modules can connected and built using microservices is illustrated in the figure 3 taken from [31], in which it is proposed a functional architecture of a PHM system applied to aircraft. It is an in-flight health management system having the following functionalities: indicating/recording system, onboard maintenance system (OMS), power plant health management system and data management system.

Finally, in [32] it is presented a tool, named "Machine Learning in Microservices Architecture" (MLMA), able to transform a monolithic architecture of a predictive analytics application working in pipeline into microservices providing different functionalities.

To conclude, assuming literature perspective, there is no constraint on feasibility aspect for micro-servitization of predictive maintenance, neither on IT nor on process sides. Literature, in fact, provides many guidelines and examples that can be followed in order to overcome possible criticalities.

Value-transfer Barrier Hypothesis

The last layer of qualitative analysis consisted in the research in literature of papers that looked at the topic from a business opportunity point of view. In particular, the objective of this last analysis was to understand if the lack of studies about micro-servitized smart maintenance could be related to the **difficulty to transfer the value of this innovative service to costumers.**

In effect, only very few papers faced the issue adopting a business perspective and, after an accurate screening of the available documentation, only one document was considered useful and significative for the scope of this work.

The paper under exam, was published in the "International Journal of Internet-based Manufacturing and Services" and written in 2009 [33] and offers interesting insights on the conception of maintenance as "service function". It also suggested to the reader an approach to build up an effective predictive maintenance solution.

In order to go through and examine the paper content the paper, some specific questions were formulated to facilitate the analysis.

1. **Are traditional business models concerning products maintenance able to satisfy nowadays costumers' needs?**

In the mentioned work some gaps related to the traditional business model through which maintenance is offered are highlighted:

- Gap in product usage: not all manufacturers companies realized smart maintenance services for the clients, many of them are still related to traditional business model in maintenance;
- Gap in production efficiency: according with the authors, the majority of the companies is people-centric with the consequence difficulty in standardising intangibles (expertise, experience, etc);
- Gap in Information Management: Difficulties to organize data in a structured way to obtain timely information that can instantly support decision making;
- Gap in Product Life Cycle Management: There is no sufficient data collected concerning the product after it is sold to the costumer, in other words, no feedback about the product that allows product designers to improve their quality is provided.

Identified gaps showed how traditional business models for maintenance services present some limitations. In this paper, it was assessed that from a business perspective, an important shift was required: it was needed to move from the conception of maintenance as "solution to a problem", towards the vision of maintenance as "value-adding and customized service". In all likelihood, this was the first time that the conception of "customized service" was associated to smart maintenance. In particular authors claimed:

*"A company can therefore implement a **tailor-made predictive maintenance service** that addresses its **unique issues** in order to improve its assets' uptime, prevent asset failures, improve productivity and have a better information flow throughout its various business units"*

Moreover, it was not enough to satisfy specific costumers needs in the moment in which they arose, but it is needed to evolve solutions considering changing needs, the evolution of enabling technologies, the market expectations. With this scope, authors proposed a systematic maintenance design able to provide a service business capable of adapting to such changes that happen very frequently in nowadays dynamic environments.

2. **Which are the service needs and the related maintenance services requirements?**

The systematic approach proposed in the paper, passed through the understanding of **which are the service needs and how they can be translated into maintenance requirements**. The highlighted services are:

i. Service for failure prevention: In this case, predictive maintenance avoids detrimental damage not solvable by typical repair;
ii. Service for uptime: it is the main service provided by predictive maintenance and consisting in the downtime elimination through the prediction of machine failures;
iii. Service for system streamlining: this is the service that can be generated by extending the concept to smart maintenance including analytics, and is the service that uses analytics to improve efficiency of processes and to eliminate or simplify unnecessary tasks;
iv. Service for productivity improvement: it is a service that includes different benefits like the reduction of downtime costs, the quality improvement, energy consumption monitoring and optimization, better control of resources, uncertainty management;
v. Service for information management: service responsible to deliver the right information to the right people and at the right time;

vi. Service for closed-loop life cycle product management: service provided by the information generated by a well-designed e-maintenance/advanced maintenance system, that can be used to improve the product and the services offered.

After having identified the service needs, authors associated via examples such services with specific different smart maintenance strategies, that are called "maintenance requirements":

- Root-Cause Analysis: consisting in the study of failure modes and criticality based on product quality and productivity (e.g. FMCA, HAZOP);
- Condition Based Maintenance: consisting of the capability to detect the failure modes (in evolution) to monitor system health (e.g. Preventive Maintenance);
- Prognostics: consisting in the study and implementation of models to predict component degradation and developing an alerting system (Predictive Maintenance)

By matching correctly those services with the identified maintenance strategies we are able to satisfy the main need of costumers: for example, prognostics can used to predict component degradation and the information collected can be used to make decisions for optimizing maintenance scheduling or build an alarming system based on fault tolerance to rise alarm to the right time and to right people; or it is possible to implement condition based maintenance in order to monitor system health and performances.

Although the importance of this paper and its relevance from a scientific perspective, the approach presented a limitation: **customization, that is firstly considered as an important requirement to satisfy costumers expectations, is then reduced to the choice of the most suitable e-maintenance strategy among the 3 proposed approaches.**

Moreover, years later it seems that the situation has not changed: reference [25] in 2018 affirmed in fact that : "*Most developed prognostics approaches are application or equipment specific. A generic and scalable prognostics methodology or toolbox doesn't exist*". This consideration was relevant from a business perspective, for two main reasons:

- It highlighted a fist important **gap** in literature but also in the practical implementation: <u>scalability dimension has not been applied yet to prognostics methodology</u>;
- On the other side, it confirmed the **need** of scalable and reconfigurable systems for predictive maintenance.

2.5. Concluding Remarks

To summarize, quantitative analysis led to following conclusions:

1) Predictive maintenance has been deeply explored in literature, the area of interest is mainly industrial one, but **research is expanding the scope to other areas** (it is progressively assuming an important role in decision-making field, but also in accounting & control, strategy, computer science, energy monitoring, health & medical field…)
2) Statistical analysis confirmed that literature is increasing its scientific interest in **service-oriented perspective**, with a totally new and unexpected segment of application: research about servitization in manufacturing and industrial field is increasing and in particular, the country that is demonstrating more interest about the topic is Italy.
3) Micro-servitization is much more related to computer science and applied mainly in IT area, **it has not been explored yet as a business opportunity**.
4) Amongst servitization examples, considering that it is mainly applied in manufacturing and industrial field, **predictive maintenance plays an important role.**

First analysis brought to light a first important gap: the possibility to confer modularity and flexibility to the existing e-maintenance business models has been considered interesting and to some extent explored, but it has not been associated to micro-servitization yet: in other, words, it seems that **the need to improve the flexibility and modularity of e-maintenance exists, but micro-services have not been yet identified as an enabler to fulfill that need**. It is a matter of the fact that the application of micro-services in predictive maintenance was not fully explored, although the single topics, taken alone, have been widely studied.

Going deeper, qualitative analysis revealed some interesting facts:

i. Micro-service can help in solve some typical challenges of predictive analytics
ii. Enabling technologies exist and can support the development and the deployment of advanced maintenance solutions
iii. Componentizing PHM process, that is a pipeline process, can be difficult but not impossible since literature provides different examples and use cases.

Having confirmed that there is a potential for advantages and benefits provided by distributed advanced maintenance solutions, and no feasibility barrier was identified, moving the focus from the technical level to a business perspective, three main gaps have been identified:

3. **1° literature gap**: there is the need of scalable and reconfigurable systems for predictive maintenance, not yet fulfilled
4. **2° literature gap**: scalability dimension has not been applied yet to prognostics methodology.

5. **3° literature gap**: the need of customization of maintenance exists, but is then reduced to the choice of the most suitable advanced maintenance strategy among the canonical approaches.

To conclude, literature review suggested the need to move smart maintenance to a new level, more and more customer-centric, in order to exploit the business opportunities related to the increase of the value of the offered services. At the same time, literature review determined an important finding: **the lack of business models able to satisfy the need of customization and scalability emerged during these last years**.

In the next chapters it will be showed how micro-servitization can fulfill the identified gap and be the key resource to provide new customized, scalable and tailored-made solutions for smart maintenance.

3 The proposed Business Model

Before going through the description of the proposed business model, it is advisable to specify the context and define the purpose of the analysis: The final aim of this Business Model is to fill up the gaps emerged from literature, especially the need of customization of the existing maintenance model and, to show how micro-servitization allows to offer new business opportunities in advanced maintenance. The model could be in the future also generalized not only to the maintenance field, but to the domain of predictive analytics.

Nowadays maintenance is not anymore seen as a cost that negatively affects the business but has acquired an increasing relevance over time. In fact, thanks to servitization and to analytics, it has been more and more considered as a key aspect to increase assets performances in some cases or as “business opportunity” in some others. Starting from this consideration, in these sections will be showed how the new maintenance paradigms (here identified with the concept of “e-maintenance” or “smart maintenance” or “advanced maintenance”) deployed using micro-services, can fill up the gaps previously identified. At the same time, it will be studied how such combination can generate many new unique, valuable and easy-scalable business opportunities that could radically change the way again the way in which maintenance is actually perceived.

To these purposes, in the next sections, the proposed model will be presented. Business idea has been built starting from a well-known "tool", the Business model canvas from Osterwalder [34]. Indeed, the proposed model is a particularization of this "tool", oriented to develop a specific business model for advanced maintenance built upon micro-servitization. The next sections are correspondingly organized based on the building blocks from the well-known from the business model canvas, illustrated by the specifications required by the innovative content addressed by this thesis work.

Therefore, each building block constituting the business model CANVAS will be detailed in order to show how micro-servitization can enforce actual e-maintenance/ advanced maintenance business model, adding value and creating new business opportunities.

A synthetic picture is presented in figure 11.

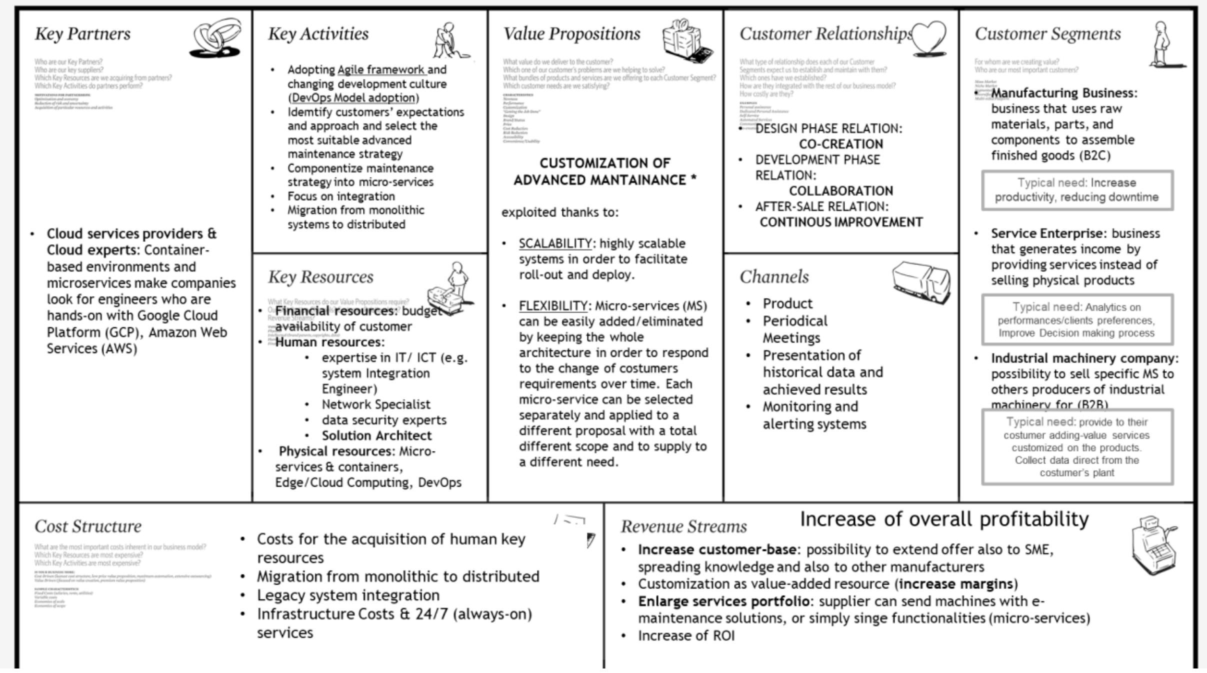

Figure 11. Business Model Canvas for Customizable Advanced Maintenance through Micro-services

3.1. Customer Segments

As suggested from Lee [33], the first challenge is "*determining and understanding the current needs and issues of a particular company, which are usually shaped by the nature of the company's assets or the company's products*". For this reason, the very first step of this business model is to analyse which are the potential costumers and their main issues.

In the article [35], it is reported that different costumer segments are identified in the following cases:

1. Their needs require and justify a distinct Value Proposition;
2. They are reached through different Distribution Channels;
3. They require different types of relationships;
4. They have a substantially different profitability;
5. They are willing to pay for different aspects of the Value Proposition.

Basing on these guidelines, in this analysis three main costumer segments have been identified:

- Manufacturing Business;
- Industrial Machinery Manufacturers;
- Service Enterprises.

Before going deeper in the definition of the first company profile identified, it occurs to define Manufacturing as "*the entire process of converting raw materials into finished products that satisfy user demands*" [36].

Considering the previous definition, it is possible to assess that a generic manufacturing business should dispose of assets and equipment to perform this kind of conversion. Moreover, taking as reference the definition of Business-to-Consumer (B2C) of Hom [37], that defines B2C as a business transaction activity in which business enterprises sells goods or services to consumers, it is assumed, in the scope of this work, the overlapping of the two concepts. In this study, Manufacturing Business is identified firm in B2C domain, that uses assets and equipment (externally provided or internally owned) to manufacture products which will be sold to its customers. Manufacturing business acquires assets and equipment from a supplier (in a B2B domain), expecting its support for a part of the whole asset/equipment lifecycle.

B2B, or business-to-business, is based on the selling of products and services from business to business, rather than business to consumer, and is the typical business model that characterizes Industrial Machinery Providers. As a direct consequence, this type of business is defined in this analysis, as company that produces and maintains machines and their related products or services for customers which are, typically, industries.

Thinking about the possibility to extend the model to other costumer segments, for which e-maintenance it is not considered as a key activity and, reasoning about the context in which e-maintenance is emerged, so the whole analytics field with which e-maintenance shares logics and benefits, it can be defined a third customer segment to which the value proposition could be addressed. Even Lee, in fact, in its work mentioned, said *"The benefits of an intelligent maintenance system will deliver new service functions to different customers of different products"*, enlarging definitively the scope of e-maintenance, from a service to maintain the product to a paradigm able to generate new business opportunities not strictly related to the maintenance of a specific product but more different products from different builders.

For this reason, the customer segments described at this point, can be further complemented by adding another profile, called "Service Enterprises". This profile can be defined both as a B2B or a B2C company that provide services -instead of products- to its customers that, by definition, can be both machinery manufacturers or final end-users.

For convenience of presentation, the scope of this work will focus only on manufacturing business segment, taking into consideration that the achievement of customization that characterized this business model makes it easily to be scaled to other industries segments.

3.2. Value Proposition

In this section, the value promise of the new business model based on micro-servitized advanced maintenance will be detailed. Methodologically speaking, it was selected the "Value Proposition Canvas" as a tool to position the service offered between costumers value and needs. The "Value Proposition Canvas" was developed by Dr. Alexander Osterwalder with the aim to model the relationship between two parts of the Osterwalder's broader Business Model Canvas: customer segments and value propositions.

On the right side of the framework, the Customer Profile is designed going through:

1. **Gains** – the expected benefits that push the customer to adopt the value proposition.
2. **Pains** – the negative experiences, emotions and risks that the customer experiences in the process of getting a job done.
3. **Customer jobs** – the tasks customers are trying to perform, problems they are trying to solve and needs they wish to satisfy.

On the left side of the framework, it is possible to find the Value Map described through the following elements:

- **Gain creators** – how the product or service creates customer gains and how it offers added value to the customer.
- **Pain relievers** – a description of exactly how the product or service mitigates customer pains.
- **Products and services** – the products and services which create gain and relieve pain, and which underpin the creation of value for the customer.

Figure 12 graphically described the value proposition Canvas. It is divided in two main parts: from one side, it describes the **costumer profile** of a generic manufacturing business in terms of pains, gains and main jobs (already detailed in paragraph 3.1); on the other side, the **Value Map** is graphically presented.

In particular, value map resumes the gains that micro-servitization can bring to advanced maintenance from the customer's point of view and how some aspects of micro-servitization can be considered relievers for their identified pains.

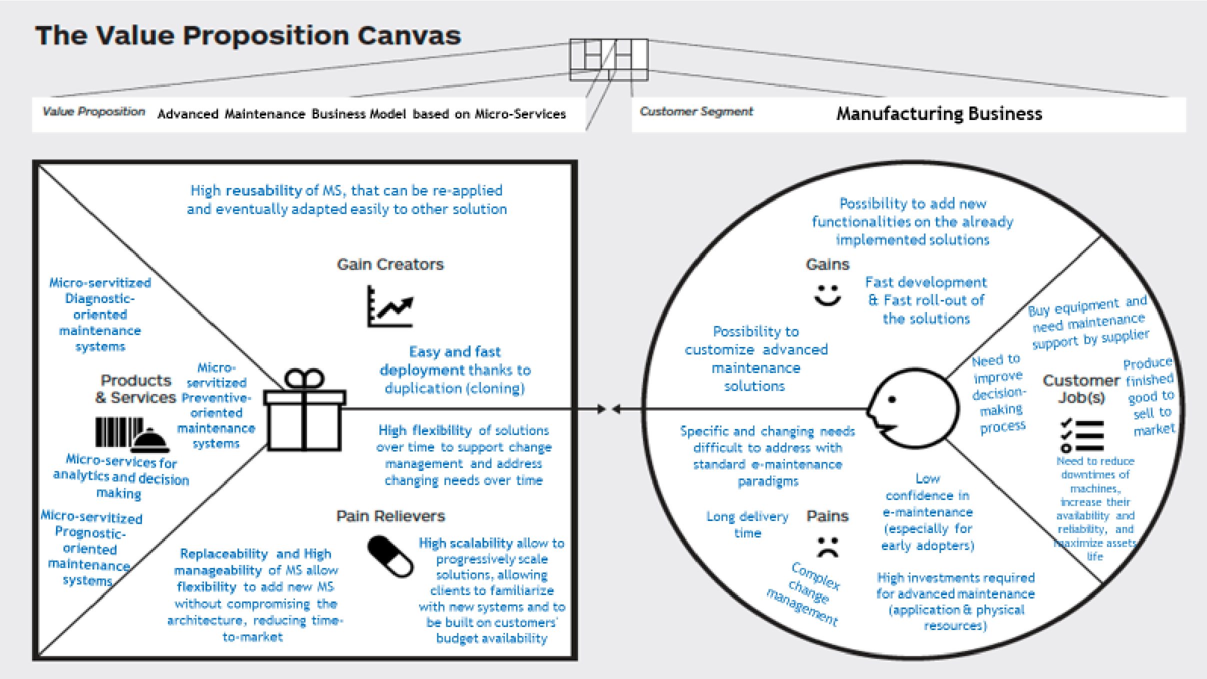

Figure 12 - The Value Proposition Canvas: Value Map & Costumer Profile

Customization and Customers' needs

It is assumed that each enterprise has different requirements, different working processes, different equipment, also in case they belong to the same industry. Moreover, the increased complexity of modern manufacturing systems requires increased flexibility and reconfigurability, not only in production design but also in all the application systems for operations and maintenance that need to evolve at the same time. Besides, correspondingly, Lee highlighted the importance of a customized e-maintenance strategy, assessing that: "*A company can implement a tailor-made predictive maintenance service that addresses its unique issues […]* [33]." However, as already highlighted from literature review, although enabling technologies are already in place, the main gap is the **lack of business models able to fulfil the requirement of customization and scalability of the actual maintenance management systems**.
In this context, micro-services applied to e-maintenance are a potential lever enabling to respond with a tailor-made solution for each of the identified needs - while monolithic e-maintenance models fail – supporting customization and generating new business opportunities.

In his work [33] Lee identified as "value promises" of e-maintenance systems improvements in uptime, failure prevention and productivity.
Among the mentioned benefits, he identified also another important aspect related to e-maintenance: **the information flow**. Introducing a better information flow in fact, allows to deliver the right information to the right people at the right time, improving at the same time the decision-making process at the costumer's side and, on the other

side, the one of the service/product providers, it allows to benefit of information feedback in order to improve product and services delivered, in what is called "closed-loop product design".
Resuming, three main benefits were identified as advantages of e-maintenance adoption, which can easily be reverted into costumers' needs:

1. Productivity Improvement
2. Product-Life Cycle Management Improvement
3. Decision-Making Process Improvement

For a manufacturing business, productivity is a measure of the rate at which output of goods and services are produced per unit of input (labour, capital, raw materials, etc.). It is calculated as the ratio of the quantity of output produced over the quantity of inputs used. A well-designed e-maintenance system can improve productivity by reducing downtime costs, improving quality, reducing energy consumption of assets and reducing the damage of the whole asset caused by the deterioration of one of its critical components, extending asset's useful life.
With particular reference to this last-mentioned items, product-life cycle management improvement is not beneficial only from a supplier's perspective, but it can be also seen as an advantage for the customer itself.

To maximise an asset life, in fact, has important impacts on productivity: improving equipment performances means more efficient usage of resources and less maintenance interventions required over the asset lifetime. Moreover, feedbacks on services offered can be also provided, for example about the predictive model performances and reliability, thus allowing supplier to improve his offer, which will finally benefit the customer as well.
Last but not least, advanced maintenance can improve decision-making process by enabling the schedule of the right maintenance interventions with a consequent optimization of machines downtime and productivity increase and, in its broader scope (including also visualization tools provided thanks to analytics), can allow to take decisions from data (for example, it allows to analyse the amount of energy consumed during production hours, or rejects analysis resulting from defective products, etc).

Benefits of Flexibility and Scalability from Micro-servitization for Customization

Flexibility and scalability together provided by micro-services when applied to advanced maintenance, can generate an important gain for the client: the possibility to customize advanced maintenance, allowing the supplier to definitely respond to each specific and unique need of the costumer.

1) FLEXIBILITY

The first identified pains of a manufacturing business are mainly related to **flexibility** and, more in general, with the ability to change or be changed easily according to the situation. Nowadays manufacturing companies work in very complex and dynamic environments that push them to change often their production context. This means that machines can work at different workloads and can be subjected to different operative conditions that can differently affect the degradation of the equipment's components requiring, as a consequence, the re-training of the data analytics/machine learning models or the substitution of the actual with more sophisticated ones for the same machine.

In [38], are listed some conditions that can push a manufacturing business to change its requirements and trigger the modification or the review of the actual e-maintenance system. In particular following items are considered:

- Changes in desired Production rates, which in turn can impact on equipment deterioration rates;
- Changes in the financial impact of failures and equipment downtime, often due to changes in external market conditions;
- Modifications to equipment;
- Modifications to operating/process parameters;
- Ageing/deteriorating equipment (or replacement/refurbishment of equipment);
- A growing understanding of how (and how often) equipment fails, and the consequences of those failures;
- Introduction of new technologies for predicting or preventing failures.

When one or more of these situations occur, the actual e-maintenance system may become obsolete and requires changes. If the actual solution is implemented through a monolithic architecture, the whole system is less flexible to the required changes. Instead, with micro-servitization, one of the main flexibility enabler characteristics of microservices is **replaceability**. In particular, micro-services, thanks to their high replaceability, allow to maintain still usable components (for example data mining modules such as: Data pre-processing MS, data integration MS, MS Orchestrator, Feature Extraction MS, etc.), and substitute the obsolete components with new ones providing new functionalities. For instance, taking as reference the case in which the critical component's cost of the monitored equipment has increased due to market reasons, could be not sufficient the actual health monitoring system based on RUL computation (on which planned maintenance interventions are based), but there is the need to develop a predictive maintenance model in order to maximize the useful life of the component and reducing at the minimum the number of interventions, to decrease costs.

In this case, with a micro-service architecture, it is possible to substitute the prognostics module that outputs the RUL of the critical components, with a package of micro-services containerized into a predictive analytic module that integrates RUL prediction with cost optimization (besides the prediction).

Another important pain for the identified costumer segment is the delivery time of time of advanced maintenance solutions. In [39], in fact, is highlighted that for a manufacturing business "*time is a big issue in maintenance*" and, in particular, "*providing the service in time is a big challenge*". In this context **manageability and easy replaceability** characterizing MS can be considered a pain reliever: the single module can be enhanced or corrected without any deleterious impact on the other service's consumers. In other words, new functionalities can be exposed without existing points of integration are disrupted. This can be translated into the possibility for the supplier to speed-up the deployment of the solutions, reducing time-to-market and supporting easier costumers' change management. Consequently, the value for the client is that final solution can be **delivered faster** with respect to monolithic architectures and **with a lower cost** (modification of the solution requires less effort than its total re-engineering).

Finally, the identified gain apported by flexibility provided by micro-services is the possibility to add new analytics functionalities, thus finally enabling the customization of the existing solutions. This is possible thanks to **reusability** of some micro-services: Micro-services re-use leads to the reduction of costs related to software development, integration and maintenance. In particular, developer can use the basic functionality module trying to adapt it, with little modifications, to provide new functionalities.
Reusability has tow main important advantages, that sometimes need to be balanced to avoid drawbacks [40]:

a) **Generalization**: it reduces dramatically the development time and means to design micro-services in such a way to make them suitable to meet the most of requirements avoiding specificity. This is particularly useful for developing the first PHM modules (data acquisition, data pre-processing)
b) **Over-specification**: it is verified when micro-services are highly specific for a determinate context. This clearly means increase customization levels, but at the same time decreasing the reusability.

So, the suggestion to exploit reusability benefits is to widely use generalization principle to design standard modules and if needed, use those basic micro-services over-specifying them in order to meet specific requirements.

In reference [41] , for example, is proposed a programming interface for new micro-services generation that will provide the flexibility level required for accelerating the development of interactive and re-usable Big Data analytics tools.

The picture provided in figure 13 is a synthesis highlighting the role of flexibility within the gain creators and pain relievers, and the main addressed gains and pains in the customer profile.

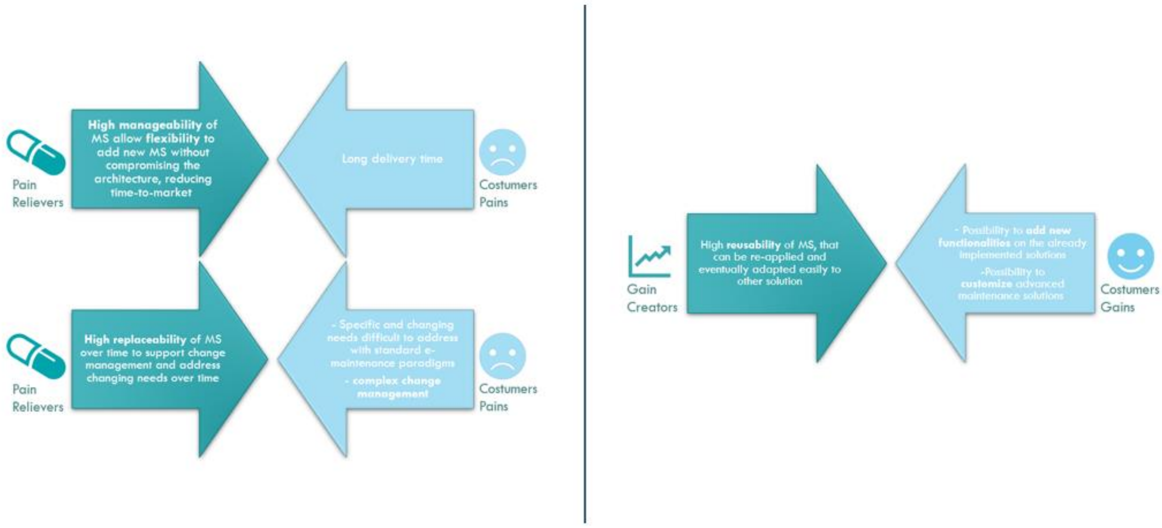

Figure 13 - Links between flexibility Gains creators/pains relievers and costumers' gains/pains for Flexibility

a) SCALABILITY

From a technical point of view, "scaling" requires to break down a software in different units (thus micro-services) and while scalability is a key-aspect resulting from microservices architecture, therefore allowing the implementation of more advanced features of the application, facilitating the deployment at different scales (i.e. from small to large scale) and supporting continuous improvement.

In [33], it is reported that "*The cost of implementation is a major constraint, most especially if the user intends to scale the use of the prognostics system to the factory level or duplicate the system on similar machines*".
It refers to roll-out of advanced maintenance solutions that can be difficult in case of legacy systems. In the case of distributed systems, instead, it is possible to scale micro-services horizontally, by centralizing for all the similar machines some specific micro-services that are not constantly operative (e.g. feature extraction MS, model selection MS, etc). This is possible thanks to **duplication** of micro-services: for similar assets, for example, it is possible to clone for each machine the modules of condition monitoring (e.g. health monitoring system MS, predictive model MS).
This results in a **fast deployment and roll-out** of advanced maintenance, scaling from a few machines to the rest of the machines on which it should be mounted on.

Additionally, one of the main costumers' pains that is often underestimated, is that it can happen that a small or medium enterprise has not enough budget availability to invest in advanced maintenance and/or has no or limited confidence in this topic.

As a matter of the fact, among the top three barriers to predictive maintenance adoption, Siemens reports the financial justification as a factor that many manufacturing businesses take into account in maintenance paradigm-shift [42]. As suggested from Siemens, adopting an **e-maintenance solution requires an initial investment that not all companies are able to sustain** and also, there are businesses not ready enough to maximize the expected benefits from a predictive maintenance system. In order to mitigate this barrier, according to Siemens, manufacturing business should "*Start small, prove gains on select assets with minimal investment and then multiply those gains*".

Micro-services can be considered also in this case a pain reliever due to the possibility to scale the solution accordingly the company's capability to invest and accordingly to their level of maturity in e-maintenance adoption (expressed in terms of knowledge and comprehension about the economical benefits provided).

To go deeper in this topic, the different approaches to build a maintenance strategy were formulated in 1992 from of L.M. Pintelon and Gelders, who define 3 decision levels: strategic, tactical and operational planning [43]. In 2002, D. Murthy, Atrens, and Eccleston defined a time-oriented theory about the strategical approaches to define a maintenance strategy, defining operational strategy as short-term oriented, tactical as mid-term oriented, strategical as long-term oriented strategy [44].

Starting from literature insights about maintenance strategy approaches, the three approaches have been elaborated and adapted to the new business model proposal:

- **Operational Approach**: deals with day-to-day operational and scheduling decisions. In this perspective company's need is monitoring actual conditions of machines in order to understand WHEN and WHAT type of maintenance intervention is required.
- **Tactical Approach**: deals with a mid-term perspective aimed at maximizing production (through downtimes minimization) as soon as possible and with the lowest investment required, by addressing effective resource utilization ensuring the availability and reliability of production equipment. Under this perspective, challenge starts to increase: the goal is now to go a step further in e-maintenance adoption and requires to add new tools able to provide new information/insights useful to improve the knowledge about the degradation

path of the critical component/equipment in order to optimize the performance of the assets in the useful life.

- **Strategical Approach**: Manufacturing Business is now adopting long-term perspective. The knowledge about asset is mature enough to increase the complexity of the already implemented solutions. E-maintenance benefits are well-known and company is willing to invest more in solutions able to provide a significant competitive advantage. Needs are more oriented to productivity and uptime maximization, maintenance costs minimization and overall efficiency improvement (rejects reduction due to defective products, smart energy management, etc.).

Similarly to above, figure 14 provides a graphic representation of how scalability gains creators/ pain relievers are linked to customer's gains/pains

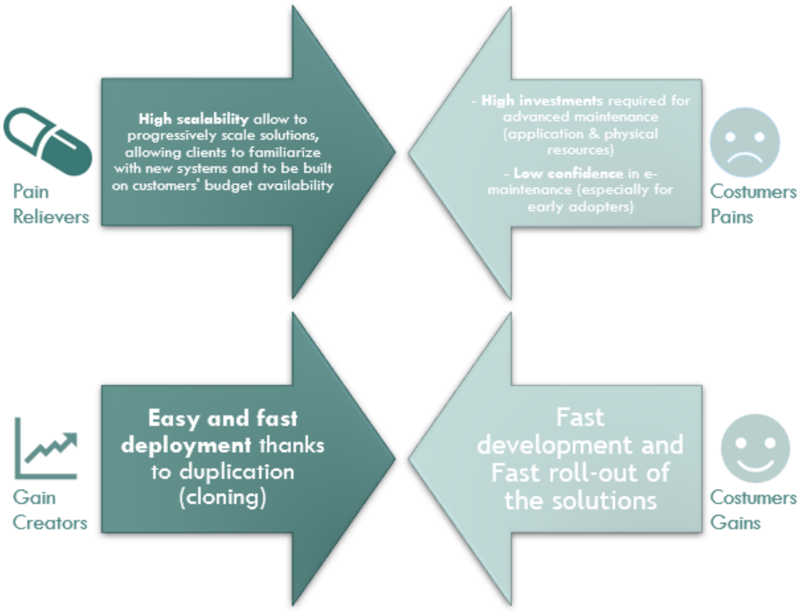

Figure 14 - Links between scalability Gains creators/pains relievers and costumers' gains/pains for Scalability

According with the vision adopted by the company, passing from operational to strategical approach, solutions become increasingly sophisticated and more technologies are needed. Even from software point of view, codes, algorithms and services increase complexity in deployment, integration with existing systems, testing and resources, consequently the cost of the service will increase. Thanks to scalability and modularity of the new e-maintenance solutions will be possible evolve progressively the strategy and the architecture.

PRACTICAL EXAMPLES OF VALUE PROPOSITION

Accordingly with the different visions adopted by the company, the critical assets and critical components costs, their economical capabilities and level of maturity in the transition to e-maintenance strategy, the previously defined benefits can be addressed in different ways by connecting the different micro-services.

For example, let's consider a generic manufacturing business that is transiting from traditional maintenance model to an e-maintenance model and that would improve its productivity in a cost-efficient way. For this "early-adopter" company, an **operative-oriented maintenance strategy** could be **preventive/analytics - oriented strategy**. In this case, it could be enough to sell to this customer a system able to compute the RUL (Remaining Useful Life) of the critical component, that can be used to schedule maintenance activity in such a way as to minimize losses and downtimes. In this case, the final aim is creating low impact to productivity even if the component's life will be not maximise. To reach the goal, not all the modules of the PHM framework will be used, but through micro-services will be possible to select and deliver only modules needed for the scope.

Let's suppose now that, after some period of time, **costumer took more confidence in the new maintenance model** and he is ready to add something more**,** adopting a **tactical approach**: the objective now is to reach a trade-off between the selection of the optimum maintenance planning moment which minimizes downtimes and, on the other side, maximises asset useful life. The previous solution can be maintained and integrated with a new module or micro-service consisting in a stochastic programming model for jointly optimizing maintenance and operations schedules, like analysed in [45], exploiting the degradation-based remaining life distributions generated from the previous implemented solution (figure 15).

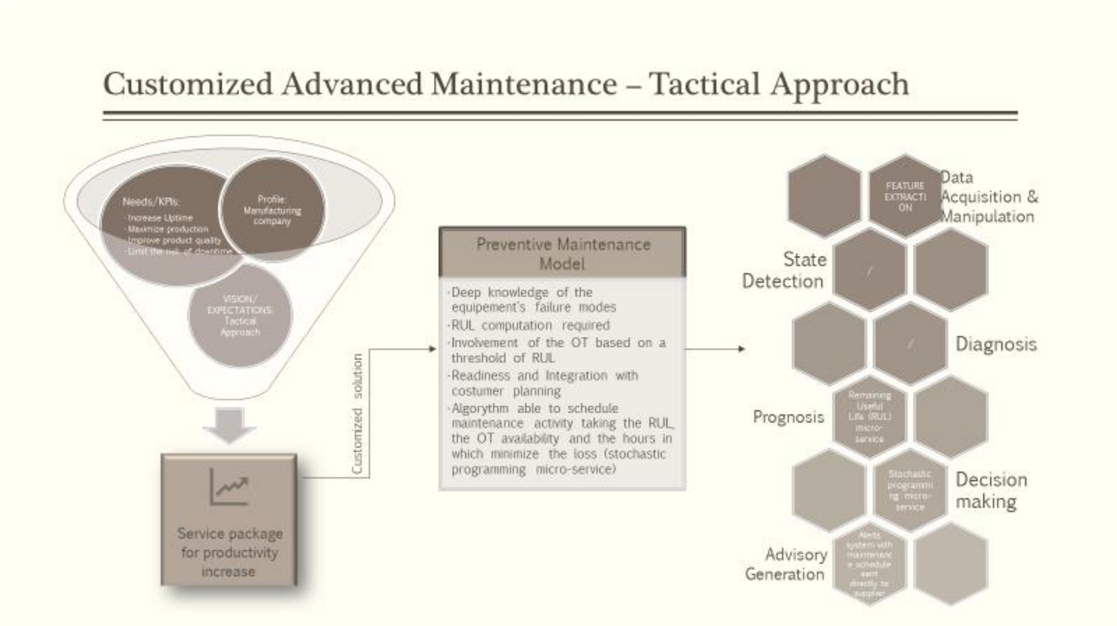

Figure 15 - Customized Value Proposition for Productivity Maximization

Consider now that the same client is willing to invest more in e-maintenance, having reached an higher level of maturity in its adoption. The objective is now improving the maintenance model, moving from time-based to usage-based maintenance in order to maximize the remaining useful life, adopting a **strategical approach**. Supposing that the new solution to be implemented consists in a condition-based maintenance monitoring system, on which is parallelly implemented an alerting system integrated with an advisory generation system, with the aim to notify the immediate intervention to supplier (figure 16).

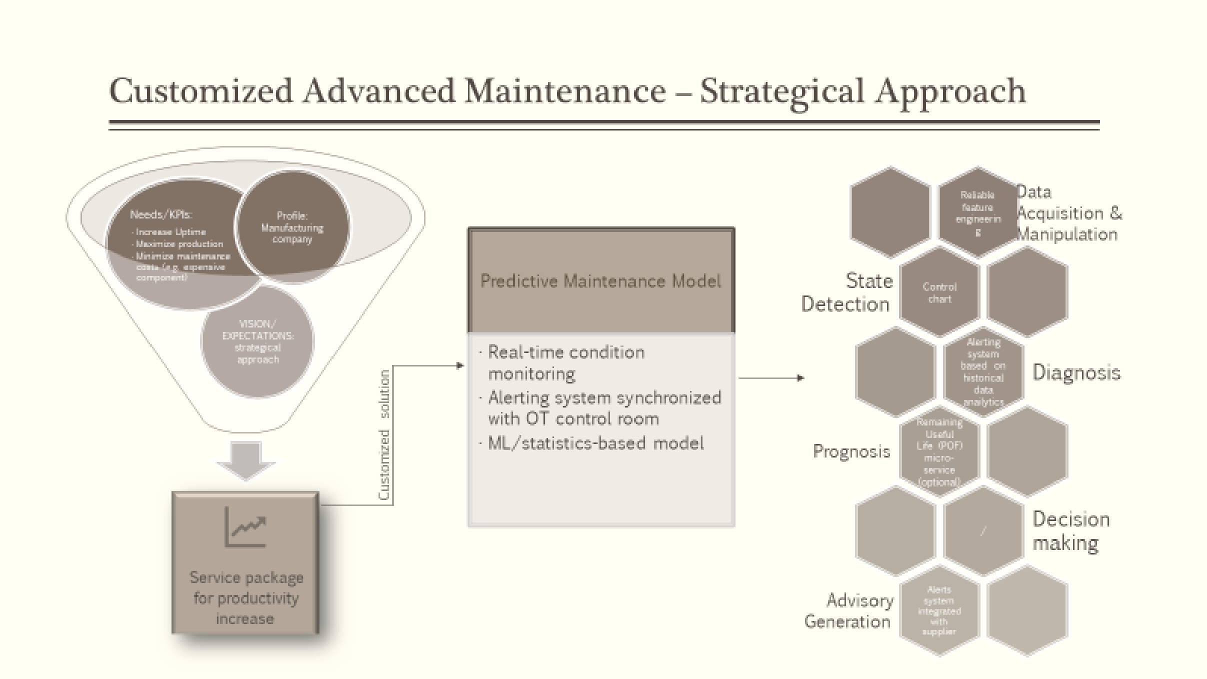

Figure 16. Customized Value Proposition for Asset useful life maximization

It is easy to notice as micro-services are key resources in this case in order to satisfy all such requirements. Data processing module (for sure included in the previous solution, as necessary for every PHM development), can be kept as it was, or adapted easily to the new solution. Micro-services, in fact, thanks to their high manageability allowing new functionality introduction where it's needed without impacting areas outside of scope. The RUL estimation module can, for the same reasons as before, easily substituted without any impact on the other micro-services. The implemented architecture can be reverted in the following way:

1. The preventive maintenance system is maintained (since many modules like data acquisition, integration, processing can be still used);
2. Predictive maintenance model is created on the old architecture and an alerting system is implemented: if sensor captures an high critical value of the critical variable, this generates an alert and supplier acts only when the red/orange alert (according with the defined severity) comes, maximising component/asset useful life. If, instead, criticality is medium, it is possible to rely to the originally implemented module aimed to compute RUL. In this case, operator will take the final decision basing on RUL computation: changing the component without waiting highly critical values (maybe by setting a RUL threshold to trigger the maintenance intervention alert) or to maximise its useful life and rely on the predictive model (see figure 17).

This aspect, finally, can have a double value:

1. For a manufacturing business, the possibility to have the immediate intervention from supplier without need to notify the expected failure.

2. For the industrial machinery manufacturer, the possibility to use the alerting monitoring system service with its database ran on-premise to collect information about the performance of its asset on operative conditions its asset, closing in this way the loop lifecycle of the product and gaining data and feedbacks directly from data acquisition module and condition-based system modules coming from costumer plants.

The alerting system monitoring can be deployed directly on supplier servers' or private cloud, without any visibility from customer side. This is possible thanks to the flexibility of communication among micro-services, typically based on events rather than centralized orchestrators, in other words it is established using pub-sub messaging protocols, making easy sharing information and events through the different micro-services [46]. Figure 17 shows graphically the previously described concepts:

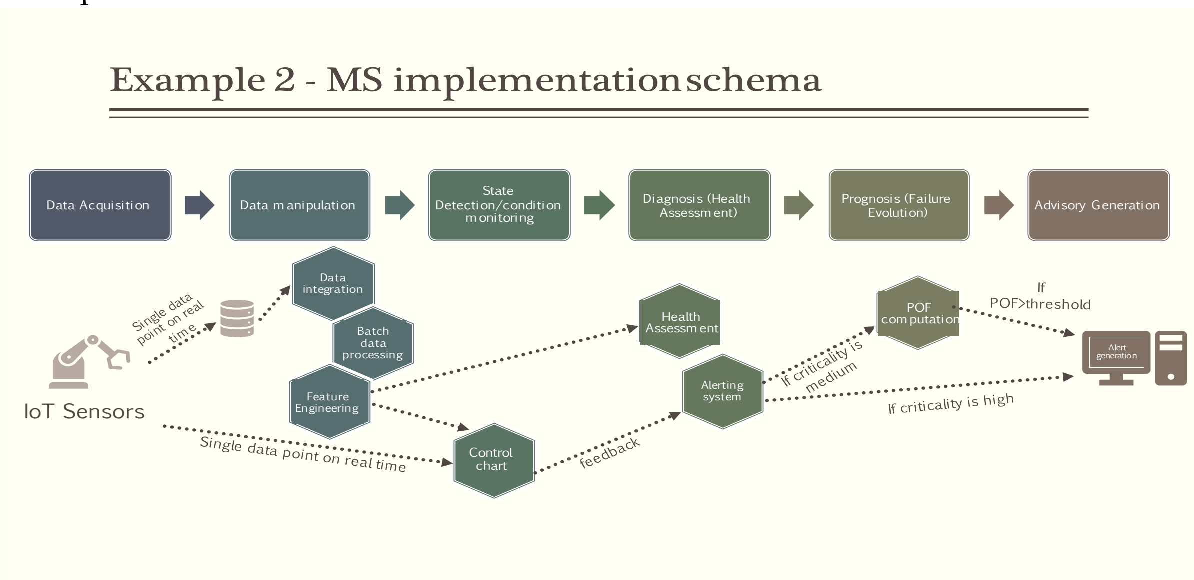

Figure 17 - Architectural pattern of Customized Value Proposition for Asset lifecycle maximization

Apart from the mentioned examples, micro-services applied to e-maintenance and PHM are able to generate in many possible different ways to meet the needs previously identified. The picture below is represented an idea about the customization potentiality of a well-designed e-maintenance system based on micro-services, by crossing the different approaches adoptable by the client and his needs.

The illustration contains only some examples of the possible solutions that could be generated thanks to micro-services. Each combination of need/approach corresponds to a specific a specific e-maintenance strategy that can be then deployed in many different modes from a practical point of view (figure 18):

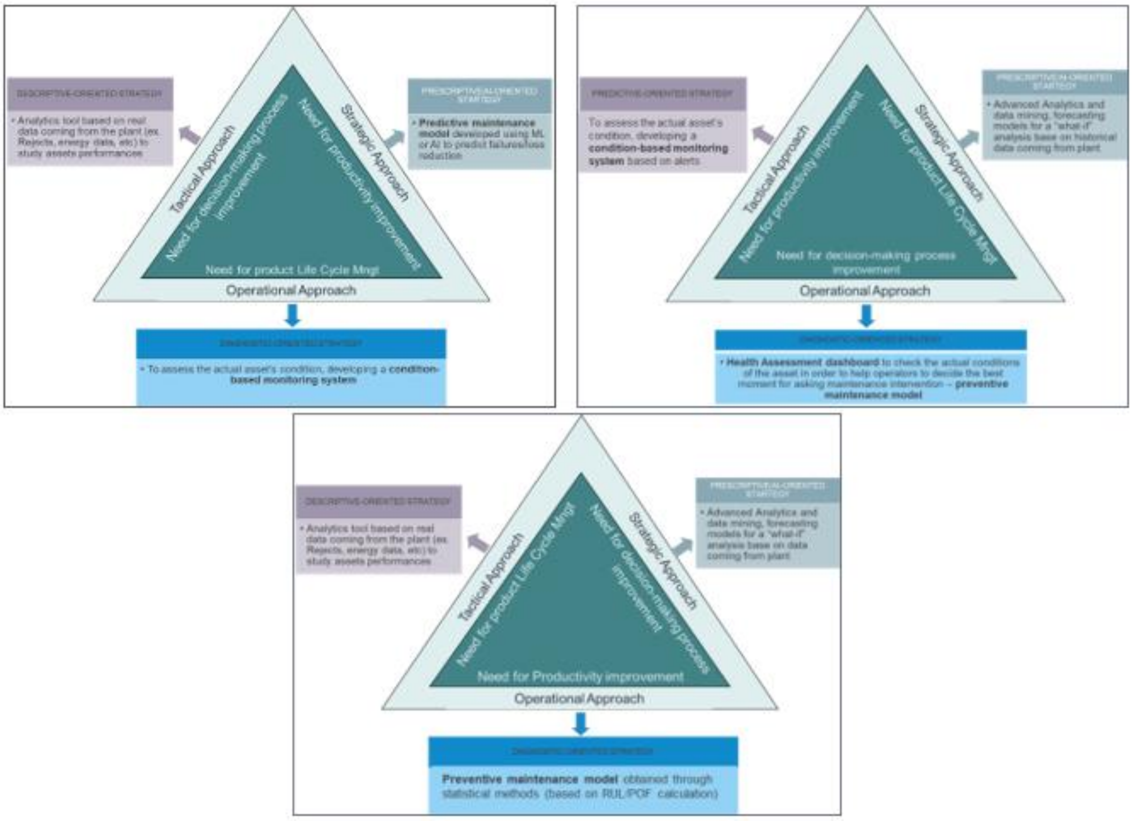

Figure 18 - Advanced maintenance strategies resulting from the crossing of most common business needs and the identified strategy approaches

Another important aspect that will increase the customization potential of this business model is the possibility to add other value-adding services not strictly related to maintenance but more related with **analytics**. For example, the possibility to introduce in the architecture a new micro-service for improving the decision-making process like a visualization/reporting tools or micro-services aimed to analyse the rejected products or the actual energy consumptions by machines over time.

Thanks to micro-services, e-maintenance business model can evolve increasing its value. A wide portfolio of micro-services can be offered to the costumer to address its proper need, increasing at the same time confidence in the new way to do maintenance and in general operational improvements. Costumer then require to "adjust", based on the necessities, the solutions implemented and scale them rapidly to other equipment, being able to receive a tailor-made e-maintenance paradigm with the possibility to evolve it over time.

3.3. Key Activities

To realize what is expected by the value proposition, it is important to consider the key activities that industrial machinery manufacturers should perform in order to ensure to their customers the value promises.
Generally speaking, the most relevant activities to perform are the followings presented in the reminder:

- **Identify the customers' expectations and approach and select the most suitable e-maintenance strategy**

That means understanding the unique need of the costumer and his necessities in terms of implementation timeline. Moreover, this means also investigating the level of confidence and knowledge about e-maintenance and basing on that, categorizing the customer' s maintenance vision. This could be done by defining the approach to be addressed, that is: operational – tactical – strategical.

This task is important in order to reduce the complexity, in particular, in relation to the portfolio of micro-services to put in place. Once built the customer profile and understood his e-maintenance adoption approach, the next step is to associate to each approach a proper e-maintenance strategy in order to simplify the design process of the solution.

The following table proposes a general combination of approach/strategy. This combination is shown as a generic model but it should be also meant as exemplary generic case: coherently with the customization target, this should be subject to a specialization in order to fit the peculiarity of customer profiles and needs:

ADOPTED APPROACH	E-MAINTENANCE STRATEGY	FUNCTIONALITY TO PROVIDE
Strategical Approach	**Diagnostic-oriented maintenance strategy**: this type of program incorporates machine learning and artificial intelligence to prescribe mitigation solutions based on health status and remaining useful life.	Failure prediction and minimization of downtimes

Tactical Approach	**Prognostics-oriented maintenance strategy**: this type of program involves the use of statistics-based models to monitor actual device health in real time and make maintenance decisions based on their Remaining useful life (RUL) or the probably of failure (POF).	Maintenance decisions based on RUL and POF of the asset
Operative Approach	**Preventive maintenance strategy**: This type of program involves creating an equipment maintenance plan that is based on knowing the historical performance of the equipment to determine when (and what type of) maintenance is required.	Optimal time to perform maintenance activities

Table 3 - E-maintenance strategy per defined approach

- ***Componentize and customize in modules containing the microservices + Develop the integration amongst the modules***

It can be useful, for each e-maintenance strategy, having already a "base solution" to use as starting point to develop new functionalities faster, simply substituting pieces, adding new micro-services to the architecture or modifying some existing ones and then testing and validating if and how the new architecture works.
For this reason, it is necessary to generate modules (at least one for each PHM phase, then there could be also specific modules for customized analytics tools). Each module from a technical perspective can be "containerized", that means to generate a package of software that works independently. On each container or module it is possible to find different micro-services exploiting different functionalities aimed to realize the functionality that the module is expected to provide. If some change is required for building up tailored solutions, it is possible to substitute one module or to act on the single MS within the module. This is possible since some PHM modules are strictly required in the majority of e-maintenance architectures, some of them are quite standard (e.g. for data pre-processing etc.) whereas others may be particularized according to the tasks (e.g. doing machine learning for anomaly detection). Some basic modules have been identified and analysed in the section "Key Resources".

Once having the whole PHM process in modules and each module into small micro-services, the next step is let them communicate with each other. Communication between micro-services and inter-operability among them has to do with **integration**. With the proliferation of fine-grained services, integrating microservices in existing application and building inter-service communication has become one of the most challenging tasks in the realization of microservices architectures and is a key activity for e-maintenance applications.

- **Adopting an Agile framework in the design process+ changing development culture**

From literature, one the main significant barrier that clients can encounter in their advanced maintenance adoption journey is the lack of confidence in adopting new solution since the benefits of e-maintenance are not immediately visible to the costumer. For an industrial machinery manufacturer one of the most challenging activity is stimulate clients to pay for a maintenance contract including services to increasing productivity. To promote this new culture and make the new business model more effective, the majority of the companies suggests to evaluate and show to the client the forecasted ROI generated from the implementation of e-maintenance solutions [47] but not always forecasting is sufficient to convince especially early-adopters to invest.

According with Siemens, one possible solution to overcome this barrier is to show progressively benefits of the solutions by a **small-scale implementation** (made feasible thanks to micro-services) because *"Once predictive maintenance has been demonstrated on a small number of assets and the benefits have been clearly understood, cultural resistance tends to melt away."*
In this task, micro-services represent a key resource and, as a direct consequence, another key activity to be performed by supplier is to shift its traditional way to design services, **including the capability to deal with an agile framework in the design process.**
Agile framework was recently developed and can be defined as a software-development approach promoting the value of iterating quickly and satisfying customers for eventually customizing some components to meet their unique needs [48].
Agile methodologies allow to release rapidly modifications to software or develop a solution in small parts with the aim to collaborate with the customer progressively in order to satisfy exactly its needs. Moreover, such methodologies use flexible approaches and support autonomous teamworking in order to facilitate continuous delivery and continuous improvement.
Thanks to the potentialities offered by distributed systems, microservices support and facilitate agile development [49] as each small team can own and focus on one service, working more effectively and efficiently.
Therefore, in this work, the adoption of Agile Methodologies is considered critical for the success of this business model implementation, since it is not only a new way to develop, but also a mechanism for gathering customer feedback since they are consulted at each release, creating a collaboration network.

To sum up, the adoption of agile framework is considering crucial for two main reasons:

- **Customer is involved in the process of designing of the solution**, this increases the customer's culture in e-maintenance and, at the same time, the supplier can gather information about the customers needs and about the product itself (strong collaboration means also improving the Closed-loop Life Cycle Product Management):
- **A fast and progressive delivery of pieces of software should be allowed.** In this way the customer can immediately see the value of the e-maintenance solution, its benefits and eventually also its weaknesses that can be collected to improve the offer.

Overall, all the above said considerations can be understood as a cultural change in the development process

- ***Migrate from legacy to distributed systems***

To switch from legacy to distributed predictive systems is not an easy task, it requires a big effort in reverse engineering in order to decompose the whole application in stand-alone micro-services. In particular, it consists in the process of rearchitecting and rebuilding totally an application. The idea behind is trying to map the whole application, then isolate components, in the first step working using containers and when achieved a deep knowledge of the process and a first isolation, opt for a microservices approach for a better scaling.

3.4. Key Resources and Key Partners

This section will present the building block of key resources, that are all the resources needed to realize and deliver the value proposition to customers. Key resources can be divided into 3 main categories:

- **Financial resources**: basically, the **budget availability of the customer** to pay the services offered.
- **Human resources & related Knowledge/Skills/Other abilities**: customer in this case is a fundamental resource since the final goal is to achieve full customer satisfaction and confidence with the new solutions implemented. Collecting progressively his feedback and involving him in the design process become crucial for the adoption of this business model.

  On the other hand, human resources are also skills and competencies to be acquired in order to successfully implement the proposed idea. What is required in this case are: a deep knowledge of the products to be sold and the acquisition of competencies not only related to data analytics and e-maintenance, but with the introduction of micro-services more technical skills are required and become key resources to acquire. In particular, it is needed **an high level of expertise in ICT**, with particular reference to new **communication protocols**, **virtualization skills** and the knowledge of new standards to build efficient architectures using MS.

In this context, the role of the **Cloud Architect and Cloud Specialist** could be crucial, considering that IT infrastructures are moving more on more on cloud to exploit its potentiality of lightness, flexibility and scalability. Cloud Architect is responsible of developing a cloud strategy in line with business goals and knows how to implement this strategy. Clous Specialist has a very deep knowledge about the most convenient cloud products' offers present in market and is responsible of management and implementation of cloud-migration projects [50]. In case the supplier decides to migrate in cloud, could be interested to start a partnership with cloud services providers (Google Cloud Platform, Amazon Web Service, etc) and cloud experts in order to evaluate the most advantageous offer in the market that perfectly respond to his needs.

Finally, it is important speaking about security when one deals with micro-services: the risk is, besides loss of control and visibility of application components, resulting in more vulnerable points. For these reasons, as Gartner refers, "*IT Ops teams will also need incident response skills. They will need to have the skills to assemble a team and do quick forensics, quick assessment, quick deep-dive analysis on what a likely problem is*." In other words, **readiness, problem-solving and data security knowledges** are required when it is decided to work with distributed systems.

- **Physical resources**: among the physical resources needed for a successful implementation of this new paradigm, the most important one are **micro-services & containers.** As already said, it is necessary to divide the PHM process into modules (technically speaking "containers") and understand their dependencies and hierarchies. Containerization is useful in such environment since it helps to isolate software packages and focus on dependencies.

  In an e-maintenance architecture built through micro-services there will be some "mandatory" modules (standard services considered fundamental for the PHM process and that must be provided in order to realize whatever e-maintenance solution) and some others that can be included or not and also internally customized. In the light of the PHM process, it is then possible to identify, as a first level of understanding, the different kins of modules. The mandatory modules are:

  - Data Acquisition module: it is a container or a set of micro-services having the aim to store all the data coming from sensors (temperature, vibrations, speed, rotation of components, etc) and all the information related to the machine/assets (technical specifications, maintenance training documents, faults reports, historical data, etc).

- Data Pre-processing module: It is a container or set of micro-services aimed to mitigate the variety of data, since data come from different systems and consequently, they present different formats. This module contains the data manipulation and integration functions in order to process raw data and convert them in insights.

Then we have some other modules that can be selected or avoided, such modules are:

- Feature Engineering module: it provides the feature engineering function, aimed to analyse data and extract one feature describing the behaviour and the evolution of the system under scope. This module is basic for other modules in case they built not on raw data but on already processed information as features.
- Diagnostic Assessment module: It is a module able to perform assessment on the current health conditions of the system. It is used for identifying potential failures of assets that may occur while checking the assets when they are running. It uses state detection and analytics tools for monitoring the performance and condition of equipment during normal operation to minimize the probability of failures. It can contain also different MS inside, such us a Machine Learning Library (containing all the algorithms), a model selection micro-service (able to select from library the most precise and accurate model). In relationship to the algorithms, when it is adopted a supervised learning, the MS should also enable training the model with historical data.
- Prognostics Assessment module: it is a module that provides the functionality of predicting the future reliability of the system by assessing current operative conditions of the asset. Output of this module are computations of Remaining Useful Life (RUL) and Probability of Failure (POF), on which preventive maintenance solutions are based and maintenance decisions will be taken.
- Advisory Generation module: It is a module aimed to generate and generates alerts to actors involved in maintenance activities (suppliers, managers and users)
- Decision making modules: this can be interpreted as more modules or packages containing many different independent, not related, optional micro-services that add value to the proposal by facilitating the decision-making process. For example, Visual Analytic Microservice can provide BI visualization tool developed with the scope to clearly show and make understandable insights by the top management (better understanding of

actual energy management, providing an overview of rejects due to defective products generated over time, etc) and/or reporting tools in which trends over time are analysed and a report on health conditions of equipment is provided to management.

Other modules can be integrated with other systems, for example a Resource Controlling Module directly integrated with the MES or a Stochastic-programming module to optimize the scheduling of maintenance interventions, directly integrated with supplier systems.

It is evident, as a concluding remark, that modules/containers of MS are essential physical resources and the previous categorization in modules is a high-level one, to be developed according to a proper componentization and customization (see back what said for the Key activities).

Additionally, in many cases, both on customer and supplier side, it is necessary a **strong and powerful computing and acquisition capability**. Such computing power can be achieved in three different ways:

- **Edge Computing**: it is a technology allowing data elaboration directly where data are produced. In this case for example, the Data pre-processing micro-service may run directly into devices, sensors other embedded platforms. In this case, supplier will sell the device (sensor, machine, etc) directly with embedded of data pre-processing services. Data in this case need to be sent to another repository because they cannot be stored locally, but the advantage is that we can send already elaborated data that means less space needed in data center or micro data center, ensuring a better latency (microservices are more responsive).
- **Fog Computing**: in this case instead the elaboration of data doesn't happen where data are produced but are elaborated by a fog node or IOT gateway situated away from the point of data generation (sensor). The advantage in this case is that there is the possibility to embed in fog nodes not only data pre-processing micro-services but also their storage components.
- **Cloud Computing**: in this case all micro-services composing the application are delivered over the Internet ("the cloud") to foster economies of scale ad flexible resources, reducing at the same time the operating costs and the capital expense of buying hardware, servers and databases. Cloud computing is considered also a key enabler for microservices-based architectures thanks to the possibility to scale elastically resources basing on actual needs, supporting application via micro-services development.

It is also worth remarking that the computing capabilities are nowadays evolving, which is a sign to declare that the computing where to run MS may find different configurations according to the opportunities resulting from the evolution and related technology enablers.

Finally, among needed finally key-resources, **DevOps** should be mentioned. In this case we speak about an intangible key resource, that relates to a ensemble of standards, procedure, tools and culture to build up applications. In this thesis, DevOps framework is considered as a key-resource since its capability, from a business perspective, is to increase **business agility**. This can be motivated in two ways:

- Improvement of **development agility**: teams DevOps are flexible realising micro-services with short cycle, collecting immediately the first feedbacks and allowing in this way **continuous improvement.** Moreover, it ensures a continuous integration & continuous delivery (CI/CD) flow that could be impacting in pipeline processes like PHM: teams using DevOps, are able to introduce modifications in a controlled and systemic way, reducing the risk to impact the whole system's performances;
- Increase of **deployment flexibility**: similarly, also testing and deployment cycles shorten, enabling **continuous delivery**. DevOps ensure tools to facilitate and automatize codes, configurations and infrastructure, allowing teams to manage complex environments on large scale.

3.5. Channels and Costumer Relationships

The building block "Channels" of the business model canvas describes how the supplier can establish a point of contact with its costumers segments and how the communication is established. In this thesis, followings channels have been identified:

1. **Product**: the first channel to sell services is the product that costumer is interesting to buy (this in the case of manufacturing business segment, of course). Equipment and machinery, in fact, are tools to offer value-adding services for advanced maintenance
2. **Periodical Meetings** to present to customer new value-adding MS to be integrated in the previous sold solution (channel for continuous delivery)
3. **Presentation of historical data and achieved results** to allow the direct evaluation of the value proposition and to receive feedback from costumers about products/services purchased (channel for continuous improvement)
4. **Monitoring and alerting systems** to support customers during post-purchase facilitating maintenance interventions.

It is also important, from the supplier perspective, to clarify which kind of relationships should be established with costumers accordingly with the costumer strategy. The different relationships approaches depend, in fact, on supplier's objectives. In this work, followings main objectives are validated:

1. Increase margins from selling new services for the same sold products;
2. Increase costumers' retention

To reach these objectives, 3 kinds of relationships have been identified:

- Design Phase Relation: in the design phase costumer should be involved in order to transfer him the new value of the new maintenance model, e.g. the possibility to customize together the system by analysing its needs and propose different possible solutions. The type of relation is **CO-CREATION.**

1. Development Phase Relation: in this phase supplier tries to understand if services delivered at this point as minimum viable services (following agile perspective) are responding to costumers needs or requirements changed are not perfectly fulfilled. This is possible thanks to the fast deployment provided by micro-services and by the easiness to modify the codes. The supplier will establish a **COLLABORATION** relation with its client.

After-Sale Relation: this is the most important relationship since it has a double function. Firstly, suppliers will be able to ask feedbacks on both product & services offered, but he could also maintain a contact with client offering new functionalities that will be deployed as micro-services and added to the implemented application, increasing furtherly margins. This can be called "**CONTINOUS IMPROVEMENT & CONTINOUS DELIVERY"** relation.

3.6. Revenue Streams and Cost structure

This last part of the business model canvas will analyse the revenue streams and the cost structure of the proposed solution. As general benefit, what is expected by its implementation is an **increase of the overall profitability,** thanks to a contemporary increase of margins and a reduction of maintenance costs.

The main revenue streams are:

- **Customer-base growth**: the business model can be extended not only to the main identified costumer segments, but also to other costumers thanks to the customization that allows (as already explained the data acquisition module can become a basis for other kind of predictive systems or for new analytics tools). Moreover, thanks to the high scalability supplier can extend the offer also to those SMEs which have not yet started the process of digital transformation, still linked to traditional maintenance model. They can progressively increase their knowledge and their budget availability over time, buying scaled systems in terms of technologies, functionalities and investments required.

- **Margins increase**: thanks to customization as value-adding characteristics for analytics and predictive systems, the supplier can gain an increase in margins.
- **Enlarge services portfolio**: the supplier can have the opportunity to enlarge its services. In particular, with the product itself, he can offer entire e-maintenance solutions, or simply specific analytics functionalities provided through micro-services.

For what concerns cost structure of the proposed business model, it is necessary to consider following costs:

- Costs for the acquisition of human key resources;
- Costs for migration from monolithic to distributed systems & legacy system integration: it refers to the costs to sustain in order to transfer the whole application to a newer hardware and software infrastructure;
- Infrastructure Costs & 24/7 (always-on) services.

On the other hand, there could be also some savings generated from the micro-servitization. In fact, all the subsequent development of an application/software must pay the cost of supporting multiple versions of services or the deployment of new services to add. In particular, there are many different changes that require to review and improve the Preventive/predictive Maintenance program on a regular basis. Deploying e-maintenance systems using micro-services will definitively **reduce the cost for maintenance,** since the visibility on the issues increase, developers will figure out root-cause quicker, and also the mean time to remediation is reduced [51].

Moreover, the possibility to generate for example some specific analytics tools and to easily export them and integrate them in another context (shift and lift approach), increases the re-usability of the solutions offered to the costumer. Think about a low-customized analytics tool, it can be sold as-is to another client with an easy deployment and, in case there is the need of adapting the product to client's requirements, thanks to the high decoupling and isolation of that micro-service, it is possible to act in the code easily. The reusability of some specific micro-services, for example the basic modules for PHM, is one of the main advantage of deploying e-maintenance solutions through micro-services since it allows to **reduce the deployment & development costs** of new solutions.

All these aspects, finally, lead to a **rapid Return on Initial Investment (ROI)**, that can be calculated as profits over the investment required.

Where profit is the result of margins net of maintenance costs. In particular, margins increase with respect to legacy maintenance applications, thanks to the increase of value provided the possibility to customize services, new possible services to sell (not only related to predictive maintenance, but also to analytics and predictive analytics). Maintenance costs decrease, while investment required depends on the readiness of the company itself (if it already owns required skills and infrastructure internally and if not, if it decides to acquire them or to outsource).

4 Model Validation

The previous described business model requires to be tested in order to avoid the risk that it is not pursuable in the reality and its application results unfeasible or not valuable. To this purpose, in this chapter, the proposed business idea will be tested and validated according to the method proposed by Osterwalder in [52]. The objective of this part of the work is to understand if the business idea:

a. is feasible from technical point of view and in particular if it is possible to access to needed resources and capabilities and to find the needed partners;
b. is desirable by the customers, interested in the value promises of the business model;
c. is viable, that is sustainable in terms of profitability over time.

4.1. Model Validation Methodology

In 2021, Alex Osterwalder proposed an iterative process to validate a business model Canvas, finally to reduce uncertainty and risk. This is mainly based on three steps:

1) Key Hypotheses formulation;
2) Experiments;
3) Key insights generation.

The main idea behind this methodology, is to transform the whole business model into hypotheses covering mainly three types of risks that need to be eliminated for achieving a successful implementation of the business idea:

1) Desirability risk: it is the risk related to the possibility that the proposed business idea is not so appreciated by costumers as it could be supposed initially and that targeted costumers' segments are too small or difficult to reach, acquire and retain;
2) Feasibility risk: this type of risk has to do with the possibility to be not able to build the value proposition due to inaccessibility to key resources needed to perform key activities, or to difficulties in retrieving right partnerships or skills required;
3) Viability risk: it is the risk that the idea is not able to generate enough revenues or presents too high costs to be sustainable over time.

➢ Hypotheses Formulation

Once risks to mitigate are defined, the first step of the methodology defined by Osterwalder consists into the conversion of the Canvas' main assumptions into **testable, precise, discrete hypotheses**. Hypotheses definition has been borrowed by Osterwalder, who defined it as the assumption on which the business strategy is built on and to be used to assess the success of the idea. According with the author, hypotheses are testable if they can be classified as "true" or "false", are precise if it is possible to produce insights from the fact that it is "true", are discrete if it is perfectly described in a distinct way the topic under investigation.

Basing on these suggestions, for each building block's assumption of the model some hypothesis were generated and can be showed in the picture below:

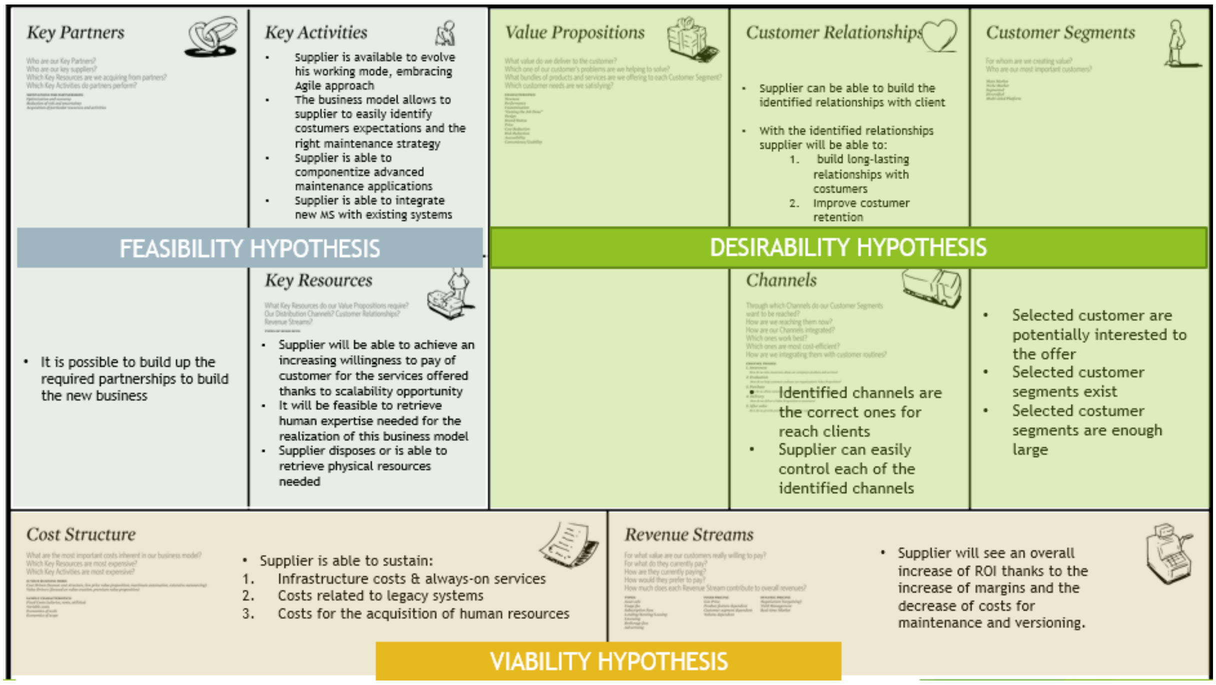

Figure 19 - Hypotheses for Business Model Canvas

Value proposition contains market risk in both value map and customer profile, for this reason, other hypotheses on desirability have been separately assessed from the rest of Canvas.

Hypothesis, for simplicity, have been categorized into six main categories: three for value map and three for costumer profile. Hypotheses for costumer profile are the following:

a. **We are considering the right costumers pains**
   a. Actual advanced maintenance business models need much time to be implemented (long delivery time pain);
   b. Not easy for a company to find the amount of money requested for implementing a whole solution in one shot;

c. Actual advanced maintenance solutions are not flexible when there is a change in the process or in the product in scope of the monitored equipment;
d. Adding new functionalities or changing some existing ones to actual maintenance systems (e.g. new tools able to visualize information easily) accordingly to changing needs, is a request that cannot be always fulfilled by supplier;
e. Operators have low confidence in such new technologies and need time to be trained and to adopt new maintenance paradigms. Scale systems progressively from a complexity point of view could be useful for the learning process and could contribute to take more confidence in the new systems;

b. We are considering the right costumers gains

a. The possibility to add new functionalities in an agile way to existing maintenance systems according with its need could be interesting for costumer (**customization of advanced maintenance**);
b. Actual advanced maintenance business models need much time to be implemented (**Fast development & Fast roll-out of the solutions**).

c. We are considering the right costumers needs

Hypothesis for Value Map are the following:

d. Our services reduce costumers' pains

a. **Replaceability and High manageability** of MS allow flexibility to add new MS without compromising the architecture, reducing time-to-market;
b. **High scalability** allows to progressive scale solutions, allowing clients to familiarize with new systems and to be built on customers' budget availability;
c. **High flexibility** of solutions over time to support change management and address changing needs over time.

e. Our services create an advantage for clients

a. High **reusability** of MS, that can be re-applied and eventually adapted easily to other solution;
b. Easy and fast deploy thanks to **duplication** (cloning) of MS.

f. Our services are an high-value solution for costumers' jobs

The second step, according to the procedure proposed by Osterwalder, consists in the **hypotheses prioritization.** To complete this phase, Osterwalder uses the "**Assumptions Map**", a tool that allows to prioritize some assumptions than others basing on two factors: their importance and the existence or the absence of evidences. The tool is composed by 4 quadrants where each hypotheses are located. In particular, assumptions can be located in:

1) Top-left quadrant: such hypotheses are important but they have evidence. What Osterwalder proposed for these assumptions is to challenge the evidences to be sure that they are strong enough, but in general they can be skipped with the condition to keep track of them over time;
2) Top-right quadrant: these hypotheses are the ones on which focus on, they need to be experimented since they are important but there is no evidence and so they can represent a risk
3) Bottom-left or right quadrant: they are both quadrants in which each hypothesis is not relevant and according to the side, it can have or not evidences. These hypotheses are not worrying and for this reason, there is no need to go deeper with them.

Similarly to what proposed by Osterwalder, the previous hypotheses have been assigned to the quadrants. For simplicity of visualization, two different assumptions maps were generated: one for feasibility and viability hypotheses and one for desirability hypotheses.

➢ Hypotheses Categorization

As already said, hypotheses have been divided and position in the 4 quadrants considering their importance and the presence/lack of evidences to support them. In following pictures it is possible to see the results of such categorization:

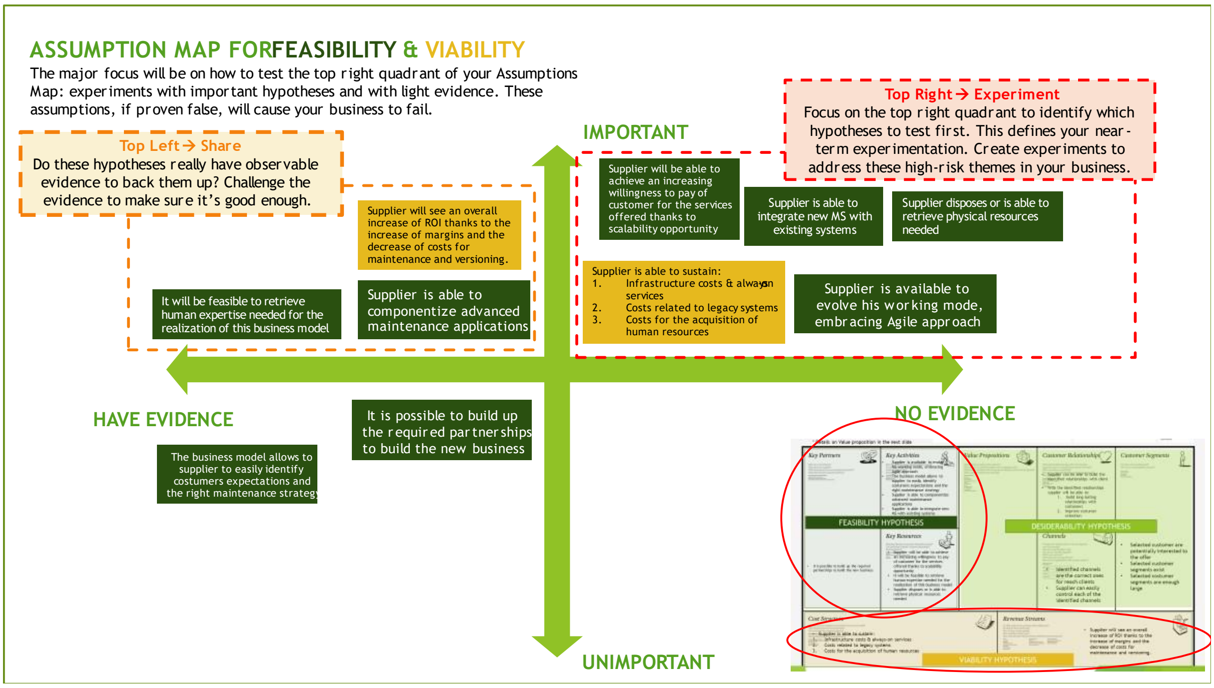

Figure 20 - Assumption Map for Feasibility and Viability Hypotheses

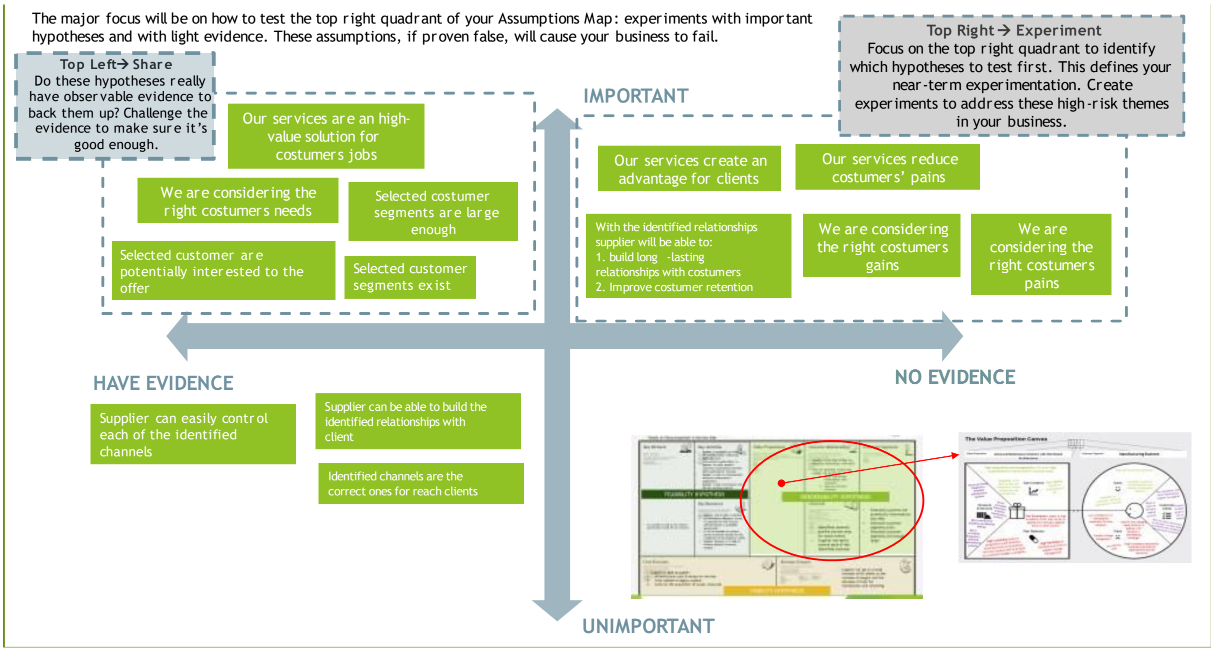

Figure 21 - Assumption Map for Desirability Hypotheses

In the positioning of the value map (pain relievers and gain creators hypotheses) and costumer profile (pains and gains), it was consider the poor exploration of the topic and the fat that such hypotheses were very specific to the idea proposed and for sure, they have not been supported by any evidence yet. On the other side, the interest of the customers and the effective capability of the proposed solution to solve his pains and to generate value, are on the basis of the business model itself and for this reason they were judged important.

Another similar consideration was done for hypothesis about customer relationships. Costumer relationships are considered fundamental from a business perspective since they increase sales by increasing customer retention and attrition [53] and it is also considered "***the key to the long-term success of a business***" [54]. Although many affirmed relationships' importance in a generic business, customers relationships seem poorly explored when speaking of maintenance business models: once again, customization in advanced maintenance has not been conceived and so, customers' involvement in the different phases of the project, has never been taken into account. For this reason, it was considering interesting to bring to the light customer point of view on the actual relationships he has with suppliers and the hypothesis was located on the top right quadrant of the assumption map.

For as it concerns the remaining desirability hypotheses on the top-left quadrant, for some of them it was supposed that they could be deduced by some ones located in the top-right quadrant, if verified. For example hypothesis 6 (*Our services are an high-value solution for costumers jobs)* is directly derived from hypotheses blocks 3.1 and 3.2: if all those related hypotheses are verified, and so if the idea is able to create advantages for customer and to relieve his pains, surely the services offered will be considered as high-value services. Also hypothesis 3 can be automatically deduced by the correct identification of customers pains and gains (that will be tested later on).

Similarly, another direct consequence of the verification of previously mentioned hypotheses, is the interest of customer to the offer itself, and so also the evidences of hypothesis *"Selected customer are potentially interested to the offer"*, can been deduced by the results.

Staying in the same building block (Customer Segments), following hypotheses:

- *Selected customer segments exist*
- *Selected costumer segments are large enough*

Can be easily confirmed by literature and online search. Already Lee in [33], divied the market in the identified costumers segments and assessed theirimportance. With particular reference with the segment on which this thesis is mainly focused, is sized about $8.8tr in US in 2022 [55], with a growth rate of 14.2% in 2022.

Considering that suppliers already provide maintenance for their customers and sell their equipment, it is supposed that customer is already able to control the mentioned channels and to build relationships with him. For this reason, there are some hypotheses that already have strong evidences and don't need a further exploration, such hypotheses are the ones located in the bottom left quadrant of the assumption map.

For as it concerns the assumption map for feasibility and viability, all the top left quadrant hypotheses find evidences by literature. While the hypothesis about the possibility to easier identify costumers expectations and the right maintenance strategy is a direct consequence of the customization capabilities of the business model itself: if customization potentiality of this business idea is confirmed by costumers and suppliers, also the mentioned hypothesis will be confirmed.

For as it concerns the hypothesis about required partnerships, it was considered unimportant since many companies can run the business without moving to cloud, building the whole infrastructure on premise. In any case, to be sure about this assumption, it was included in the testing phase, although not needed for this type of hypotheses according to Osterwader's procedure.

➢ Experiments

The major focus has to be put on the top right quadrant of each assumption map: where are located the important hypotheses that do not have any evidence and need to be tested. The procedure proposed for testing such hypotheses consists on two main steps:

a. Design experiment: means that the right experiment approach should be defined
b. Run experiment: it is the process aimed to generate evidences.

An evidence able to support hypothesis can be data, facts, quotes provided by relevant roles or observable behaviour, such evidences will be used to validate and confirm previous defined hypotheses. Different experiments types create different evidences, that could be strong or weak.

Osterwalder in his work, defined clearly which types of experiments generate strong evidences and which ones generate weak evidences. In any case, the author assessed that the hypothesis confidence level increases with the number of iterations performed and it is not strictly related to the strengths of evidences obtained. It is important to highlight that in this thesis, just one iteration of the process has been performed since the work can be intended as a business idea that is not ready for be moved to an implementation level. Anyway, it can be considered as an early exploration of the topic that could be used as starting point for more structured business models. For this reason, also the validation purposes of this work are more focused on the reduction of the main identified feasibility, desirability, viability risks than their elimination. Osterwalder itself, in his work, claimed that first experiment should be "quick and cheap" at the beginning, since the strength of evidences will be increased by running multiple experiments for the same hypothesis over time. Uncertainty & risk, as showed in the following picture, decreases with the proximity to execution of the idea and at the same time, also the effort to test the solution (cost and time) increases by getting closer to execution moment.

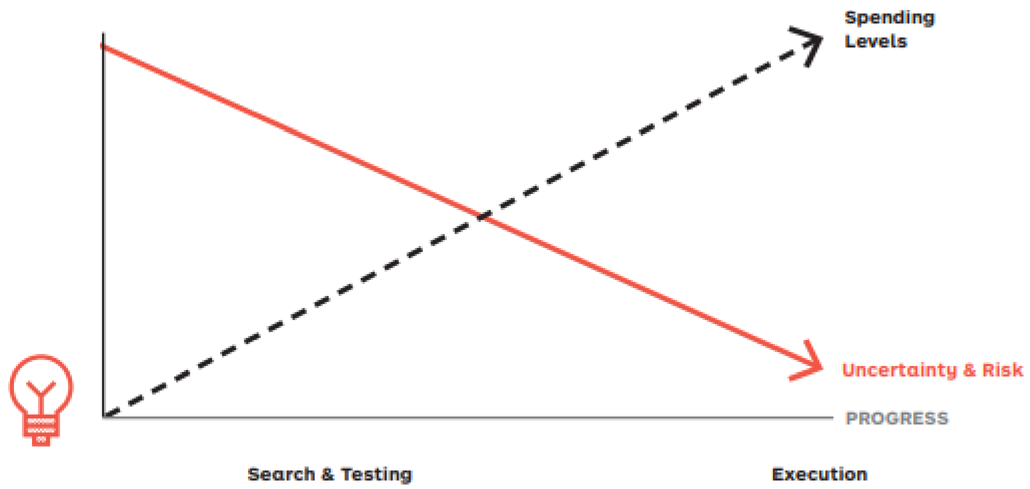

Figure 22 - Uncertainty & Risk reduction Progress

For this reason, in this thesis, validation of results must be contextualized in its "discovery" phase, for which weak and medium evidences are sufficient to discover if the general direction of this work is right and to produce useful insights that could be confirmed with further stronger tests.

For the testing phase, two companies were engaged: a company operating as manufacturer in the B2C market manufacturing business), involved as a possible **customer** to whom the offer could be addressed; and another company operating in the B2B context, involved as **supplier** (it is an industrial machinery company). For the latter, in particular, it was needed to involve two different departments: R&D department and Marketing & Sales departments, wit two different purposes better explained in the next paragraphs.

For as it concerns, experiments methods, they were selected between the ones proposed by Osterwalder in his work [52], who provides a list of possible testing tools indicating for which risks (desirability – feasibility – viability) each of the proposed testing strategy is suitable. Each experimentation method, in fact, is evaluated (from 1 to 5) on followings criteria: cost, setup time, run time, evidence strength. For this business model, followings methodologies were selected:

- **Costumer survey**: this method was selected with the aim to confirm an effective interest on the solution from the costumer and to address the main value proposition's hypotheses. Costumer survey is considered to be low-cost, quick and provides a weak evidence. To increase the strength of output evidences, also the stakeholders interview were associated to address desirability hypotheses.
- **Expert Stakeholder Interviews**: taking as reference Osterwalder's methodology, expert stakeholders are intended as a particular category, defined considering their specific role and related sensitiveness, even if they are on the side of the supplier's company. They are representatives of the R&D department of the supplier. According with Osterwalder, expert stakeholders interviews can be useful to determine if a desirability and feasibility risks can exist and provides a medium level of evidence strength and requires an high time to be executed. The R&D department is then involved, as a role more sensitive to the technology development and only partially related to the customers' interface.
- **Marketing & Sales Department Interviews**: finally, this type of experiment was conducted to eliminate the identified relevant risks on viability side, providing an high level of evidence strength and requiring an high run time.

Interviews' purpose was to verify the hypotheses already discussed in previous section and provide missing evidences. As highlighted by Osterwalder in his work, top right quadrant hypotheses MUST be all verified: **if one hypothesis is not confirmed**, business idea will fail. Top left hypotheses don't need to be tested.

The results are respectively presented in section 4.2 and 4.3.

4.2. Suppliers Interviews Results

Company involved is a world leader in the design and production of automatic machines for the processing and packaging of pharmaceutical, cosmetic, etc products. As already said, for the suppliers interviews 2 different departments of the same company were involved, they are:

- Marketing & Sales (supplier interviews)
- R&D department (expert stakeholders interviews)

The type of interview was a face-to-face typology with open questions (see Appendix A). This choice has been made in an exploration optic since, as already mentioned, the scope of this investigation was not only related to the research of evidences to support the business idea and to check if the right hypotheses have been made, but its aim was also having an open discussion in order to collect as much as possible feedbacks from experts to provide a valuable contribution for further studies. Open questions and face-to-face interviews have been evaluated as particularly suitable to this scope.

➢ Marketing and Sales Department Interviews

Starting from **marketing and sales department**, the purpose of the interviews was to address the viability risk of the proposed solution, in particular the analysis was focused on the confirmation/rejection of the following hypotheses:

1. *Supplier will be able to achieve an **increasing willingness to pay** of customer for the services offered thanks to scalability opportunity*
2. *Supplier is able to **sustain identified costs** (Infrastructure costs & always-on services, costs related to legacy systems, costs for the acquisition of human resources and partnerships)*
3. *Verify the choice to assume the hypothesis of building key partnerships **as evident and not important**, is true (equivalent to say, is this choice a true or false assumption?).*

The first question was aimed to assess the capability of a distributed solution for advanced maintenance to increase the interest of the costumer, from the perspective of marketing division of supplier. It was asked if interviewees think that the possibility to scale maintenance solutions, thanks to microservices, can contribute to increase costumers' confidence and make it willing to invest more and more in new analytics tools and e-maintenance systems. All the 3 interviewees answered positively and, in particular, one affirmed that customization and scalability of predictive maintenance are ***"the best and the most promising scenario"*** from a marketing point of view. Moreover, it is emerged that from the moment in which the company adopted digital solutions and started to deploy e-maintenance services in a distributed manner, it was possible to include scalability in the company's strategy, but this requires lot of time and a certain level of complexity: to reduce it and increase costumer engagement, it is

always provided the advanced maintenance solution and how it will evolve in the long period.

In the second question, it was provided to interviewees an estimation of the average salary (taken from some internet references) for each key human resource to be acquired in case they were not yet present in the organization, and it was asked if company was able to sustain the mentioned costs. All the interviewees assessed that the **mentioned roles were all already present in the company and internally acquired**. Solution architect, system integration engineer, cyber security specialist and network engineer are figures present at central IT level, even if not dedicated to each company's division. Considering the need that brought the company to invest in such roles, the interest of the company to acquire these roles is clearly confirmed and consequently, it is verified the assumption stated in the assumption map, i.e. **their importance for this business model**.

The third question was aimed to validate the availability of the company to invest in infrastructure and always on services, required for the development of micro-servitized e-maintenance solutions. In particular, it was asked if company was available to face costs related to the migration of legacy systems, distributions and hosting infrastructure, monitoring tools and test suites. All the interviewees affirmed that their company **has invested a lot during last years in digital field and keep to invest**. Moreover, one of them, declares to see **digital as a new business opportunity**, and that IT advancements like micro-services are providing interesting results from a business perspective, thanks to their use in different technological fields not only in predictive maintenance solutions development.

The fourth and last question was focused on understanding supplier's perspective on the key partnerships. The answers in this case provided followings evidences:

- Company under exam has **already migrated all the solutions in a cloud platform**, both private and public (provided by external actors), from which is derived the possibility for suppliers to establish partnerships with cloud providers
- Cloud is considered a key resource for this business model for 2 out of 3 interviewees
- The hypothesis about partnerships, initially considered as a "not important" assumption for running the business model, appears to be important.

Expert Stakeholders Interviews

The interviews addressed to **R&D department** were aimed to provide evidences about the hypotheses developed from this perspective on the topic. Therefore, the main objective was to support hypotheses about the **technical feasibility** of the solutions, but the same roles were involved also as **expert stakeholders** to provide information about the advantages that the solution can bring on costumers' side.

Starting firstly from technical feasibility, the hypotheses to validate are the followings:

1. *Supplier is* ***able to integrate new MS with existing systems****;*
2. *Supplier* ***has available at hand or is able to retrieve the physical resources needed****;*
3. *Supplier* ***is available to evolve his working mode, embracing Agile approach****.*

To evaluate the first hypothesis, a specific question was formulated in regard to the most complex activities to consider when advanced maintenance solutions are developed using micro-services. One interviewee out of three, claimed that the **integration is the most difficult key activity** when speaking about micro-servitization: it can be difficult to manage especially when new micro-services should be integrated in already existing legacy systems. In this case, integration is very difficult, and solution should be totally re-thought in a micro-servitized way. This requires **high delivery times,** and this effort is not always clear and visible to costumers.

Another interesting aspect about integration that emerged is the difficulty to use the same software and technologies (**integration with existing infrastructure**) when adding new micro-services to an existing architecture. On the other side, 2 interviewees did not consider integration among the most complex activities: both of them affirmed that the major issue is related to **data availability and collection**. In any case, although the pain points emerged during interviews, **none of them said that integration is not possible**. So, we can conclude that hypothesis of integration feasibility is confirmed, but on the other side, in the business model another emerged key activity needs to be added since considered as critical: data acquisition and availability.

The second hypothesis aimed to verify if the supplier already owns or has the possibility to buy the needed physical resources to build the presented business idea. All the interviewees answered that **they actually dispose of a service contract for ensuring always-on (24/7) services**. They also affirmed that **they already have the computing power needed to support the advanced maintenance micro-services exploiting cloud computing** (all their solutions are already migrated on cloud).

Finally, last hypothesis assessed that the supplier is available to evolving its working mode, embracing agile approach. The knowledge of agile framework cannot be given for granted, although some companies operate with a very similar approach to the agile one, even if they do not know exactly the principles.

For this reason, firstly, it was asked if the interviewee knew agile framework and if not, it was investigated the actual development and working mode of supplier. As result, all interviewees did not know agile framework as expected, but from the interviews emerged that they actually have a very close working mode to agile approach. In fact, they affirmed to develop by realising the whole solution progressively with **small periodic releases** (minimum viable products in agile), with an high costumer involvement only during development especially in the case in which predictive maintenance is applied on complex machines. In such cases, interviewee claimed that **costumer participation is fundamental** during ideation and progressive creation of the model. Costumer involvement and iterations are considered basics for agile adoption. So, it is possible to conclude that supplier is to some extent ready to switch totally to adopt agile working mode.

Similarly to what already said for agile, all declared to not use DevOps tools and procedures not for inaccessibility reasons, but for a knowledge or lack of information about DevOps. This, from one side, eliminates the risk of unfeasibility due to eventual inaccessibility to the resource, but on the other side, it highlights the poor interest on this topic that, before evaluating the importance and utility of DevOps adoption, should be filled.

As already specified, the same actors were involved as expert stakeholders to validate some other aspects related to the value proposition. In particular, questions were formulated in order to verify if the proposed services are able to create an advantage for clients and if they are able to reduce costumers' pains.

1. **"Our services create an advantage for clients"**
    a. ***High reusability*** *of MS, that can be re-applied and eventually adapted easily to other solution*
2. **"Our services reduce costumers' pains"**
    a. ***High flexibility*** *of solutions over time to support change management and address changing needs over time*
    b. ***Replaceability and High manageability*** *of MS allow flexibility to add new MS without compromising the architecture, reducing time-to-market*
    c. ***High scalability*** *allows to progressively scale solutions, allowing clients to familiarize with new systems and to be built on customers' budget availability*

The discussion about how micro-servitization can improve predictive maintenance services creating advantages for costumers with expert stakeholders was interesting and brought many contributions to this work. In particular, one of the people interviewed said that in his opinion, micro-services can be applied to predictive maintenance and in this case, advantages for clients include an **high scalability**, since it is possible to modify single microservices without modifying the others according to future needs or adding or removing specific micro-services. Moreover, in his opinion, supplier can improve the management of multiple projects thanks to the fact that some specific microservices can be re-used for different projects when deployed and this can bring to a **reduced cost for clients**.

All the three interviewees think that design & deploy e-maintenance systems using micro-services can make applications more flexible and adaptable to changing needs over time, because they "*modify, add and remove further micro-services to the already developed ones with the minimum effort*".

Regarding the possibility to make advanced maintenance solutions customized on costumers' needs, one interviewee only affirmed that clients look more at rapid and concrete results, rather than an high customization level. Another interviewee affirmed that **customization opportunity stays more in the scalability characteristic** and in the **possibility to add new functionalities**, but until now supplier has not yet increased its services portfolio including other types of analytics services. This could highlight an important hidden evidence: supplier has always been focused on improving assets and providing assets maintenance as after-sale offer. With the evolution of technologies, he has progressively started to see in maintenance services an important business opportunity for which post-purchasing services could provide high value to product themselves and he has started to specialize in e-maintenance. It seems, now, that supplier has not seen until now any other opportunity more related to analytics that could be furtherly added to the maintenance services offer, furtherly increasing the value transferred to clients. In other words, **it is required another important effort from supplier's side, aimed to enlarge services portfolio**.

Finally, considering costumers' pains, to the question "Have you ever noticed an initial scepticism in the customer for the proposed predictive maintenance services that deviated from the traditional maintenance model?", all the interviewees answered that they recognised this **scepticism on clients with respect to prescriptive/preventive maintenance business models** and added that in many cases costumers require some other business cases similar to their scenarios. Another interviewee affirmed that models that are based on statistical rules are usually classified as difficult to be applied and require an high number of meetings to explain deeply the main functionalities, confirming one of the identified costumers' pains.

Moreover, one interviewee affirmed that distributed predictive maintenance is not immediately perceived as a value, unless the supplier is not proposing microservices previously developed at a minor cost. In this context, **releasing progressive and periodic "packages" of the solution over time, increases confidence to adopt new smart maintenance models in costumers** and allow them to notice progressively concrete results, so that first advantages are more evident.

4.3. Costumer Survey Results

Costumer survey was addressed to digital manufacturing department of a manufacturing business company (B2C) operating in the tobacco industry and adopting the industry 4.0 paradigm. Population involved consisted of 10 people between data scientists, deployment leaders, digital manufacturing leads and process engineers. The aim of this analysis was to test desirability from the costumer's side.

In particular, survey (that can be seen in appendix B) has the aim to verify that in this work the right costumers' gains and pains were identified and going deeper also analysing the quality of the the relationships that supplier has with his costumers.

1. ***"We are considering the right costumer gains"*:**

The first gain that are tested are herein reported:

a. *The possibility to add **new functionalities** in an agile way to existing maintenance systems according with its need could be interesting for costumer (customization of advanced maintenance)*

Such hypotheses have been already validated as results of expert stakeholders interviews seen before. Stakeholders, in fact, affirmed that scalability make possible to buy some micro-services already deployed at minor costs, or to add new functionalities in a progressive way. Assuming costumers' perspective:

- 50% of interviewes said that it was never asked to add new tools to an existing predictive solution;
- the 40% declared that when this need arose suppliers was able to respond at the right time;
- the remaining 10% (just 1 interviewee out of 10) declared that when new functionalities were required, supplier implemented the new features but with a longer delivery time than expected, saying also that the new functionalities implementation was longer than the initial maintenance model itself.

The fact that 50% of the involved population declared to have never asked new functionalities to implemented in an existing solution, can be explained by different hypotheses. First of all, budget availability was enough to buy the whole solution without any need to scale it over time; secondly, in those cases, no particular customization needs emerged.

In any case, it is important to underline that the remaining 50%, admitted that with actual advanced maintenance solutions, **suppliers are not able to follow company's changes and they demand a more "customizable" offer in maintenance and analytics**.

b. *"Costumers need to receive solution on time and to deploy them quickly on all the lines (fast development & fast rollout)"*

According to survey's results, the 90% of interviewees considered not satisfying the delivery time of the advanced maintenance solutions require. Generally speaking, by motivating the answer saying that **it takes too much time to move from the idea generation to industrialized solution** and that it should be likely to have a more **timely response on business needs**. Such high percentage of results confirmed that the high delivery time is a pain for costumers.

2) We are considering the right costumers pains

The pains that are tested are herein reported.

a. *"Not easy for a company find the amount of money requested for implementing a whole solution in one shot"*
b. *"Operators have low confidence in such new technologies and need time to be trained and to adopt new maintenance paradigms. Scale systems progressively from a complexity point of view could be useful for the learning process and could contribute to take more confidence in the new systems"*

The 50% of costumers, noticed that, especially at the beginning, operators had **low confidence in the new technologies** and needed time to be trained and to adopt the changes. The 40% of interviewees, instead, said that adoption not only is an issue for operators who use the final solutions, but it is also difficult to convince managers to invest in such type of products. Only the 10% affirmed to not have faced any issue on adoption perspective. Results brought to the light followings insights:

i. The initial customers' scepticism with regards to new advanced maintenance paradigms, previously discussed with suppliers, seems to be confirmed by the 40% of interviewees who affirmed the difficulty to convince managers to invest in advanced maintenance. Management, in fact, is sceptic about the benefits that could be achieved by adopting new advanced maintenance services and so, budget addressed to e-maintenance is limited or not available at all. Hypothesis 2.a is then definitively confirmed.
ii. On the other side, the 50% of interviews affirmed that adoption barrier comes from operators. In particular, here the identified cause is related to the difficulties that people on floor can face when dealing with advanced maintenance tools.

As already assessed by supplier, scalability can definitively contribute to minimize both identified scepticism about expected benefits and adoption barrier caused by unknowledge and untrust in the tools themselves, by increasing confidence over time.

From one side in fact, scaling solutions means to invest progressively and allow management to see little improvements and benefits, pushing them to invest more and more. On the other side, scalability allows to move from relatively simple tools easy to learn in the short period to more sophisticated and complex ones in the long period, providing a time window in which operators can be trained and acquire confidence with the tools. So, we can conclude that also hypothesis 2.b was verified.

c. *"Actual advanced maintenance solutions are not flexible when there is a change in the process or in the product in scope of the monitored equipment"*

In survey, it was asked to express the satisfaction level about the level of flexibility (adaptability of the existing system to new process or different products worked by the machines) offered by company's supplier in terms of predictive maintenance solutions acquired and to motivate the choice. **More than the majority of interviewees felt dissatisfied about actual level of flexibility provided**, motivations are different: one interviewee affirmed that in its opinion, normally suppliers are not ready enough as they do not have the embedded functionalities in the machines and this makes poorly agile to adapt the model to business processes changes. Another interviewee affirmed that the poor flexibility, in his opinion, is more related to the fact that not all vendors have the same knowledge and skills in advanced maintenance solutions development, so it is to early for some suppliers to speak of adaptability and flexibility of advanced maintenance solutions, since they are still "early movers" in this business.

Another important aspect that emerges is the consideration that more than one interviewees brought about the **lack of equipment standardization**: they affirmed that flexibility cannot be reach easily by suppliers since same machines of one unique vendors are often released in production in different moments and present different connectivity packages, different data formats and data models, and this delays significantly projects timelines. Complementing that **some specific systems are very hard to be adaptable** since they require to implement new functionalities not included since the design phase of the solution and rarely supplier is able to integrate them.

d. "Adding new functionalities or change some existing ones to actual maintenance systems (e.g. new tools able to visualize information easily) accordingly to changing needs, is a request that is not always is fulfilled by supplier"

Last topic, was elaborated by asking costumers if they have ever requested to their suppliers to provide new functionalities or improvements to add to the already implemented solution. Here the heterogeneity of the answers can be explained by the different roles and so by the different type o project interviewees deal with in their day by day activities. Among the interviews, in fact, it is possible to distinguish between roles having more to do with predictive maintenance solution projects and roles which followed mainly analytics related projects (mainly visualization tools implementation or other software more decision-making oriented and not related to production floor).

To the question, the first category of roles (40%), answered "*Yes, but supplier answered that the whole existing solution had to be substituted completely with the new one with another new investment required*". 10% answered "others" specifying that yes, they asked new functionalities after the deployment of the solution itself, but they experienced too long delivery times.

3) With the identified relationships supplier will be able to build long-lasting relationships with costumers and improve costumer retention

In the model conception, it was described how it is necessary to establish with costumers 3 types of relationships according with each project phase. Such relationships have been judged important for the successful implementation of the business idea because considered as a basis for successfully deliver customized solutions and scalability to clients. This hypothesis was based on the strong belief that supplier with current maintenance business model do not need costumer involvement, since solution is delivered directly to the costumer, without monitoring the level of costumer satisfaction and checking if needs are still the same or have changed over time.

To confirm or reject this hypothesis, in costumer survey was included an open question aimed to analyse the level of costumer satisfaction about their relationships with vendors. Results showed that the majority of interviewees (90%) was satisfied about the vendors' approach, recognising an high professionality, interest in costumer's needs and responsiveness. On the other side, the same affirmed that relationships, in the phases after solution implementation (after-sale), are usually limited to provide support to client in case it is needed. Only the 10% felt dissatisfied about relationships with vendors since "*they normally spend huge amount of time to engage vendors without having a real output. It seems that they do not have any interest to improve maintenance approach or to offer something more*".

It is clear from the answers that, even if the majority of respondents felt satisfied, **the relationships are not aimed to engage costumer over time and considering the possibilities exploited by micro-services**, limiting relationships to run and support could be a **lost opportunity cost** for the supplier from a business perspective, due to the fact that suppliers don' exploit the opportunity to sell new services. Moreover, in 10% of cases is perceived as "lack of interest to improve and to follow costumers' needs".

4.4. Concluding Remarks

Results of this last phase definitively confirmed the need, emerged from literature review, of a customizable (flexible and scalable) advanced maintenance both from supplier and costumer perspectives, adding some other important data that can be interpreted as follows:

- supplier, in this case, was ready enough to switch to the new business model strategy, especially from a mindset and resource acquisition point of view. It, in fact, has already acquired human skills needed internally, confirming the assumptions done in chapter 3 on the importance of required figures for running the proposed model and providing evidence that those required figures, although most of them are quite new in manufacturing panorama, can be retrieved and acquired.
- Digitalization and servitization, as deducted from quantitative analysis of literature, are assuming an increasing importance: both B2B and B2c, for different reasons and with different scopes, recognise their importance and invest a lot in new projects, resources, capabilities and technologies.

- Integration is considered by supplier, as expected, one of the most difficult key activity to deal with when advanced maintenance solutions are developed via micro-services. In particular, differently from what initially considered, two types of integrations should be taken into considerations:
    a. Integration with existing systems/micro-services, (both legacy and distributed ones, where the level of integration complexity decreases the more we move towards distributed architectures), especially for pipeline processes characterized by many dependencies like PHM
    b. Integration with in-use technologies and infrastructure: adding new functionalities can have hidden costs that should be included in the proposed business model and that are related to investments in other technologies or tools required (Databases, new types of orchestrators, etc.)
- Supplier interviews confirmed the expected benefits already mentioned in the value proposition (paragraph 3.2), including the fact that the cost for the addition of new functionalities can be reduced thanks to reusability of microservices
- Both supplier and costumers confirmed scepticism and difficulties in advanced maintenance solutions adoption. In particular, supplier affirmed the need of costumer to "touch with its hands" the solutions before acquiring. Supplier agreed that scaling those solutions, possible thanks to MS, can help in reducing this costumer pain: further progressive and periodic releases over time increases confidence to adopt new smart maintenance models in costumers, giving the possibility to see progressively concrete results and first advantages are more evident.
- Both supplier and costumers affirmed that delivery time is a very important aspect when speaking about advanced maintenance. In particular, supplier admits that modifications and releases are not fast to achieve, and this effort is not understood by client that instead felt unsatisfied about actual delivery times, affirming that new functionalities requires more time than re-built the whole existing solutions in some cases. Supplier assessed that, thanks to re-usability, high manageability and duplication possibility provided by MS, they should be able to develop and deploy faster, reducing time-to market and increasing their capability to quick innovate and respond to costumers needs.
- An important confirmation arrived from customers side: suppliers are not able, with actual maintenance business models, to follow company's changes and they would receive a more "customizable" offer in maintenance and analytics. Additionally, clients would have an higher level of flexibility of advanced maintenance, that they have not seen yet affirming that if the requirements change and new functionalities are needed, existing predictive models have to be substituted completely with a new one requiring new huge investments.

Finally, relationships with clients for such business model are fundamental for both customers and suppliers. Costumer must be involved in all the phases of the projects and to engage him and stimulate its interest is necessary, as affirmed by supplier, to provide him short-medium-long period visions.

In the following tables the main results are summarized:

DESIRABILITY HYPOTHESES	RESULTS	CONCLUSIONS
• High flexibility of solutions over time to support change management and address changing needs over time • Replaceability and High manageability of MS allow flexibility to add new MS without compromising the architecture, reducing time-to-market	• Suppliers "*modify, add and remove further micro-services to the already developed ones with the* ***minimum effort***".	• All mentioned hypotheses are definitively confirmed thanks to suppliers' considerations emerged by interviews
High scalability allows to progressively scale solutions, allowing clients to familiarize with new systems and to be built on customers' budget availability	• clients look more at rapid and concrete results, rather than a high customization level • supplier has not yet increased its services portfolio including other types of analytics services	• customization opportunity stays more in the scalability characteristic and in the possibility to add new functionalities • supplier has not seen until now any other opportunity more related to analytics that could be furtherly added to the maintenance services offer
High reusability of MS, that can be re-applied and eventually adapted easily to other solution	• Supplier confirmed that some specific microservices can be re-used for different projects • Reusability brings reduced costs for clients	• Reusability hypothesis is verified and provides the expected benefits, according with suppliers
With the identified relationships supplier will be able to build long-lasting relationships with costumers and improve costumer retention	• the relationships instaured with clients are not aimed to engage costumer over time and considering the possibilities exploited by micro-services, this for the 10% is perceived as "lack of interest to improve and to follow costumers' needs".	• Relations are important for this business model, not only to improve costumer retention but also to enhance the revenues opportunities

Table 4 - Results for Desirability Risk Analysis

DESIRABILITY HYPOTHESES - COSTUMERS PAINS	RESULTS	CONCLUSIONS
• "Not easy for a company find the amount of money requested for implementing a whole solution in one shot" • "Operators have low confidence in such new technologies and need time to be trained and to adopt new maintenance paradigms. Scale systems progressively from a complexity point of view could be useful for the learning process and could contribute to take more confidence in the new systems"	• 40% of interviewees affirmed the difficulty to convince managers to invest in advanced maintenance • 50% of interviews confirmed difficulties that operators can face when dealing with advanced maintenance tools. • 10% affirmed to not have faced any issue on adoption perspective	• Hypotheses made on skepticism and low confidence are correct, in particular, as assed by supplier scalability • can definitively contribute to minimize both identified skepticism about expected benefits and adoption barrier caused by unknowledge and untrust in the tools themselves, by increasing confidence over time
"Actual advanced maintenance solutions are not flexible when there is a change in the process or in the product in scope of the monitored equipment"	• More than the majority of interviewees felt dissatisfied about actual level of flexibility provided, providing different possible insights about the causes	• Flexibility is a characteristic required by costumers but not yet provided by the actual maintenance models
"Adding new functionalities or change some existing ones to actual maintenance systems (e.g. new tools able to visualize information easily) accordingly to changing needs, is a request that is not always is fulfilled by supplier"	• 50% of interviews affirmed that supplier is available to add new functionalities but with new high investments required and long delivery times	
DESIRABILITY HYPOTHESES - COSTUMERS GAINS	**RESULTS**	**CONCLUSIONS**
"The possibility to add new functionalities in an agile way to existing maintenance systems according with its need could be interesting for costumer (customization of advanced maintenance) "	• 50% of interviewees said that it was never asked to add new tools to an existing predictive solution; • the 40% declared that when this need arose suppliers was able to respond at the right time; • the remaining 10% (just 1 interviewee out of 10) declared that when new functionalities were required, supplier implemented the new features but with a longer delivery time than expected	• suppliers are not able to follow company's changes and they demand a more "customizable" offer in maintenance and analytics.
"Costumers need to receive solution on time and to deploy them quickly on all the lines (fast development & fast rollout)"	• 90% of interviewees considered not satisfying the delivery time of the advanced maintenance solutions require	• Costumers would have timely response on the needs

Table 5 - Results for Desirability Risk Analysis (Pain & Gains verification)

FEASIBILITY HYPOTHESES	RESULTS	CONCLUSIONS
Supplier is able to **integrate new MS** with existing systems	• One interviewee out of three, claimed that the integration is the most difficult key activity when speaking about micro-servitization • Integration can be responsible of the high delivery times • For none, integration is unfeasible	• It was meaningful including integration as key activity in the business model • On the other side, data availability and collection should be included since, form supplier point of view, it is critical • The hypothesis of integration feasibility is confirmed
Supplier has available at hand or is able to retrieve the physical resources needed	• Supplier already disposes of a service contract for ensuring always-on (24/7) services • Supplier already has the computing power needed to support the advanced maintenance micro-services exploiting cloud computing	• Supplier already disposes of the mentioned key physical resources
Supplier is available to evolve his working mode, embracing Agile approach	• Supplier has not adopted agile framework/DevOps approach yet • Supplier working mode passes through small periodic releases and high costumers participation especially in the design phase	• Since costumer involvement and iterations are considered basics for agile adoption, it is possible to conclude that supplier is to some extent ready to switch totally to adopt agile working mode • Agile/DevOps methodologies are accessible but not known by supplier
Supplier will be able to achieve an **increasing willingness to pay** of customer for the services offered thanks to scalability opportunity	Customization and scalability of predictive maintenance are *"the best and the most promising scenario"* from a marketing point of view	• Scalability should be included in the company's strategy
VIABILITY HYPOTHESES	**RESULTS**	**CONCLUSIONS**
Supplier is able **to sustain identified costs** (Infrastructure costs & always-on services, costs related to legacy systems, costs for the acquisition of human resources and partnerships)	• All the interviewees assessed that the mentioned roles were all already present in the company and internally acquired. • All the interviewees affirmed that their company has invested a lot during last years in digital field and keep to invest • 1 interview over 3 declares to see digital as a new business opportunity	• Hypothesis was verified: supplier effectively sustained the mentioned costs • The key human resources of the business model were correctly identified

Table 6 - Results for Feasibility & Viability Risk Analysis

5 Conclusions & Future Developments

This work aimed to explore the interest on the possibility to improve actual advanced maintenance business models using the potential of micro-services. Moreover, the ultimate purpose of this thesis is to try to fill gaps found in literature about this topic, by proposing an innovative business model for advanced maintenance development.

For reaching these goals, three main researches were conducted:

a. the first initial research aimed to explore the **state-of-art** about predictive maintenance, servitization and micro-servitization and related combinations of concepts, in order to analyse the **interest trend evolution** on these topics over time based on the number of papers found on the most diffused online libraries
b. the second part of literature review proposed a more "qualitative" study conducting by a deeper screening and study of most relevant papers, aimed to **individuate potential gaps or hidden insights** that could reveal potential **business opportunities**;
c. the third research was mainly aimed to **validate and support the proposed new advanced maintenance model** based on micro-services, using a well-know and innovative business idea testing approach proposed by A. Osterwalder in 2021 in which two companies were involved and interviewed in order to offer supplier and costumers point of views on this matter.

This last experiment involved suppliers and costumers in two different ways: supplier was interviewed involving its R&D department firstly, as expert stakeholder to have specific feedbacks about the considerations made on possible benefits and pain points reduction of the business models; secondly, to evaluate a possible unfeasibility risk not emerged during the business idea design. Always on supplier side, also marketing & sales department was involved to test mainly cost structure and revenues streams assumptions.
On the other side, costumer was approached in a different way: through a mixed survey with open and close questions sent to a sample of 10 people with different roles (process engineers, digital manufacturing leads, data scientist, etc).

With particular reference with the last analysis, interviews confirmed that **the actual direction of the presented business model is overall the right one to follow**, but some limitations should be considered. First of all, the number of interviewees is low: the approach followed in this work aimed, in fact, to select more focused roles rather than extend survey and interviews to a wider and variegate population. People involved were all fully aware about the context of this work, presenting a sufficient level of knowledge about the topics in scope that allowed to open discussions. In particular, the low number of respondents, decreased the strength of collected evidences and in order to support the results they were integrated also with stakeholders perspectives.

On the other side, involving people "sensible" to this topic allowed to reflect on same other points not immediately emerged, providing useful insights for future researches on this theme.

Another limitation that should be consider is related to the process used: as already explained, the testing procedure proposed by Osterwalder is iterative. For time constraints, in this work only one iteration was done, but by using more than one testing methods at the time. In any case, this could be interesting as future development iterate the testing process other times, using different experiments with increasing level of effort and evidences strength enriching the idea with other details.

A possible recommendation for future developments is to go deeper in the agile/DevOps adoption when changing the business strategy. As already mentioned, many references speak about the importance of adopting such innovative working approach when developing using micro-services but from interviews has emerged that, although the high maturity level of supplier in micro-servitization and predictive maintenance, he does not have enough knowledge on such approaches. Evaluating if such method can be considered as relevant for build the present business model is out of scope for this thesis, but could be interesting understand if changing the mindset and the working mode can have relevant impacts on complex activities like integration or process decomposition and micro-servitization.

Another consideration that can be made for future studies is that in this work supplier involved, as already said, presented a certain readiness on that matter and for this reason, the majority of key activities, resources and partnerships were already put in place. It could be interesting to conduct other interviews with suppliers that have not the same level of readiness in order to evaluate more precisely if new difficulties can arise. Similarly, also costumer involved had an high maturity level in industry 4.0 and relatives, living in a advanced step of digital transformation and having high budget availability to invest in digital projects. It could be useful to contribute to this initial work, involving also small and medium enterprises to test their interests and needs and see if micro-services can boost the digital transformation process and support them in changing their maintenance paradigm.

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Acknowledgments

Inizio con il ringraziare il prof. Marco Macchi per aver creduto nelle mie capacità sin dall'inizio di questo lavoro. Lo ringrazio in particolare per la passione e le conoscenze che mi ha trasmesso verso la manutenzione predittiva e, più in generale, verso il mondo dell’industria 4.0. La sua guida e i suoi consigli mi hanno accompagnato attraverso tutte le fasi della stesura della tesi e mi accompagnano quotidianamente nella gestione de progetti del mio attuale lavoro.

Ringrazio inoltre Alessandro Ruberti e Adalberto Polenghi per avermi sostenuta e motivata fino alla fine del progetto, proponendomi spunti, riflessioni e consigli fondamentali per la riuscita di questo lavoro.

Ringrazio la mia famiglia, a cui dedico questo traguardo, per la forza che mi hanno sempre trasmesso e per aver sempre creduto in me più di quanto lo abbia fatto io.

Ringrazio gli amici più cari: Federico, Gaetano, Roberta, Federica, Chiara, Ivana, Sowjanya, Cristina, per il supporto e la carica motivazionale datami, per la loro sincerità, il loro affetto gratuito, i loro consigli mai scontati e soprattutto la vicinanza nei momenti più difficili. Mi avete davvero resa una persona migliore, grazie.

Infine, ringrazio me stessa, forse per la prima volta. Perché credo profondamente in quello che faccio, per l'ostinazione e la dedizione che oggi mi hanno portata fino a qui.

A Appendix A

A.1. Costumer Survey

1. How much are you satisfied about the **delivery time** of actual Advanced Maintenance solutions (e.g. predictive maintenance models, monitoring systems, adding-value tools…) provided by your suppliers/machine vendors?

   a. Very satisfied:
   b. Satisfied
   c. Dissatisfied
   d. Very dissatisfied

   Please, motivate your answer:

2. Has your company ever faced difficulties in the **adoption** of advanced maintenance solutions?
   a. No, in my company advanced maintenance has been fully adopted since its implementation without particular difficulties
   b. Yes, at the beginning operators had low confidence in such new technologies and needed time to be trained and to adopt new maintenance paradigms
   c. Yes, it was not easy convince my managers to invest in such kind of projects
   d. Yes, for both of the previously mentioned reasons

3. Have you ever asked supplier to **deliver progressively** advanced maintenance functionalities and/or specific analytics tools in the initial phase of the project? If yes, why?

   a. No, I never had the need to ask a partial/progressive delivery of the whole offer.
   b. Yes, I asked only some specific tools or less sophisticated e-maintenance solutions for budget availability related reasons, with a future possibility to add new functionalities or to evolve the advanced maintenance model in the future
   c. Yes, I asked supplier a less performant advanced maintenance system because I was sceptical about its benefits and I needed a period to acquire confidence with the new tool

d. Other: ____

4. Are you satisfied about the **level of flexibility** (adaptability of the existing system to new process or different products worked by the machines) of the actual suppliers' offer for advanced maintenance?

   a. Very satisfied
   b. Satisfied
   c. Dissatisfied
   d. Very dissatisfied

   Please, motivate your answer:

5. Have you ever asked supplier to provide **new functionalities/improvements to already implemented** maintenance systems (e.g. new tools able to visualize information easily) consequently to new needs arose?

   a. No, I never asked new tools/improvements as additional to the existing e-maintenance projects
   b. Yes, supplier implemented the new functionality/improvement without any difficulty and in the right time
   c. Yes, but supplier answered that the whole existing solution had to be substituted completely with the new one with another new investment required
   d. Other: ____

6. Do you think that the actual suppliers' offer for advanced maintenance is able to perfectly fulfil you company's needs?

   a. No, suppliers is not able to follow my company's changes and I would like more **"customizable" solutions** in both maintenance and analytics
   b. Yes, supplier is able to deliver solutions that match exactly with my company needs
   c. Other:____

7. How much are you satisfied about **the actual relations** with your suppliers?
   a. Very satisfied:

b. Satisfied
c. Dissatisfied
d. Very dissatisfied

Please, motivate your answer:

B Appendix B

B.1. Supplier Interviews - guidelines

1.1 Pensi che partire da soluzioni per la manutenzione preventiva non sofisticate in modo da facilitare al cliente la transizione verso un nuovo modo di fare manutenzione, per poi "scalarle" nel tempo grazie ai micro-servizi (per esempio, aggiungendo nuovi MS che passino da control chart iniziali a modelli predittivi veri e propri), possano contribuire al creare fiducia nel cliente verso i nuovi servizi offerti e renderlo sempre più disponibile a investire in essi?

2.1 Quali delle risorse umane chiave presentate nel modello (IT/ICT experts, network specialists, data security experts, solution architect) sono già parte del team di sviluppo della sua azienda? Considerando i seguenti costi medi per ciascuna figura, la sua azienda è disposta a sostenere tali costi per acquisire le competenze attualmente mancanti?

- € 41 000 / anno per un solution architect (https://it.talent.com/salary?job=solution+architect)
- € 25.992 / anno per un System Integration Engineer (https://www.glassdoor.it/Stipendi/integration-engineer-stipendio-SRCH_KO0,20.htm)
- € 68,006 / anno per un Cyber Security Specialist (https://www.erieri.com/salary/job/cyber-security-specialist/italy)
- € 33,066 / anno Per un Network Engineer (https://www.payscale.com/research/IT/Job=Network_Engineer/Salary)

2.2 Lo sviluppo di applicazioni in micro-servizi richiede importanti investimenti legati all'infrastruttura necessaria per lo sviluppo e la delivery. In particolare ogni nuovo microservizio può avere i propri costi per suite di test, playbook di distribuzione, infrastruttura di hosting, strumenti di monitoraggio, migrazione degli esistenti sistemi legacy e molto altro. La sua azienda sarebbe disposta a sostenere tali investimenti in caso di ROI atteso positivo?

2.3 Sebbene i costi relativi al passaggio da sistemi legacy a sistemi distribuiti possano essere elevati, recenti ricerche hanno dimostrato come questi possano essere notevolmente ridotti in caso di migrazione in cloud. Considera fattibile per la sua azienda l'avvio di partnership con cloud service providers con modello IaaS?

B.2. Expert Stakeholder Interviews - guidelines

1. Pensi che la modularità tipica dei micro-servizi possa essere applicata alla manutenzione predittiva e all'analytics in modo tale da rendere una soluzione scalabile, aggiungendo e integrando progressivamente nuove funzionalità ad una soluzione esistente senza compromettere le altre funzionalità (per esempio aggiungendo un micro-servizio di ottimizzazione delle risorse ad un modello di predittiva oppure sostituendo opportunamente alcuni specifici micro-servizi con altri cosi da convertire una control chart in un modello di predittiva implementato con ML)? Se si, quali pensi siano i vantaggi per il cliente nell'acquisto di una soluzione di manutenzione predittiva scalabile? Pensi che i micro-servizi possano generare un portfolio innovativo di servizi di advanced maintenance a valore aggiunto customizzati sulle esigenze del cliente?
2. Quanto valore aggiunto potrebbe dare al prodotto un servizio di manutenzione predittiva customizzato sulle specifiche esigenze del cliente? Quali sono secondo te i costi che possono essere ridotti passando allo sviluppo di applicazioni distribuite in predittiva e analytics?
3. Ritieni che costruire e disegnare sistemi di manutenzione predittiva tramite micro-servizi possa rendere l'applicativo più flessibile e più adattabile alle diverse esigenze del cliente nel tempo?
4. Pensi che nel contesto della manutenzione predittiva, una architettura distribuita possa facilitarne lo sviluppo e l'implementazione (per esempio riapplicando micro-servizi già precedentemente creati a nuovi contesti)?
5. Quali pensi siano le principali complessità nella realizzazione e integrazione di sistemi di advanced maintenance distribuiti invece che legacy?
6. Riguardo alle risorse fisiche necessarie per sviluppare in micro-servizi, l'attuale infrastruttura di cui disponete, garantisce la scalabilità dei servizi distribuiti? In particolare:
    a. La sua azienda dispone della potenza computazione richiesta? Di che tipo?
    b. L'infrastruttura di distribuzione offre un contratto di servizio per la disponibilità always-on 24/7)?
7. Un'architettura di microservizi è destinata a facilitare lo sviluppo agile nelle applicazioni per aumentare l'agilità organizzativa. DevOps è una delle procedure chiave che è necessario implementare per ottenere questa competenza.
    - Attualmente seguite le procedure agile?

- Conoscete le procedure fondamentali e i principi di DevOps?

SE sì….

- ✓ I team sono in grado di implementare correttamente le procedure DevOps?
- ✓ I team di svuluppo utilizzano attualmente gli strumenti di controllo del codice sorgente e la loro integrazione con pipeline CI/CD?

SE no…

8. Come avviene attualmente lo sviluppo di un software per la manutenzione predittiva presso la sua azienda?
9. Il software viene consegnato al cliente come prodotto finito o il cliente viene periodicamente coinvolto durante lo sviluppo per testare il modello e/o valutare insieme l'aggiunta di altre funzionalità aggiuntive al servizio offerto? Pensa sia fattibile un maggior coinvolgimento del cliente in fase di sviluppo di un software per la manutenzione predittiva? In quale fase e per quali attività pensa che il cliente possa essere coinvolto maggiormente o possa facilitare lo sviluppo?
10. Com'è organizzato l team? I team sono multifunzionali, con capacità sufficiente per creare e gestire i micro-servizi correlati in modo indipendente? Come vengono apprese e fornite esperienze tra i team?