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CLOUD MANUFACTURING: A MODEL TO ASSESS THE APPLICABILITY OF MANUFACTURING-AS-A-SERVICE IN DIFFERENT KINDS OF BUSINESS

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"Some people want it to happen, some wish it would happen, others make it happen."

Michael J. Jordan

Summary

Abstract

In recent years some digital technologies have been changing so deeply the processes of manufacturing companies that many authors from literature and practitioners started to talk about the 4th Industrial Revolution.

Among these technologies, the Cloud Computing seems to be one of the most interesting technologies. Cloud Manufacturing is a new and interesting paradigm that could be defined as the manufacturing version of Cloud Computing: the resources are virtualised to support the manufacturing process. A growing debate in literature started in 2011 on Cloud Manufacturing, facing technological problems, defining benefits and architectures but nowadays it is still difficult to understand where Cloud Manufacturing can be applied, in particular the Manufacturing-as-a-Service paradigm, that concerns the virtualisation of manufacturing resources offered through the cloud as-a-service.

In this work the authors create a model to assess the applicability of Manufacturing-as-a-Service. Starting from a systematic literature study, the authors define the terms related to Cloud Manufacturing explaining divergences, they make clear the possible configurations of participants of a cloud system and show different kinds of cloud environments. By integrating the literature study with case studies conducted in different industrial sectors, the authors build a model to understand where the Manufacturing-as-a-Service could be applied.

The model considers all the main aspects in the process starting from the customer's request to the service delivery, so as to assess the potential applicability of the cloud for each aspect.

The model is validated in agreement with experts in the academic field of Cloud Manufacturing, and comparing the quantitative results of the model with the qualitative considerations for each company considered.

The model has been applied to six industrial sectors, and interesting results are reported in the conclusions. Some sectors seem to have ideal features to work with Manufacturing-as-a-Service, but some technological problems are still open and these ones make difficult the application of this new manufacturing paradigm.

KEYWORDS

Industry 4.0 - Cloud Manufacturing - Manufacturing-as-a-Service - Resource sharing - Collaborative Manufacturing

Chapter 1
Introduction

This chapter starts with a general overview of the current industrial situation, considering the main manufacturing revolutions that in the last years are rising. Focusing on the most recent (Industry 4.0), the main trends and applications are presented, developed in the main classifications. In the last part, it is illustrated the method with which the work is conducted.

1.1. The fourth industrial revolution

Nowadays, the accent of manufacturing has transferred from maximizing production to maximizing customisation, and consequently from product-oriented to service-oriented.
To be able to be competitive on a global marketplace, meeting and satisfying dynamic customer demands, many companies are paying attention to a collaboration within critical and complex manufacturing activities such as design and manufacturing.
Sharing resources, knowledge and information between geographically distributed manufacturing entities can make them more agile and cost-effective, with higher resources' utilisation, leading to a competitive edge, in a win-win scenario for all participants. The success of many international manufacturing enterprises relies on the distribution of their manufacturing capacities over the globe. With a worldwide integration of their distributed product development processes and manufacturing operations, they are taking advantage of the many benefits of resource coordination and sharing (G. Adamson, L. Wang, M. Holm, P. Moore, "Cloud manufacturing: a critical review of recent development and future trends", 2017).

Future manufacturing systems must be able to address the emerging requirements for agility, scalability, resilience, and adaptability, while maintaining high quality at minimum cost.

Furthermore, the current customisation requires the coordination of the entire supply chain. A production network to produce complex products may involve different suppliers and manufacturers working in collaboration within a distributed manufacturing environment. This presents challenges across different tiers of the supply chain such as the management of customised product specifications and to coordinate customised production across the different production network participants.
Consequently, to support product customisation within production networks, manufacturing systems need to be responsive to customer demand and dynamically adjust the entire production network (A. L. K. Yip, U. Rauschecker, J. Corney, Y. Qin, A. Jagadeesan, “Enabling product customisation in manufacturing clouds”, 2014).

Regardless, many small-medium enterprises tend to keep their own interests and concerns, instead cooperating with other supply members. This fact causes several contradictions between the members who should competently cooperate and collaborate with each other to achieve the overall goal of the network.
Therefore, coordinating, managing, and orchestrating the operations of such enterprises become the biggest organizational challenges.
Solving this fact, and through the government incentives in the technologies and the machineries related to Industry 4.0, the SMEs can start to develop their manufacturing systems and increase the collaboration with others, and can start to be actively involved in the 4th Industrial Revolution.

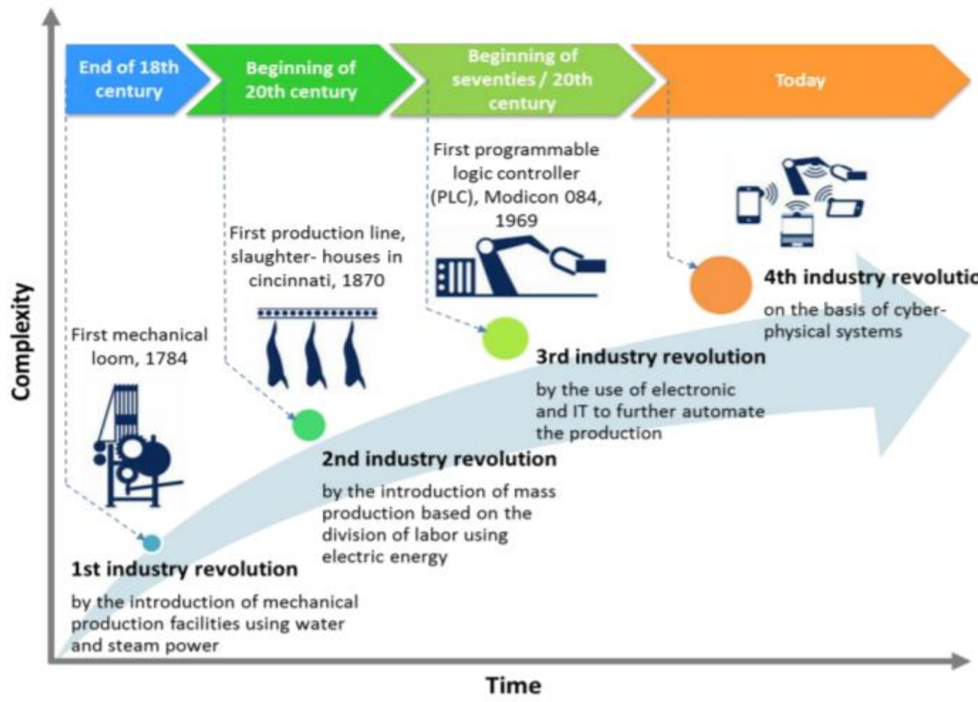

Fig. 1.1 - *Industrial revolution time framework.*

1.2. Context and trends

The actual industrial revolution is based on the concept of "Smart Manufacturing" or "Industry 4.0".

But what does *"Smart Manufacturing"* mean with?

A clear set of definitions is provided by "Osservatorio Smart Manufacturing" of "Politecnico di Milano", that in 2015 has considered two possible interpretation of this phenomenon.

The first interpretation in which Smart Manufacturing is a reviewed of evolutionary path of all manufacturing technologies and of IT solutions that supported them. This has been possible thanks to continuous job of universities and research centres.

The second one detects a conjunction from contemporary maturation of different technological trends, that have in common the ability to interconnect physical world to digital world.

So, the Smart Manufacturing is destined to become but first and foremost to be now the paradigm of the manufacturing: this concept is based on the idea that, thanks to some innovative digital technologies, called "Smart Manufacturing Technologies", all the companies are be able to interconnect and work together, sharing all types of resources (physical, information, people etc...), and this change drastically their efficiency and competitivity.
During the industry progression, some informatic applications are developed supporting the manufacturing processes, and these "Traditional Informatic Solutions" give to the Industry a lot of benefits about product development, material procurement planning and production planning etc.
So, a clear correlation between the maturation of "Traditional Informatic Solutions" and the new informatic solutions provided by Smart Manufacturing exists.
The main technologies composing Smart Manufacturing can be grouped in two macro-areas ("*La digitalizzazione dell'industria: Italia, Work in Progress" Osservatorio Smart Manufacturing, Politecnico di Milano, 2016*):

- about the *Operation Technology (OT)*
  1 - Advanced Automation (AA)
  2 - Advanced Human Machine Interface (Advanced HMI)
  3 - Additive Manufacturing (AM)

- about the *Information Technology (IT)*
  4 - Industrial Internet of Things (IoT)
  5 - Industrial Analytics (IA)
  6 - Cloud Manufacturing (CM).

1. **Advanced Automation (AA)**: regards latest developments in automated production systems, characterized by high cognitive capacity, interaction and ability to adapt itself to context, self-learning and reconfigurability. The main example of this technology family is the collaboratives robots (co-bots), designed to work with the operators.

2. **Advanced Human Machine Interface: (Advanced HMI)**: regards latest developments about wearable devices and new interface devices between man/machine for acquisition and/or sharing of vocal, visual and tactile information.
These devices include stabilized systems, as touch display or 3D scanner to obtain gestural movements, while more innovative and bi-directional solutions are growing, as augmented

reality devices or Performance Support System, solutions that support operational activities and operator training.

3. **Additive Manufacturing (AM):** also called 3D Printer, modernize the approach of classic production processes (material removal and plastic deformation), creating an object printing layer by layer.
It was born in the first half of 80's, in the last years it had a great development, increasing the group of "basic processes" (as Selective Laser Sintering, Electron Beam Melting, Fused Deposition Modelling) and the group of workable materials, like plastic and metals, with good performances of finishing and metallic high-strength.
It's applied in four fields: Rapid Prototyping (product production process), Rapid Manufacturing (saleable products fulfilment), Rapid Maintenance & Repair (products repair), Rapid Tooling (printer production).

4. **Industrial Internet of Things:** represents an evolutive way of web network, in which everything is virtualized in the digital world; on the base of IoT there are intelligent objects (able to identification, localization, state analysis, data acquisition, elaboration, check and communication) and intelligent network (open, standard and multitasking). IoT applications to industrial world are known as "Industrial Internet" or "Cyber-Physical Systems".

5. **Industrial Analytics (IA):** methodologies and instruments for the analysis and elaboration of Big Data from IoT systems linked to production layer or from the data exchange between IT systems in support of planning and synchronization of production and logistic flows.
Concretely, in Industrial Analytics some new applications as Business Intelligence, Visualization, Simulation and Forecasting, Data Analytics are treated to highlight the hidden information of data and the capacity to use it to support rapids decisions.

6. **Cloud Manufacturing**: is the application of Cloud Computing to manufacturing. Thanks to the cloud, the Cloud Manufacturing enables ubiquitous and on-demand network access to a virtualised, shared and configurable pool of resources supporting the manufacturing processes and the supply chain management.

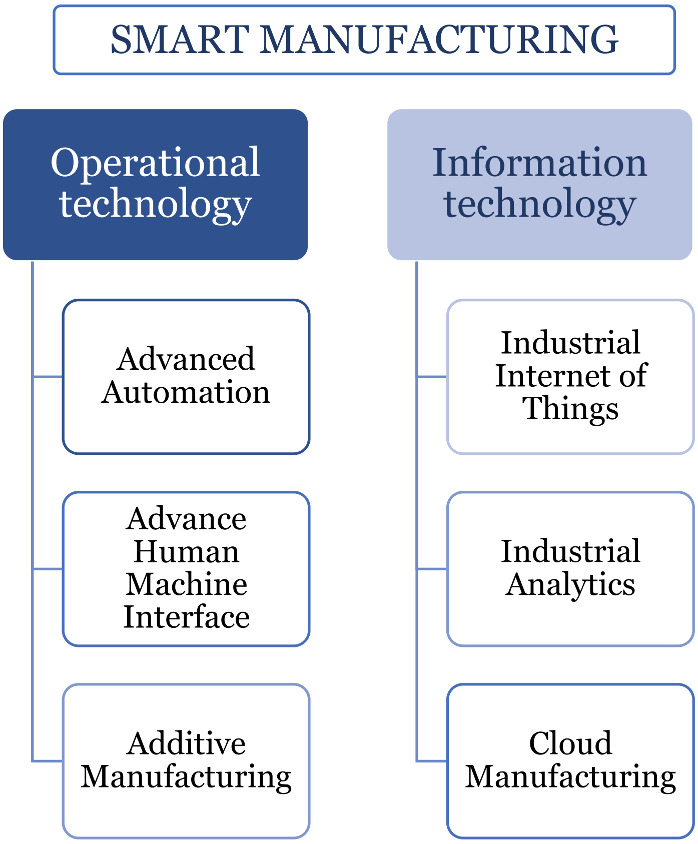

Fig. 1.2 - *Smart manufacturing main technologies.*

1.3. Research method

This work is logically organized in three main parts: a literature study, the creation of a model and finally its validation.
The beginning point of this work is the interest and will to know more about the new industrial revolution (or evolution for someone), especially about the paradigm of Cloud Manufacturing. This involvement led the authors to ask some questions, detailed below, and start to this first step of the job, the literature study.
Many papers are written about this theme, being a very new topic working in progress not yet applied. So, had to define well-defined constraints that precisely define research work. This step is treated more in detail later.

The second step of the work is the construction of the model. So, starting from the literature study and authors' academic background, they tried to create a qualitative and quantitative model, that could help to answer to the research questions.
The result it was a creation of a matrix, including the main steps needed from the request of client to the delivery of the service, according to the study, to reach the goal.

The last step was the validation of the model. To support and strengthen the model, the authors compared with the main world expert of Cloud Manufacturing and they chose the way of the industrial cases, which were very useful also for the future application of the model.
Thanks to the expert opinions and suggestions and thanks to the opportunity to meet and visit about ten companies, the authors could modify model, in terms of rows added or removed, or in terms of less general subjectivity. It will be not, of course, an ultimate model without any chance to be modified, in fact it allows a very good evaluation and lays out the excellent bases for future implementations.

In the end, the authors wanted to test the model, trying to apply it to the companies visited, in order to obtain some results that, united to some considerations from the literature, allowed the authors to draw interesting conclusion about the application of the new paradigm of Manufacturing-as-a-Service.
Pros and cons regarding the model were run through as well as the possible future developments on MaaS and of the model itself.

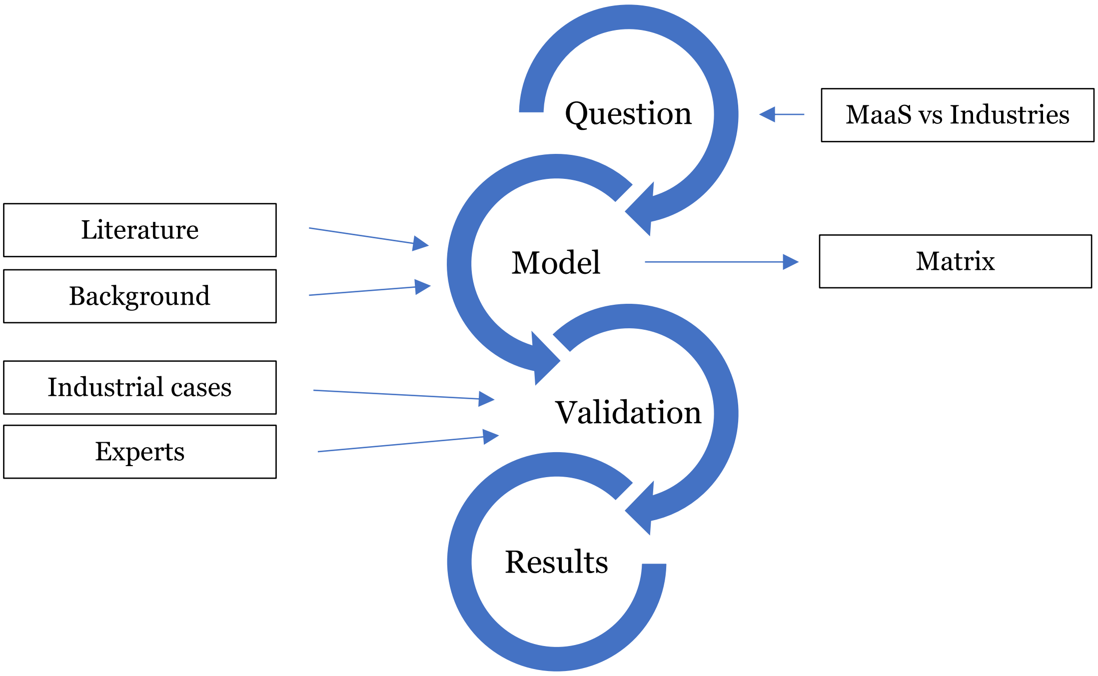

Fig. 1.3 - *Research method steps.*

1.4. Research questions

Considering Manufacturing-as-a-Service as the main topic of the work, it was necessary to focus on which main questions investigate.

First, it was the priority define the participants involved in a cloud system: the service consumer, the operator of the cloud system and the service provider.

Then, during the work, the authors realized that it would have been fundamental to specify the different kinds of provider that can exist, that often correspond to a specific cloud environment.

The authors defined a theoretical structure of MaaS, consisting in four layers: manufacturing resource layer, virtual service layer, global service layer and application layer.
In fact, any company can refer to this structure to associate the MaaS elements with the company elements.

One of the main feature of this topic is that a great literary work has been done but no one started its application. From here it was born main question of the thesis:

- which are the industries closer to apply MaaS?

To answer to this question, the authors searched in the literature any consideration related to any industrial sectors.
Unfortunately, the authors found some cases study, but nobody evaluates the applicability of MaaS to any industrial sectors.
To link the theoretical work about MaaS with the industrial world, it is needed a model to evaluate which industry can apply MaaS. So, this is the aim of the thesis.

To do this the authors started from a literature review. The questions for the literature review became:

- which are the steps necessary to use MaaS in a company?
- what are the main aspects involved from the RFQ to the service delivery?

Evaluating the steps described in many cloud-based system and the existing methods for each step (from the technical point of view), the authors achieved the goal consisting of identify the main step necessary to evaluate the potential applicability of MaaS.

During the literature review work, it was necessary to unify the terminology about MaaS, both for the general definition (Cloud Manufacturing) and for the basic terms (e.g.: resource).

Chapter 2
Literature review

In this chapter it is showed how the entire work started, considering the main initial questions and the main method used to develop the project. So, after a brief explanation about the literature review carried out, there is a part where there is a part where the Cloud Manufacturing is treated in all its main features studied until now in the literature world.
In the last part of the chapter the main step from the request for quotation to the delivery of the service, both from the operational (or technical) and business point of view.

The authors started from a literature review, more precisely a "Systematic review", a type of literature review that collects and critically analyses multiple research studies or papers, using methods that are selected before one or more research questions are formulated, and then finding and analysing studies that relate to and answer those questions in a structured methodology.

Systematic reviews are characterised by being objective, systematic, transparent and replicable.
This methodology also allows other researchers to update the review later to integrate new findings.
In fact, the systematic review definition is: "A review of a clearly formulated question that uses systematic and explicit methods to identify, select, and critically appraise relevant research, and to collect and analyse data from the studies that are included in the review. Statistical methods (meta-analysis) may or may not be used to analyse and summarise the results of the included studies" (Cochrane Collaboration, 2014).

The authors considered very important to start from this work because it relies at the first time a wide and clear overview about the interested topic (e.g. Cloud Manufacturing) and then it organizes the research more in detail, allowing the reader to repeat the same research and maybe to develop same areas of the topic.

The main objective of the research is the state of the art of *Manufacturing-as-a-Service* (MaaS), trying to identify the main aspects, both technical and business point of view, and trying to understand at which point of development they are nowadays, and progressively trying to intercept any research gaps, application ones and their influence about the MaaS applicability in general.
Obviously, it was a dynamic work that did not include only research. More researches have been carried out, increasingly more targeted thanks to new keywords and new questions arising during the research and the various readings.

The questions of literature research have been the following:

1. What is Manufacturing-as-a-Service?
2. What is the main architecture of a cloud system?
3. How is Manufacturing-as-a-Service developing in the manufacturing world?
4. Which are the type of companies and areas interested in?
5. How many types of Manufacturing-as-a-Service application exist?
6. Which types?
7. Which are the main problems/benefits about its application?
8. Which are the areas of development and future research emerged?
9. Which types of services can a company offer? E.g. referring to the product complexity.
10. Does an ontology exist about which steps could support every step from RFQ to service delivery?

It is possible to note that some questions coincide with research question explained before, but before to start with literature review the authors wanted to find some questions more precise and accurate, to find documents and paper more useful.

To analyse the topic, the research process has been structured in two stages: the first is a preliminary study, the second is a deeper analysis and selection of the research material.

During the first step, the authors carried out an initial reading on several scientific articles to refine the research idea based on the topic of Manufacturing-as-a-Service. This early effort is also particularly useful for a more considered definition of search keywords and of material selection criteria.

Thanks to this, it was possible to move to the second stage, and due to the vastness and newness of the topic, the authors tried to give, as mentioned above, an order and a direction to literature research, setting some limits and main specifications that could characterize the most papers available.

First, the authors used Scopus as a pool. To find some available articles, authors also used few times Google Scholar, but as mentioned above, the main papers source was Scopus.
Authors started with “From Cloud Computing to Cloud Manufacturing” (X. Xu, “From Cloud Computing to Cloud Manufacturing”, 2011), because they considered it like a detailed map of the evolution of this concept and it contains the definitions upon they based the research. It is possible to imagine the great number of scientific articles available, and for this reason it was fundamental to add other limits to the research.
So, it became important the use of some “Keywords”, that help us to do a more accurate and precise paper research, it was fundamental. Starting from the more general term “Cloud Manufacturing”, the authors focused on the topic of Manufacturing-as-a-Service (MaaS), but the results were inadequate, because it is not a term common in the manufacturing and academic world. So, in general the authors tried to set up their research basing the more used terms in the world about this topic like “Cloud-based Manufacturing”.
Basing mainly on the number of citations, the authors identified the main experts to refer to: Xu Xun, Wang Lihui, Schaefer Dirk, Tao Fei, Wu Dazhong, Wang Xi Vincent, Zhang Lin, Mourtzis Dimitris, Liu Yongkui, Lu Yuqian.
It is interesting to notice that the main studies come from China, USA and New Zealand. Considering also the Germany, more focused on the application than the theoretical study, these are the main countries implicated in the Industry 4.0.
Moreover, authors considered only “Engineering” and “Computer science” as area of interest.
To evaluate also the reliability of scientific documents, authors used Scimago, considered an indicator which measures the degree of scientific influence of academic journals; it uses the number of citations received from a magazine and the importance or prestige of the magazines from which these quotes come from.
Since Scimago gave evaluations about many years ago, authors considered only the last three years, in order to have even stronger reliability.

As it is possible to understand, during the second stage the authors adopted an iterative process in keyword definition, search, selection and recording. Therefore, each iteration corresponded to a more precise approach to the subject.
In this phase, authors added some keywords to the previous ones: scheduling, matching, resource virtualisation, overview, review, chain.

To sum up, the main conclusions deriving from these steps were:

1) Disagreement and contrast in the terminology of the topics in literature depending on different authors and different part of the world. In fact, many concepts are used as synonyms in some cases, while in others as completely different ones. This forced authors to fully understand how all the ways in which Manufacturing-as-a-Service is treated and considered, in order to consider only the most pertinent to the project.

2) A great gap between industrial cases and literature. As already said, there are so many studies about this topic, but at the same time the real application, even in the most active countries, is hard to assert itself. In fact, despite there are some examples of possible applications studied or some companies that trying to invest a lot in this direction, it is hard to find a company that bases its entire manufacturing process on the concepts of MaaS.

3) Some of the initial questions (number 3, 4, 7, 8, 9, 10) have not been answered, precisely those related to the industries that are developing cloud systems, and the sectors suitable to use cloud. This fact leads the authors to think of developing a model that could help them to evaluate the suitability of industrial sectors.

So, the following part of the chapter shows a general view of Cloud Manufacturing, trying to clear up where the paradigm of Manufacturing-as-a-Service can be inserted, and trying to explain the main characteristics like, kinds of environments, participants, the architecture of this new paradigm.

2.1. Cloud Manufacturing

2.1.1. Definitions and classification

The Cloud Manufacturing is the application of Cloud Computing to manufacturing. Thanks to the cloud, the Cloud Manufacturing enables ubiquitous and on-demand network access to a virtualised, shared and configurable pool of resources supporting the manufacturing processes and the supply chain management.

The Cloud Computing is a model for enabling ubiquitous, convenient and on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interactions. It provides resources to a user on the "pay-as-you-go" basis (X. V. Wang, X. Xu, "An interoperable solution for Cloud manufacturing", 2013).

The inclusion of CC as a core enabling technology is one of the major differences between CM and other advanced networked manufacturing paradigms, as it makes possible to provide manufacturing activities as services in a distributed environment.
Following, the service is defined as what the company can offer: it can be physical goods (a product or a component) or/and processing.

The aim of CC is that to provide convenient, scalable access to IT services and computing resources. It offers on-demand and strategic outsourcing, providing IT resources as a standard commodity, delivering real-time access to software, application development and infrastructure (G. Adamson, L. Wang, M. Holm, P. Moore, "Cloud manufacturing: a critical review of recent development and future trends", 2017).

In Cloud Manufacturing, everything is treated as a service (XaaS), which can be provided (provider point of view) or can be used (consumer point of view), and the service is located at different levels:

- concerning at a first approach referred to CC traditional architectures, but applied to support the processes (in the enterprise) and the supply chain:

    - Infrastructure as a Service (**IaaS**)
    - Platform as a Service (**PaaS**)
    - Software as a Service (**SaaS**)

- concerning at a second approach referred to the possibility to have a diffused access and on demand (by the network) to a virtualized, shared and configurable set of resources:

    - Manufacturing as a Service (**MaaS**).

<u>IaaS:</u> IaaS provides consumers with fundamental computing resources, e.g., high performance servers and storage space. IaaS promotes a usage-based payment scheme, meaning that customers pay as they use. This service is extremely useful for enterprise users as it eliminates the need for investing in building and managing their own IT systems. Another important advantage is the ability of having access to, or using, the latest technology as it emerges. On-demand, self-sustaining or self-healing, multi-tenant, customer segregation are the key requirements of IaaS (X. Xu, “From Cloud Computing to Cloud Manufacturing”, 2011). Infrastructure-as-a-Service is sometimes called Hardware-as-a-Service (HaaS).

IaaS provides a bunch of physical and virtual machines, based on which users can install and deploy their own operation systems and working environments (X. V. Wang, X. Xu, “An interoperable solution for Cloud manufacturing”, 2013).

Example: **Amazon EC2**: Amazon Elastic Compute Cloud (Amazon EC2) provides scalable computing capacity in the Amazon Web Services (AWS) cloud. Using Amazon EC2 eliminates your need to invest in hardware up front, so you can develop and deploy applications faster. You can use Amazon EC2 to launch as many or as few virtual servers as you need, configure security and networking, and manage storage. Amazon EC2 enables you to scale up or down to handle changes in requirements or spikes in popularity, reducing your need to forecast traffic.

PaaS: As the name implies, Platform-as-a-Service provides developers with a platform including all the systems and environments comprising the life cycle of development, testing, deployment and hosting of sophisticated web applications as a service delivered by a cloud-based platform (X. Xu, “From Cloud Computing to Cloud Manufacturing”, 2011).

PaaS provides an environment and a set of tools (e.g. an interactive virtual social platform, a negotiation platform and a search engine for design and manufacturing solutions) to consumers and application developers to assist them in integrating and delivering the required functionality.

A PaaS model packages a computing platform including operating system, programming language execution environment, database, and web server. A PaaS client can develop and run its applications at the software layer (X. V. Wang, X. Xu, “An interoperable solution for Cloud manufacturing”, 2013).

Example: **Salesforce**: is an American cloud computing company headquartered in San Francisco, California. Though its revenue comes from a customer relationship management (CRM) product, Salesforce also capitalizes on commercial applications of social networking through acquisition. As of early 2016, it is one of the most highly valued American cloud computing companies with a market capitalization above $61 billion. In August 2017, Salesforce announced that it had breached the $10 billion revenue run rate becoming the first enterprise cloud company to do so.

SaaS: Software-as-a-Service is sometimes referred to as Application-as-a-Service (AaaS). It offers a multi-tenant platform, whereby common resources and a single instance of both the object code of an application and the underlying database are used to support multiple customers simultaneously. To this end, SaaS is also referred to as the Application Service Provider (ASP) model (X. Xu, "From Cloud Computing to Cloud Manufacturing", 2011).

SaaS simplifies the utilization of a large amount of software applications remotely, elastically and seamlessly (X. V. Wang, X. Xu, "An interoperable solution for Cloud manufacturing", 2013).

Example: **Microsoft Azure:** Azure is a comprehensive set of cloud services that developers and IT professionals use to build, deploy, and manage applications through the global network of data centres. Integrated tools, DevOps, and a marketplace support you in efficiently building anything from simple mobile apps to internet-scale solutions.

MaaS: is the process resources virtualization, where the demanders can upload the production specifications of a product (design, qualitative requirements, volumes, cost target, etc) on a cloud platform and can obtain directly finished products.

It's difficult to find MaaS definition, for example in the literature world, because it is often considered with the more general term of Cloud Manufacturing.
In fact, one of the most famous and utilized definition on which the literature is based is following: "The Cloud Manufacturing may be defined as a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable manufacturing resources (e.g. manufacturing software tools, manufacturing equipment, and manufacturing capabilities) that can be rapidly provisioned and released with minimal management effort or service provider interaction (X. Xu, "From Cloud Computing to Cloud Manufacturing", 2011). The Cloud Manufacturing definition is very similar to the MaaS one.

The MaaS concept enables the provision of customisation options based on available manufacturing capabilities and resources of the production network. In other words, the approach offers end-users access to dynamic product customisation that is limited only by the capability of the manufacturing facilities (A. L. K. Yip, U. Rauschecker, J. Corney, Y. Qin, A. Jagadeesan, "Enabling product customisation in manufacturing clouds", 2014).

The following figure has been created to scheme the CM levels.

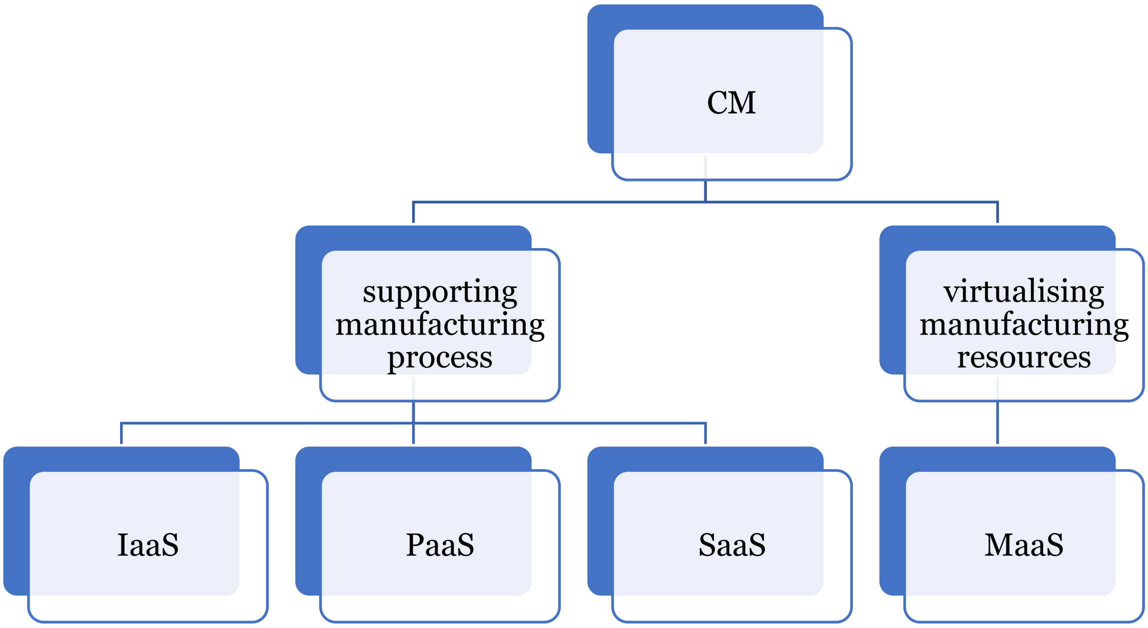

Fig. 2.1 - *Cloud Manufacturing different application levels.*

2.1.2. Participants

A typical MaaS environment consists mainly of three roles: *Provider*, *Operator* and *Consumer*.

1. *Provider:* the providers own and provide the manufacturing services involved in the whole lifecycle of manufacturing process. They can take the form of a person, an organization, an enterprise, or a third party.

2. *Operator:* responsible for the operation and management of the cloud system. The operators operate the MaaS platform to deliver services and functions to providers, consumers, and third parties. They deal with the organization, sale, licensing, and consulting of the manufacturing cloud services, and provide, update, and maintain the technologies and services involved in the operations to manufacturing cloud services and the platform.

3. *Consumer:* the consumers purchase the use of the manufacturing cloud services from the operator on an operational expense basis according to their needs. In other words, he consumes services offered by the cloud service provider (individual customers or companies).

In Manufacturing-as-a-Service, there are two fundamental company roles, namely consumers and providers, but a company can present three different types of business:

1. **Service Provider Only (SPO) company:** only provide services, but not consume any services.
2. **Service Consumer Only (SCO) company**: only consumes services but does not provide any services.
3. **Dual-role company**: provides as well as consume services.

Companies 1 and 2 are solely CM-facing companies and they are formed for and survive in a well-established CM ecosystem and economy. It is early that most of the companies these days will be Dual-role companies.

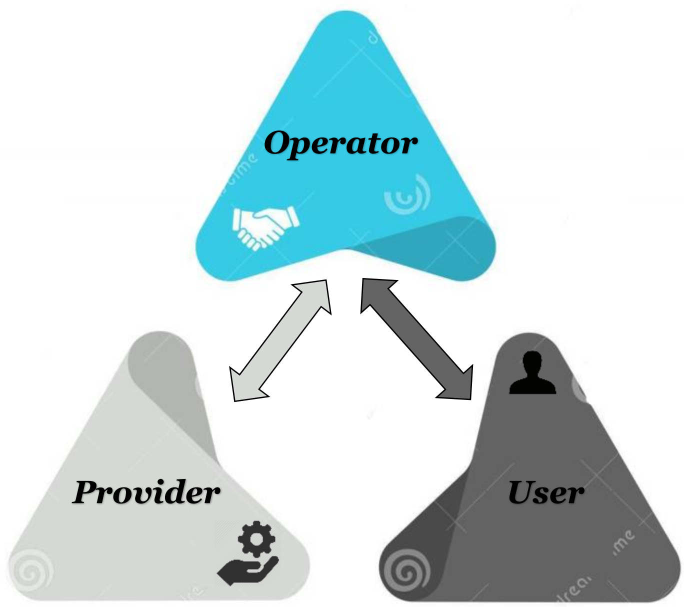

Fig. 2.2 - *Main three cloud environments participants.*

2.1.3. Environments

About the cloud environments it is more useful and smart, according to the authors, to consider separately the two main different points of view: the consumer one and the provider one. In this way, the definitions of every kinds of environments are more accurate.
From the consumer point of view, the authors focused on who uses the service, considering the availability of the service in a cloud platform. From the provider one, the focus is on who supplies the service, so considering the provision of the service to a cloud platform.

Consumer point of view (service availability):

- **Private Cloud**: manufacturing services are shared within one company or its subsidiaries.
- **Community Cloud**: manufacturing services are available to a Group of Companies or, more in general, organisations (gathered thanks different reasons like geographical location, same business etc..).
- **Public Cloud**: manufacturing services available to the public.
- **Hybrid Cloud**: a mixture of two or more clouds (private, community or public) that remain distinct entities, offering the benefits of multiple deployment modes.

Using private cloud provides better security and control over data, services and resources, which might be distributed in different departments, branch companies, etc. locally and/or globally (G. Adamson, L. Wang, M. Holm, P. Moore, "Cloud manufacturing: a critical review of recent development and future trends", 2017).

The community cloud is shared between several organisations belonging to a specific community.
The use of community cloud entails sharing specific requirements (e.g. extra high security or manufacturing requirements) or a common high-level manufacturing task or mission (e.g. aerospace industry) (G. Adamson, L. Wang, M. Holm, P. Moore, "Cloud manufacturing: a critical review of recent development and future trends", 2017).

The public cloud realises the key concept of sharing the services with the public in a multi-tenant environment. "A public cloud platform for SMEs" has been developed, to provide an interactive environment for manufacturers to publish their capabilities, and customers to submit their requests.

The public cloud is used by SMEs, mainly because is often the best solution both for company both for the customer of a SME company: providers benefit from selling idle manufacturing resources and capabilities, demanders from being able to buy only what is temporarily required, and the operator from charging a service fee from both providers and demanders (G. Adamson, L. Wang, M. Holm, P. Moore, "Cloud manufacturing: a critical review of recent development and future trends", 2017).

The hybrid cloud is a composition of two or more clouds (private, community or public) that remain distinct entities but are also bound together, offering the benefits of multiple deployment modes.
In the hybrid cloud, business-critical services and sensitive data are kept unpublished, while services that are not critical are published for others to share and use.
Complexity of determining how to combine and allocate tasks and services may initially lead to unconditional, simpler applications, not requiring synchronisation (G. Adamson, L. Wang, M. Holm, P. Moore, "Cloud manufacturing: a critical review of recent development and future trends", 2017).

In reality, a very common situation in every company is "market change" or "business upgrades". The main consequence is that if it needs to carry out business collaboration with a set of companies different from its current business partners, a company should switch to another suitable resource sharing model. So, a company could incorporate many and multiple deployment modes, with the aim to have the best interests of its in-house resources.
From these reasons, there could be a need to develop a cloud environment that permits to respond to "market changes" and can permit to companies to create different cloud mode that suit their business situations.

Provider point of view (service provision):
Manufacturing services may be provided by (a) a Single Company (often in a Private Cloud); (b) a Group of Companies (often in a Community Cloud); or (c) anyone and everyone (often in a Public Cloud).
For example, related to the Group of Companies' providers, group of smaller companies can cooperate and virtually act as a big enterprise. On the other hand, utilisation can be increased, as spare capacity can be made available for others to buy and use.

The most common situation is represented by the following matching: the Single Company provider with a Private Cloud, the Group of Companies' providers with a Community Cloud and the Any Company with a Public Cloud. It is very important to highlight these most common situations because they will be object of this work.

The following figure represents the potential participants in a cloud system.

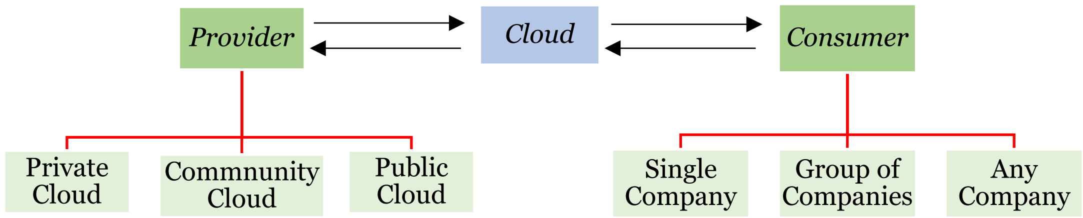

Fig. 2.3 - *Main possible kinds of cloud environments.*

2.1.4. Architecture

In Cloud Manufacturing, distributed resources are encapsulated into cloud services and managed in a centralized way. Clients can use the cloud services according to their requirements. Cloud users can request services ranging from product design, manufacturing, testing, management and all other stages of a product life cycle.
A Cloud Manufacturing service platform performs search, intelligent mapping, recommendation and execution of a service.

For this specific research, the authors considered the X. Xu's framework, because it's the most complete and the most general. In fact, it can include most of the architecture proposals in the literature.

Professor X. Xu (X. Xu, “From Cloud Computing to Cloud Manufacturing”, 2011) illustrates a Cloud Manufacturing system framework, which consists of four layers, manufacturing resource layer, virtual service layer, global service layer and application layer.

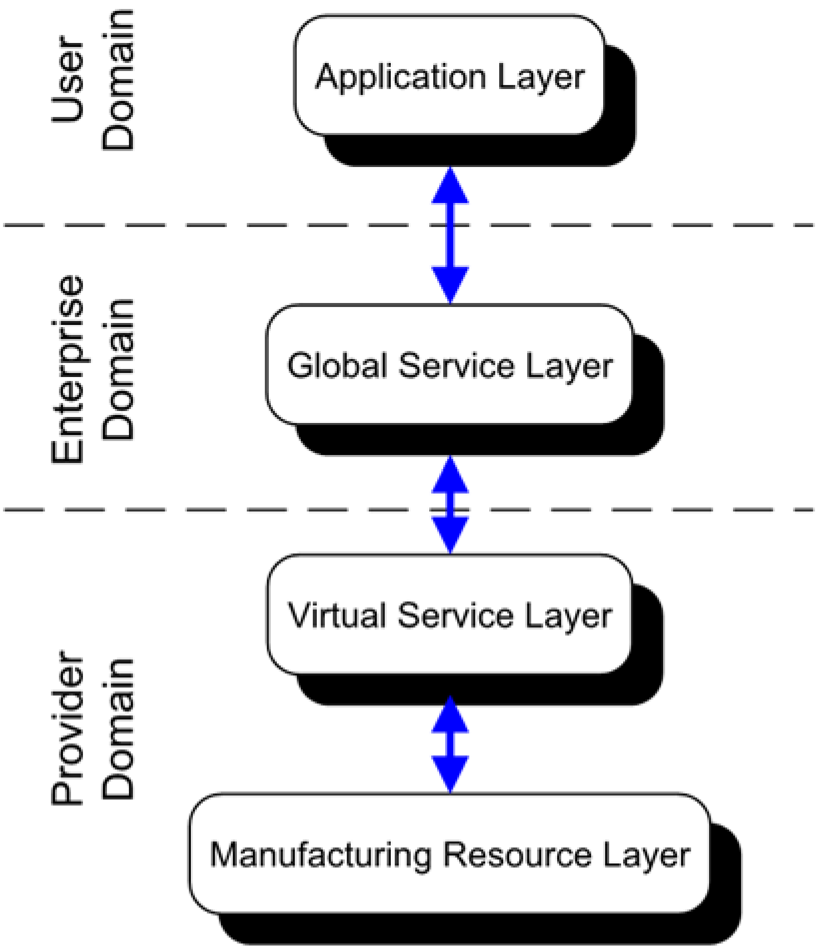

Fig. 2.4 - *Cloud manufacturing architecture (X. Xu, “From Cloud Computing to Cloud Manufacturing”, 2011).*

- The manufacturing resource layer encompasses the resources that are required during the product development life cycle. These manufacturing resources may take two forms, manufacturing physical resources and manufacturing capabilities.
  - Manufacturing physical resources can exist in the soft or hard form. The former includes software, knowledge and personnel.

The latter includes machining resources, computational resources and materials.

- Manufacturing capabilities are intangible and dynamic resources representing the capability of an organization undertaking a task with competence. These include product design capability, experimentation capability, production capability and management capability.

The types of service delivery models that may exist at this layer are IaaSs and SaaSs.

Considering the resource as the material and non-material manufacturing supplies including equipment, machine, device and intelligent properties; the capability as the ability of transforming one form into another in manufacturing domain.

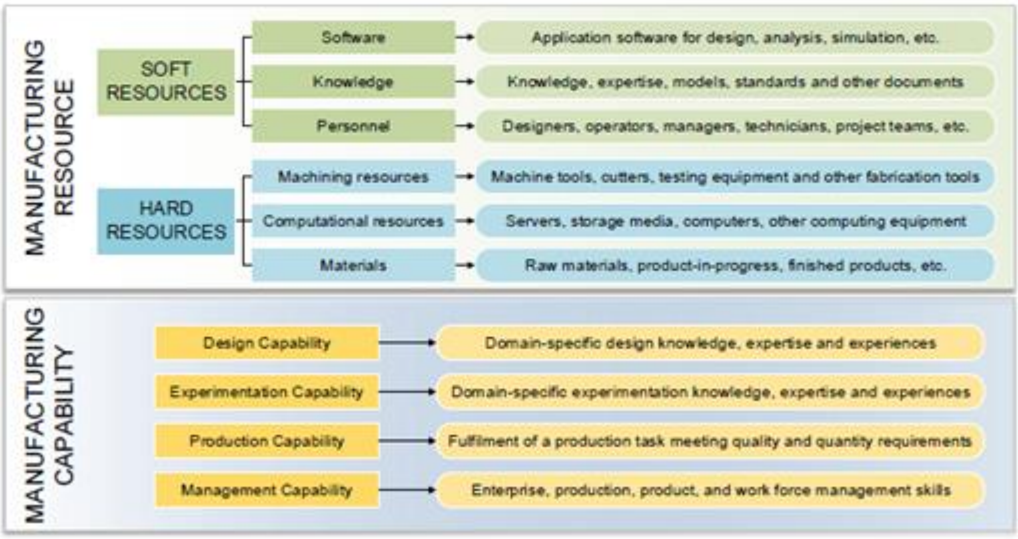

Fig. 2.5 - *Manufacturing kinds of resources and capabilities (Y. Lu, J. Xu, X. Xu, "Development of a Hybrid Manufacturing Cloud", 2014).*

About manufacturing capability

A model for describing manufacturing equipment resources (MERs) is provided in Y. Zhao, Q. Liu, W. Xu, L. Gao, "Modelling of resources capability for manufacturing equipment in cloud manufacturing", 2013
They describe manufacturing capability (MC) of machinery equipment from two aspects: static functional capability and dynamic production capability, using an ontology methodology to model this. Both these aspects are of great importance to CM users.

Functional capabilities are inherent and stationary, and describe what kind of work a machine can perform.
Production capability reflects, during a given time, the performance of that machine.
Functional capability tells if a request can be performed, whereas dynamic production capability tells when it can be performed (G. Adamson, L. Wang, M. Holm, P. Moore, "Cloud manufacturing: a critical review of recent development and future trends", 2017).

Zhao et al. (Y. Zhao, Q. Liu, W. Xu, L. Gao, "Modelling of resources capability for manufacturing equipment in cloud manufacturing", 2013) proposed an approach based on Web Ontology Language for modelling manufacturing resource capabilities, which are classified in two forms: static functional capability and dynamic production capability.
Static functional capabilities describe what manufacturing jobs can be done and include five aspects: accuracy capability, shape capability, craft type capability, process size capability, and workpiece type capability.
Dynamic production capabilities refer to the working situation of the equipment, including equipment state, task load, production cycle, process schedule and process quality (Y. Lu, J. Xu, X. Xu, "A new paradigm shift for manufacturing businesses", 2013).

- Virtualization layer: the key functions of this layer are to (a) identify manufacturing resources, (b) virtualized them, and (c) package them as Cloud Manufacturing services. Comparing with a typical cloud computing environment, it is much more challenging to realize these functions for a Cloud Manufacturing application.

    - Several technologies can be used for identifying (or tagging) manufacturing resources, e.g. RFID, computational RFID, wireless sensor networks (WSN), Internet of things, Cyber Physical Systems, GPS, sensor data classification, clustering and analysis, and adapter technologies.
    - Manufacturing resource virtualization refers to abstraction of logical resources from their underlying physical resources. Quality of virtualization determines the robustness of a cloud infrastructure. Different manufacturing resources are virtualized in different ways. Computational resources and manufacturing knowledge can be virtualized in similar ways as are the general Cloud computing resources.
    - The next step is to package the virtualized manufacturing resources to become Cloud Manufacturing services. To do this, resource description protocols and service description languages can be used.

- The Global Service Layer relies on a suite of cloud deployment technologies (i.e. PaaS). Internet of things has advanced to a new level with RFID, intelligent sensors, and nano-technology as the supporting technologies. In a complete service mode, the Global Service Layer takes full responsibility of the entire cloud operational activities. The type of cloud service that suits this mode is virtualized computing resources, e.g. CPU, RAM, and network. These cloud services can be dynamically monitored, managed and load-balanced with ease. Layer is mainly responsible for locating, allocating, fee-calculating and remote monitoring the manufacturing resources. The hardware providers are still responsible for executing the manufacturing tasks and ensuring the quality of the manufacturing job.

- The Application Layer serves as an interface between the user and manufacturing cloud resources. This layer provides client terminals and computer terminals.

In the literature, it is very important another classification, cited by G. Adamson (G. Adamson, L. Wang, M. Holm, P. Moore, "Cloud manufacturing: a critical review of recent development and future trends", 2017), considering 7 layers: resource, perception, virtualization, cloud service, application, interface and supporting layer.

Paying attention on the following framework, it's foreseeable that the reader can trace back to Xu's framework:

- *Resource layer*: CM being service-oriented rather than production oriented, a manufacturing activity is regarded as a service, being requested or provided. A service is the providing of one or a combination of many resources, and different manufacturing resources support manufacturing activities through the whole product life cycle. Some different resource classifications with minor differences exist, but most agree to that there are two different types of manufacturing resources that can be provisioned and consumed in CM: *physical manufacturing resources* and *manufacturing capabilities* (sometimes also referred to as 'abilities').

    - *Physical resources* can be either hard (such as manufacturing equipment, computers, networks, servers, materials, facilities for transportation and storage, etc.) or soft (e.g. applications, product design and simulation software, analysis tools, models, data, standards, human resources such as personnel of different professions and their knowledge, skill and experience, etc.).

- *Manufacturing capabilities* are intangible and dynamic resources that represent an organisation's capability of undertaking a specific task or operation with competence, using physical resources (e.g. performing product designs, simulations, manufacturing, management, maintenance, communication, etc.). Both manufacturing resources and capabilities are virtualized and encapsulated as manufacturing Cloud services, which are on demand, configurable and self-contained services, to fulfil a consumer's needs.

- *Perception layer:* responsible for sensing the physical manufacturing resources and capabilities, enabling them to be interfaced into the wider network, and processing the related information and data.

- *Virtualisation layer:* for virtualisation of manufacturing resources and capabilities, and encapsulation into Cloud services.

- *Cloud service layer* (Core middleware): Handles management of system, services, resources, tasks, etc. Activities for services such as access, invocation, description, publication, registry, matching, composition, monitoring, scheduling, charging, etc.

- *Application layer:* Depending on the participating providers and their offered manufacturing Cloud services, dedicated manufacturing application systems can be aggregated, i.e. Manufacturing, Collaborative supply chain, Collaborative design, Simulation, ERP, etc. Consumers can browse and access these different application systems for manual/automatic service configurations. A manufacturing resource provider can let consumers select from different possible part properties and predetermined manufacturing constraints (sizes, materials, tolerances, etc.).

- *Interface layer:* provides consumers with an interface for browsing available services and publishing their requirements and requests. Manual selection and combination of available resources/services, or automatic Cloud-generated suggested solutions.

- *Supporting layers:* knowledge – Provides knowledge needed in the different layers, i.e. for virtualisation and encapsulation of resources, manufacturing domain knowledge, process knowledge, etc.

    - Security – Provides strategies, mechanisms, functions and architecture for CM system security.
    - Communication – Provides the communication environment for users, operations, resources, services, etc. in the CM system.

2.1.5. Key effects

The authors summarized the main benefits, coming from the literature review, especially from D. Wu, D. Schaefer et al (D. Wu, J. L. Tharnes, D. W. Rosen, D. Schaefer, "Enhancing the product realization process with cloud-based design and manufacturing systems", 2013) and G. Adamson et al. (G. Adamson, L. Wang, M. Holm, P. Moore, "Cloud manufacturing: a critical review of recent development and future trends", 2017):

- On-demand self-service: a customer can provide and release engineering resources, such as design software, manufacturing hardware, as needed on demand. It provides a platform and intuitive, user-friendly interfaces that allow users (e.g., designers) to interact with other users (e.g., manufacturers) on the self-service basis.

- Ubiquitous network access: there is an increasing need for a so-called customer co-creation paradigm, which enables designers to proactively interact with customers, as well as customers to share different thoughts and insights with designers. To easily reach such a communication capability, broad, and global network access is required. MaaS allows various stakeholders (e.g., customers, designers, and managers) to participate actively throughout the entire product realization process.

- Rapid scalability: the MaaS allows enterprises to quickly scale up and down, where manufacturing cells, general purpose machine tools, machine components (e.g. standardized parts and assembly), material handling units, as well as personnel (e.g. designers, managers, and manufacturers) can be added, removed, and modified as needed to respond quickly to changing requirements. It helps to better handle transient demand and dynamic capacity planning under emergency situations incurred by unpredictable customer needs and reliability issues. For example, the MaaS system allows these service consumers to quickly search for and fully utilize resources, such as idle and/or redundant machines and hard tools, in another organization to scale up their manufacturing capacity.

- *Resource sharing*: convenient resource sharing in a flexible pay-as-you-go mode ensures the exchange of services between manufacturing service providers and consumers.

- *Economy*: to increase utilisation of manufacturing resources and capabilities through outsourcing.

- *Information sharing:* there is a vast, increasing amount of data for the manufacturing activities, in different formats and information systems. It is envisioned that MaaS could facilitate the management and sharing of this information within and between the systems of MaaS users.

- *Agility*: adaptive and rapid response to changing customer demands through the ability to invoke different combinations of manufacturing and product design services.

The MaaS model enables convenient and on-demand network access to such a shared pool of configurable manufacturing resources.
The real-time sensor inputs, capturing the status and availability of manufacturing resources, ensures effective and efficient resource allocation.

These characteristics offer enterprises flexibility in managing their businesses. With the cloud approach, there is no need for enterprises to make costly upfront investments in purchasing manufacturing equipment, maintaining their shop floor. Instead, they can have instant access to the most efficient, innovative business technology solutions on a pay-as-you-go basis.

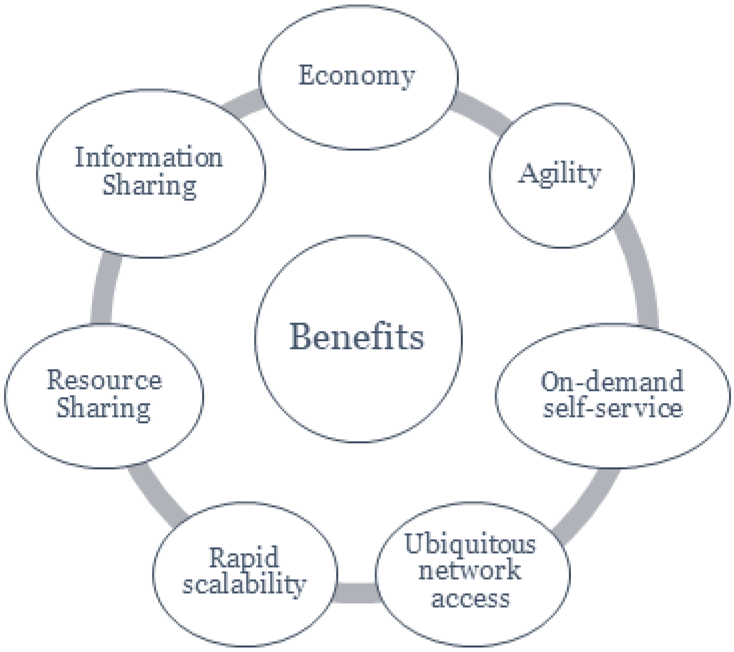

Fig. 2.6 - *Main key benefits of cloud system.*

Inspired by D. Wu et al. (D. Wu, D. Rosen, L. Wang, D. Schaefer, "Cloud-based design and manufacturing: a new paradigm in digital manufacturing and design innovation", 2015), the main requirements for a MaaS system are:

- To connect individual service providers and consumers in a networked design and manufacturing setting, a MaaS system should support social media-based networking services. Social media applications allow users to utilize/leverage crowdsourcing processes in design and manufacturing. In addition, social media does not only connect individuals; but it also connects design- and manufacturing-related data and information, enabling users to interact with a global community of experts on the Internet.
- To allow users to collaborate and share 3D geometric data instantly, a MaaS system should provide elastic and cloud-based storage that allows files to be stored, maintained, and synchronized automatically.
- To process and manage large datasets, so called big data, with parallel and distributed data mining algorithms on a computer cluster, a MaaS system should employ an open-source software/programming framework that supports data-intensive distributed applications.

- To allocate and control manufacturing resources (e.g., machines, robots, manufacturing cells, and assembly lines) in MaaS systems effectively and efficiently, real-time monitoring of material flow, availability and capacity of manufacturing resources become increasingly important in cloud-based process planning, scheduling, and job dispatching. Hence, a MaaS system should be able to collect real-time data using IoT technologies such as radio-frequency identification (RFID) and store these data in cloud-based distributed file systems.
- To assist users to find suitable manufacturing resources in the cloud, a MaaS system should provide an intelligent search engine for design and manufacturing to help answer users' queries.
- To streamline workflow and improve business processes, a MaaS system should provide an online quoting engine to generate instant quotes based on design and manufacturing specifications.

Note:
Focusing on manufacturing services, they can be:

- Extended: The structure of manufacture services should be extendable to not restrict their usage to the integration of pre-defined manufacturing facilities. This includes the representation of various aspects in their descriptions (product characteristics, quality constraints to manufacturing process, organisational information, financial aspects, logistics information…).

- Combined: The aggregation of manufacturing services must be possible.

- Configure: Manufacturing services should be configurable and provide configuration options based on the product options.

- Manufactured: this is an important requirement because all options of services are manufacturable by the expressed resources and capabilities. So, matching, validation, and calculation mechanisms must be included to represent the respective interrelationships among product parameters.

- Owned: Manufacturing services should include a static connection to their sources to be able to measure delivery dates and costs.

- Minimal: Manufacturing service descriptions should include the minimum level of information required to avoid unnecessary administration efforts and therefore make the integration and aggregation of services applicable for a wide range of user groups.

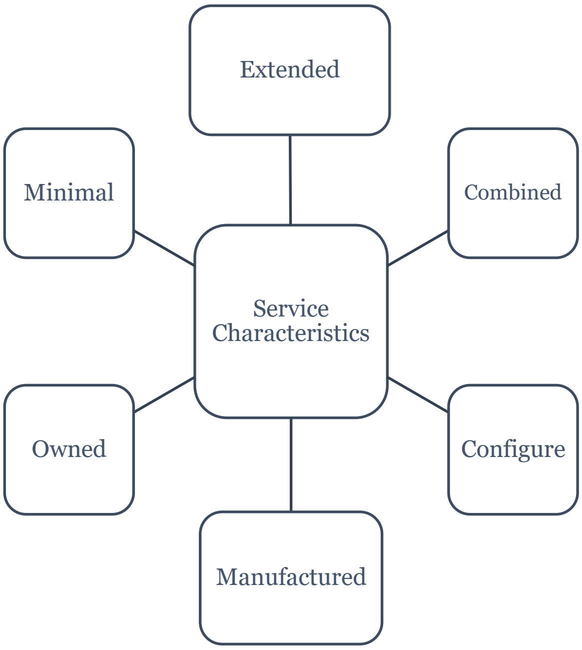

Fig. 2.7 - Manufacturing service main features.

2.2. Main steps from "Request For Quotation" to service delivery

To better understand the new current of MaaS and to identify the main step needed to apply it, it has been considered interesting and fundamental to analyse these steps from two main points of view from which a company can be analysed and studied: the technical (or operative) one and the business one.

2.2.1. Operating point of view

An important goal of MaaS is to provide to users on-demand services for the manufacturing resources and capabilities that they need through the Internet. Hence, there is a strong need to effectively manage these services in a centralized way to ensure the service performance, quality, and successful operation of manufacturing clouds (F. Tao, L. Zhang, Y. Liu, L. Wang, X. Xu, "Manufacturing Service Management in Cloud Manufacturing: Overview and Future Research Directions", 2015).

Based on F. Tao, L. Zhang, Y. Liu, L. Wang, X. Xu, "Manufacturing Service Management in Cloud Manufacturing: Overview and Future Research Directions", 2015, the main technical and operative aspects (from the service lifecycle perspective) included in the process from the customer Request for Quotation (RFQ) to the delivery are:

1. Resource Perception and Connection
2. Data transmission
3. Data filtering and processing
4. Resource virtualisation
5. Service Modelling and Digital Description
6. Service Searching and Matching
7. Service Evaluation
8. Service Selection and Composition
9. Service Scheduling
10. Service Transaction
11. Logistics services
12. Service Fault-Tolerance
13. Service Execution and Monitoring
14. Service Release

In addition, another main aspect is:

15. Safety and Security

In terms of the beginning-of-life (BOL), middle-of-life (MOL), and end-of-life (EOL) of manufacturing service, MSM can be divided into four main phases: service generation stage, service pre-application stage, service application stage, and service after-application stage.

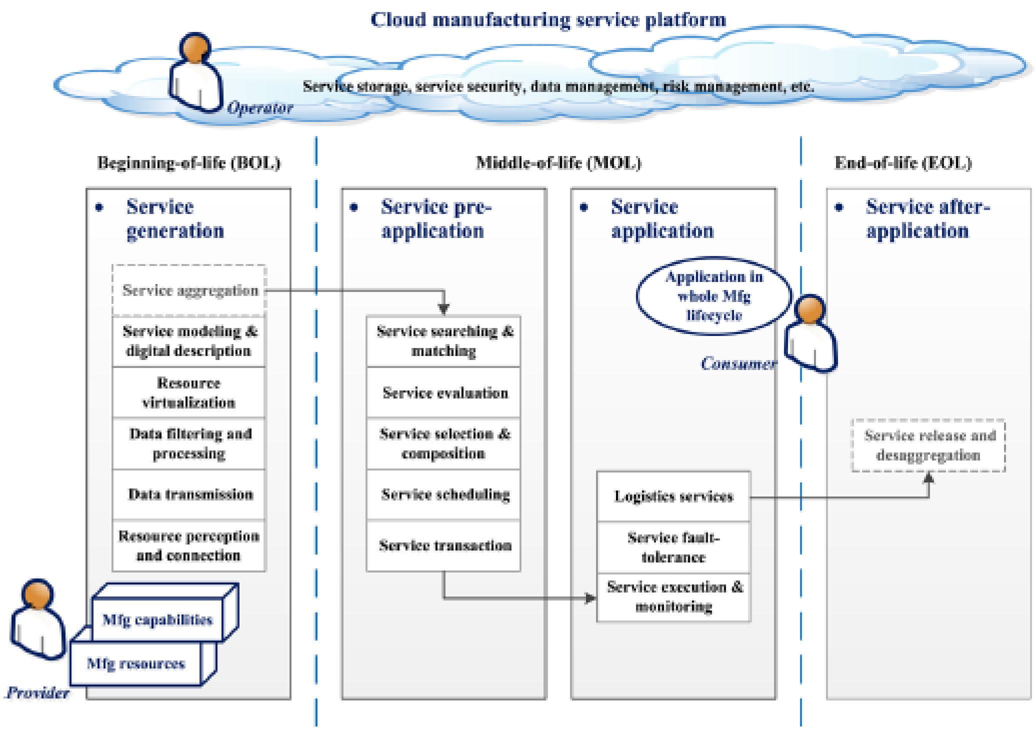

Fig. 2.8 - *Cloud manufacturing platform main steps (F. Tao, L. Zhang, Y. Liu, L. Wang, X. Xu, "Manufacturing Service Management in Cloud Manufacturing: Overview and Future Research Directions", 2015).*

2.2.1.1. Resource perception and connection

The services are generated by the identification, virtualisation and encapsulation of manufacturing resources.

With the object to identify the manufacturing resources exist many technologies: radio frequency identification devices (RFID), computational RFID, wireless sensor networks, IoT, CPS, global position system (GPS), sensor data classification, clustering and analysis, and adapter technologies.

The perception and access technologies of manufacturing equipment resources have three aspects including condition perception of manufacturing equipment, IoT, and access adaptation. However, according to the form of virtualized resources, the computational and knowledge resources would be virtualized in a similar manner using cloud computing technologies, and the hardware resources would be converted into virtual machines using agent based technologies for distributed control and communication (F. Tao, L. Zhang, Y. Liu, L. Wang, X. Xu, “Manufacturing Service Management in Cloud Manufacturing: Overview and Future Research Directions”, 2015).

The listed techniques can transform those passive machines into proactive agents.
For example, pressure sensors and temperature sensors can be used to perceive the real-time state of chemical devices, and once a dangerous signal appears, the remote controller in a cloud can throw an alarm in time. As known, RFID has been applied in tracing materials in logistics. Sensor data will be collected and pre-processed, then delivered to a cloud platform via the Internet (L. Ren, L. Zhang, F. Tao, C. Zhao, X. Chai, X. Zhao, “Cloud manufacturing: from concept to practice”, 2015).

A Cloud Manufacturing resource service platform based on Fiber Bragg Grating (FBG) perception network was proposed in F. Zhang, Z. Zhou, W. Xu, Y. Zhao, “Cloud manufacturing resource service platform based on intelligent perception network using fiber optic sensing", 2012. The platform consists of a manufacturing resources layer, a manufacturing resource perception layer, an adapter access and Internet of Things layer, and a perception information processing layer. Manufacturing resource conditions and key parameters are perceived in a real-time and dynamic manner by the FBG intelligent perception network. After this, the collected information is transmitted by heterogeneous network environments, such as WSN, Internet, LAN and FBG network. Finally, the resource information is processed by the information fusion method and transmitted to the main Cloud Manufacturing system through the resource access interface (Y. Lu, J. Xu, X. Xu, “A new paradigm shift for manufacturing businesses”, 2013).

2.2.1.2. Data transmission

The Data Transmission, or Conversion, is about the translation of product request to the unique and same informatic language (e.g. OWL).

In this phase, the system converts the customer files in a data format readable by the cloud system.

Several ontologies language have been proposed and used in the context of semantic web.
XML, a widely used data format in the web environment, is the backbone for various semantic web languages. Other ontological languages, such as RDF (Resource Description Framework),

RDFS (RDF Schema) and OWL are an extended version of the XML syntax, aiming to provide greater machine interpretability and semantic interoperability (Y. Lu, H. Wang, X. Xu, “ManuService ontology: a product data model for service-oriented business interactions in a cloud manufacturing environment”, 2016).

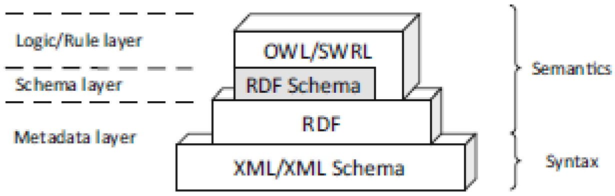

Fig. 2.9 - Main ontologies languages (Y. Lu, H. Wang, X. Xu, “ManuService ontology: a product data model for service-oriented business interactions in a cloud manufacturing environment”, 2016).

RDF (O. Lassila, R.R. Swick, “Resource Description Framework (RFD) Model and Syntax Specification”, 1999) is a language for representing information about resources in the World Wide Web. It is particularly proposed for representing metadata about things that can be identified on the Web, even when they cannot be directly reclaimed on the Web.
RDF is based on the idea of identifying things by using Uniform Resource Identifiers (URIs), and describing resources in terms of simple properties and property values. It should be noted that RDF can link pieces of information across the Web using URIs. Furthermore, RDF URIs can refer to any identifiable thing, including things that may not be directly retrievable on the web (such as a CNC machine tool). Therefore, in addition to describing things such as web pages, RDF can also describe cars, businesses, people, new events, etcetera. This linkage mechanism makes the semantic world a connected network, with the relationship between each node precisely specified. This distributed, yet connected, data environment makes it a natural choice for business interactions in a cloud environment where data are flowed from various stakeholders (e.g., service consumer, manufacturer, resource vendor and knowledge contributor).

RDFS is a semantic extension of RDF. It provides mechanisms for describing groups of related resources and the relationships between these resources. RDFS allows users to make statements about classes of things and types of relationship. It provides the facilities needed to describe such classes and properties, and to indicate which classes and properties are expected to be used together.

OWL has more mechanisms for expressing meaning and semantics than XML, RDF, and RDF-S, and thus OWL goes beyond these languages in its ability to represent machine interpretable content on the Web. With the OWL specifications, three sub-languages of OWL are described, each of which provides a different level of expressiveness: OWL Lite, OWL DL, and OWL Full. OWL Lite is the least expressive sub-language and is often cited as the least widely adopted. OWL Full, on the other hand, is the most expressive sub-language; it is perhaps too expressive, mainly because it employs all the OWL language constructs, unlike the two other sub-languages. For instance, OWL Full does not include restrictions on the use of transitive relationships, which is a requirement of decidability. OWL-DL can be considered a sub-language of OWL Full, in that it was designed to provide maximal expressiveness while retaining decision-making. For this reason, OWL-DL permits efficient reasoning support, and there exist numerous OWL-DL reasoners.
For the reasons described above, OWL-DL is the most promising choice among the three sub-languages, to represent the semantics of manufacturing services while retaining decidability for inference purposes.

Semantic web rule languages provide the required expressiveness, enabling machine interpretation, automated processing and translation into other such semantic web languages, some of which are also the execution syntax of rule engines. They may be used for data publication purposes on the semantic web as well. There have been several efforts aiming at building a general rule mark-up standard for the semantic web.

2.2.1.3. Data filtering and processing

The Data Filtering, or Parsing is represented by "product parser" and it should read the product (that was translated in a right language in the previous step, “Data conversion”) and to provide the input (service request) to the system.

This tool can parse STEP data format to RDF/XML format which is still following STEP data structure.

The product parser reads and then writes the service request inputs in the system.

Service request

A service request is a complete document that details a manufacturing project with all specifications on product characteristics, manufacturing processes, cost expectations, logistics requirements, etcetera.
In the process of reading service request input from consumers, a Cloud Manufacturing system should also be able to validate all the attributes of each data object, against standard data models and recommended engineering knowledge in the target domain. This process is also called manufacturability analysis, essential step in intelligent machining systems.

A service consumer submits an explicit representation of customised products to the cloud system, which typically consists of a Bill of Materials (BOM) and corresponding design files.

Y. Lu et al. (Y. Lu, H. Wang, X. Xu, “ManuService ontology: a product data model for service-oriented business interactions in a cloud manufacturing environment”, 2016) described the service-oriented product specifications.

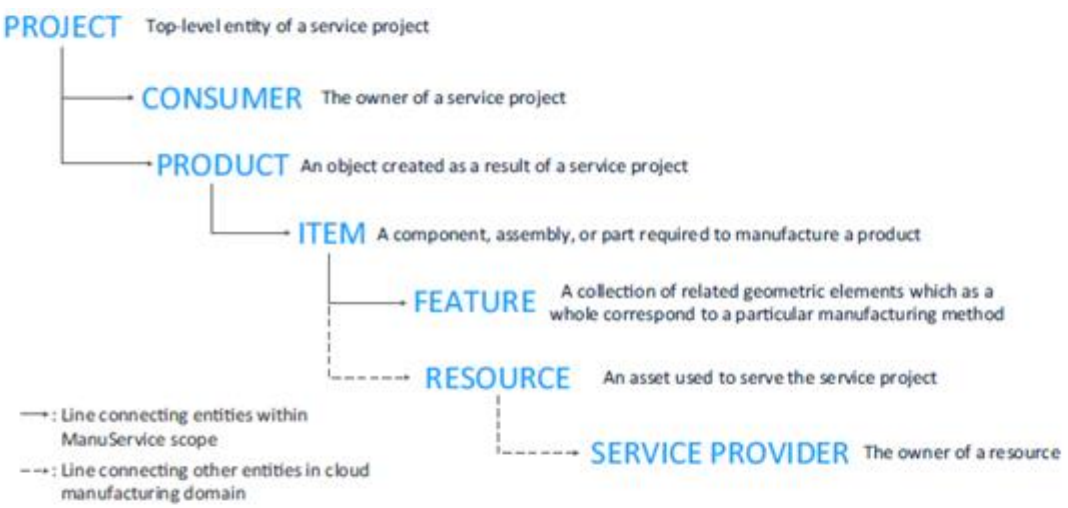

Fig. 2.10 - *Service-oriented product specifications (Y. Lu, H. Wang, X. Xu, “ManuService ontology: a product data model for service-oriented business interactions in a cloud manufacturing environment”, 2016).*

In a Cloud Manufacturing business, a consumer raises a request for a manufacturing service. This request is in the form of a personalised project, in which product information such as

quantity, ownership, and material is specified. A product includes a list of items, each of which can be either a part or an assembly.
An item physically consists of a list of predefined features. It is believed that each highly customised product can be broken down to feature level and the pre-defined feature list can facilitate representation of the manufacturing information of a product. It should be noted that definition of a feature only includes attributes that are essential to resource selection in the cloud. An item is also associated with a list of manufacturing resources from different service providers (Y. Lu, H. Wang, X. Xu, "ManuService ontology: a product data model for service-oriented business interactions in a cloud manufacturing environment", 2016).

2.2.1.4. Resource virtualisation

Based on "From cloud computing to cloud manufacturing" (X. Xu, "From Cloud Computing to Cloud Manufacturing", 2011), Cloud Manufacturing can give to manufacturing companies a new great opportunity to engage in the global business environment, to provide scalable and virtualized resources as consumable services over the internet. This is a new way for the companies to work together in the manufacturing world. In a cloud environment service provider can come together to create a temporary and cloud-based alliance to take manufacturing jobs. Geographically isolated manufacturers integrate and share manufacturing resources and knowledge, to provide configurable services, in a cloud environment. In this way, to facilitate effective business interactions, distributed resources and capabilities need to be identified, virtualized, and encapsulated.
Resource virtualization is the conversion of a physical resource to a resource that can be consumed through the cloud; this improves agility, flexibility, and cost (I. Hashem, I. Yaqoob, N. Badrul Anuar, S. Mokhtar, A. Gani, S. Ullah Khan, "The Rise of Big Data on Cloud Computing: Review and Open Research Issues", 2014).

Based on the discussions of previous chapters, a virtualized manufacturing resource includes two parts: a mandatory ontology instance represented in RDF or XML format, and an optional capability description represented in Jena. Semantic rules provide users the possibility of modelling implicit knowledge in the manufacturing domain that cannot be represented by ontologies. This feature will largely improve the modelling capability of manufacturing resources. Both parts refer to a shared vocabulary for manufacturing resources and capabilities, which is an ontology that was developed in this project. In this virtualisation scheme, different instantiation templates are provided to enable fast virtualisation of typical resources used in engineering practice.

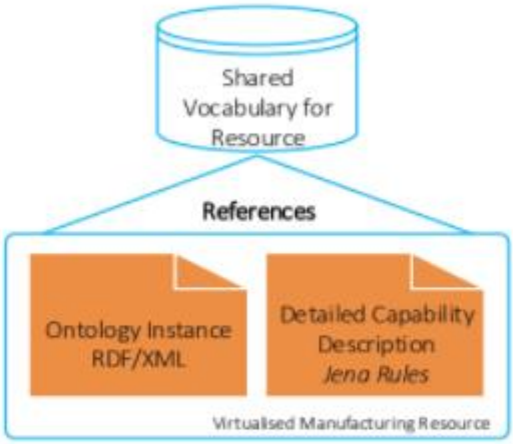

Fig. 2.11 - *Virtualisation scheme. (I. Hashem, I. Yaqoob, N. Badrul Anuar, S. Mokhtar, A. Gani, S. Ullah Khan, "The Rise of Big Data on Cloud Computing: Review and Open Research Issues", 2014).*

Virtualization enables two of the most appealing advantages of the cloud: scalability and pay-as-you-go. Before any resource is implemented for CM, it should be virtualized.

As, mentioned before, it's important to remember that the manufacturing resources may take two forms, manufacturing physical resources and manufacturing capabilities:

- Manufacturing physical resources can exist in the soft or hard form.
  - The former includes software, knowledge and personnel.
  - The latter includes machining resources, computational resources and materials.

- Manufacturing capabilities are intangible and dynamic resources representing the capability of an organization undertaking a specific task with competence. These include product design capability, experimentation capability, production capability and management capability.

As already explained, distributed resources and capabilities need to be identified, virtualized, and encapsulated.
The robustness of a cloud infrastructure and accuracy of a service offered depend on quality of virtualisation so, in this three-step process, resource and capability virtualisation is perhaps the most challenging step.
Compared with a typical cloud computing environment, it is much more challenging to realise these functions for a Cloud Manufacturing application. One of the key reasons is that there are a wide variety of manufacturing resources used in practical production activities. For this reason, it is hard and difficult to establish an integrated model for representing complex resources and capabilities.

Basically, whatever can be used over the duration of the whole product life cycle can be potentially virtualized to the cloud and offered as a service.
The manufacturing assets (resources and capabilities as shown before) are usually allocated to consumers on demand. To achieve this, the following actions need to be performed:

- creating models for resource data: abstraction of real-world manufacturing assets and services as virtualized assets stored in the cloud;
- performing the description of these virtualized assets as cloud services that can be used by any consumer in the cloud.

The virtualization process starts with the identification of manufacturing resources, that should be performed. Then, manufacturing resource information should be virtualized and monitored in real-time. The main problem to be addressed here is heterogeneity of manufacturing assets. Compared to virtualization in cloud computing, for representing manufacturing assets, the virtualization in Cloud Manufacturing addresses the problem of establishing a comprehensive data model.

However, the determination of the capabilities of a manufacturing resources is still based on the experience of engineers. To better represent the capabilities information of a resource, a 'capability-oriented' data model is required. In this data model, information should focus on 'what-I-can-do' information. What does it mean? The data model can adequately reveal what a manufacturing resource can be used for under which conditions. Under this framework, it is best that the capability of a manufacturing resource can be represented at various granularity levels. Thanks to this, the main advantage is that allows the right level of capability information to be used for a service need at a certain level.

In resource virtualisation, another important issue is that different companies may have different definitions of a manufacturing resource's capability, due to differences in engineer capability, business constraints, etcetera. Therefore, an optimal resource virtualisation mechanism should allow customised description, to reflect these differences. This means custom know-how, associated with a manufacturing resource, should be part of the description model, and become a great and helpful instrument for everyone which wants to take part to the cloud.

A very important aspect to evaluate and consider in the resource virtualization is the Multi-granularity. In respect to Cloud Manufacturing, this term refers to the amount of functions a resource can provide and the level of issues encountered.
The core of multi-granularity is the same of the concept of granularity, but because a lot of machines have many capability, in order to have a more specific and right matching with the customer requests, there was needed to develop granularity for every capability. In these terms, the authors talk about multi-granularity.
The main issue with multi-granularity is that providers do not know in advance about what the user will want and will require, so incorrect granularities could be used and create a "gap between resource providers and users".
Multi-granularity resources are virtualized using three steps:

- in the first one, elements relating to the virtualization are defined;
- second step is about the three levels of resource granularity (process, activity, and attribute levels), that are used to create groups of similar resources;
- last one concerns resources conversion.

Features can have either a fine or coarse granularity: for example, a fine granularity is associated with features such as angle or rotation, while coarse granularity is typically associated with drilling or milling. Another example that provides granularity could be related to product handling: fine granularity could involve the location of the warehouse for storage and coarse granularity could refer to how much product can be stored in the warehouse or transported at a time.

Virtualizing resources and capabilities requires consideration of resource characteristics and diversity, user requirements and demands as well as performance requirements of resource management. As a result, some resource virtualisation models have been proposed. For example, N. Liu and X. Li (N. Liu, X. Li, "A Resource Virtualization Mechanism for Cloud Manufacturing Systems", 2012) propose a resource virtual description model to encapsulate both non-functional and functional features of manufacturing resources into cloud-based services. Chen et al. (X. Chen, J. Zhang, J. Li, X. Li, “Resource virtualization methodology for on-demand allocation in cloud computing systems”, 2011) propose a heuristic resource combination algorithm (HRCA) to implement a mapping from physical resources to virtual resources.

In Cloud Manufacturing, most of resources are very complex, different and dynamic. In the practical applications, the resource description focuses on the most important attributes about both the inherent nature of the resources and the application requirements.

The authors summarized three main types of information of manufacturing resources: non-functional features, functional features, and QoS:

- Non-functional features are used for identifying a resource and tracing the state of a resource
- Functional features demonstrate the manufacturing capabilities of a resource from three granularity levels (process, activity, attribute)
- QoS reflects the quality when a resource provides a service for a user

After the reading about resource virtualization, the authors understood that the resource discovery and selection are mainly based on functional features of a manufacturing resource. For example, when a request is submitted to the cloud platform, the resource consumer focuses on what functionalities a manufacturing resource can provide rather than just what resources are available. For this reason, resources should be clustered according to their functional features.

The following figure shows the generic resource profile implemented for manufacturing equipment. It includes the three types of information of manufacturing resources (N. Liu, X. Li, W. Shen, “Multi-granularity resource virtualization and sharing strategies”, 2014).

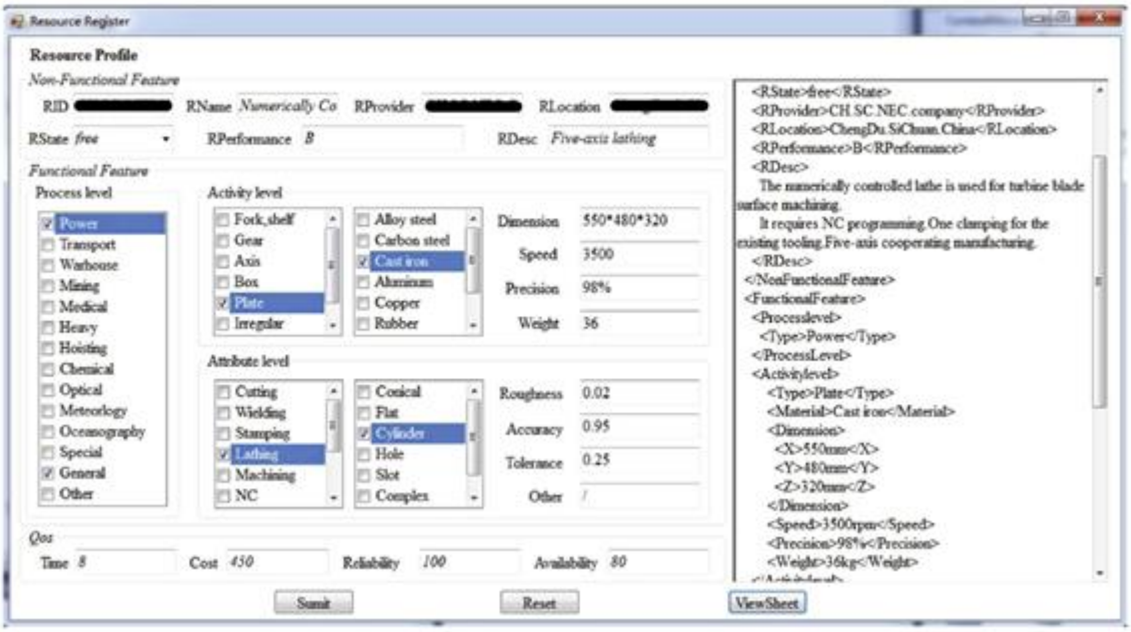

Fig. 2.12 - A generic resource profile implemented for manufacturing equipment (N. Liu, X. Li, W. Shen, "Multi-granularity resource virtualization and sharing strategies", 2014).

2.2.1.5. Service modelling and digital description

Service modelling and digital description are the base for realizing the application of service (service search, matching, evaluation, composition, and other operations in the Manufacturing Service Management).

In Cloud Manufacturing, various kinds of virtual resources are published to service platform after the encapsulation and description based on the service description language such as simple HTML ontology extension, DARPA agent mark-up language, and web ontology language (OWL).

Furthermore, some core and extensible ontologies of CM services based on the formal description models are built with the consideration of the service correlations (H. Guo, L. Zhang, F. Tao, L. Ren, Y. Luo, "Composable correlation mining of cloud service in Cloud Manufacturing", 2011), the knowledge-based multidimensional information of manufacturing capability (Y. Luo, L. Zhang, K. P. Zhang, F. Tao, "Research on the knowledge-based multi-dimensional information model of manufacturing capability in CMfg, 2012), the appropriate service description syntax with technical and product related contents as well as business and logistics information (U. Rauschecker, M. Stohr, "Using manufacturing service descriptions for flexible integration of production facilities to manufacturing clouds", 2012), the semantic description of external collaborative processing resources (S. Yin, C. Yin, F. Liu, X. Li, "Outsourcing Resources Integration Service Mode and Semantic Description in Cloud Manufacturing Environment", 2011), the maturity model of manufacturing services D. C. Zhan, Z. Cheng, X. B. Zhao, L. S. Nie, X. Xu, "Manufacturing Service and Its Maturity Model", 2012), etc. (F. Tao, L. Zhang, Y. Liu, L. Wang, X. Xu, "Manufacturing Service Management in Cloud Manufacturing: Overview and Future Research Directions", 2015).

2.2.1.6. Service searching and matching

When the authors talk about service searching and matching it's a common situation that a lot of customers are undefined for their personal demand in the first phase of customization, and their expression is fuzzy and less formal. It usually happens that customers are not professional worker and so it is very difficult for them to express their demands requests clearly. So how to represent various customers' demands and matching their requirements is crucial and fundamental to have efficient and economic business decision in a Cloud Manufacturing process.

In practice, what happens users' requirements can be satisfied by one service or multiple services. In the first case, the system should select the optimal and best service to execute to complete users' service requirement, that is on-demand provide; in the second one, the system should search a set of services for each subtask and then understand and select an optimal composite service to complete the task collaboratively, that is on-demand composition.

Based on J. Xinjuan, L, Quan, "Research on the On-Demand Service Mode in Cloud Manufacturing", 2017, the main steps of the matching process can be summarized as follows:

1) When accessing in a common CM platform, consumers will submit their requirements to the system. There's a part in the system (e.g. called "request capturing module") responsible for receiving and processing customers' demands through the internet connection. Because the customers usually have different knowledge background and means of expression, most of the customers' requirements are uncertainty and fuzzy. Therefore, users' individual requirements are carried out and finalized based on a set of task templates and described by semantic ontology.
At first the request processing is based on the experience of the system, so it is carried out based on the successful task cases stored in the task history database. The cloud

service matching and optimization is developed under the premise that there are similarity cases. Otherwise, the authors should do the on-demand decomposition. The process of on-demand provision makes full use of successful cases and enhances system efficiency.

2) The complex manufacturing task is decomposed into subtasks until they can be matched by appropriate manufacturing services. Otherwise, the sub-tasks are further decomposed into sub-sub-tasks. So, in the task decomposition in Cloud Manufacturing, the granularity of the tasks is crucial. In a system, the process of service searching and matching is a very important step, and a lot of relevant algorithms are adopted to find suitable services based on the descriptions of manufacturing tasks.

3) If no suitable results return, the platform enables manufacturing enterprises to design new service through bidding and then complete users' tasks. The new service will be evaluated and virtualized, then stored in cloud service database, which enhance manufacturing service sharing.

To simplify the comprehension of the matching process it is possible refer to the follow figure:

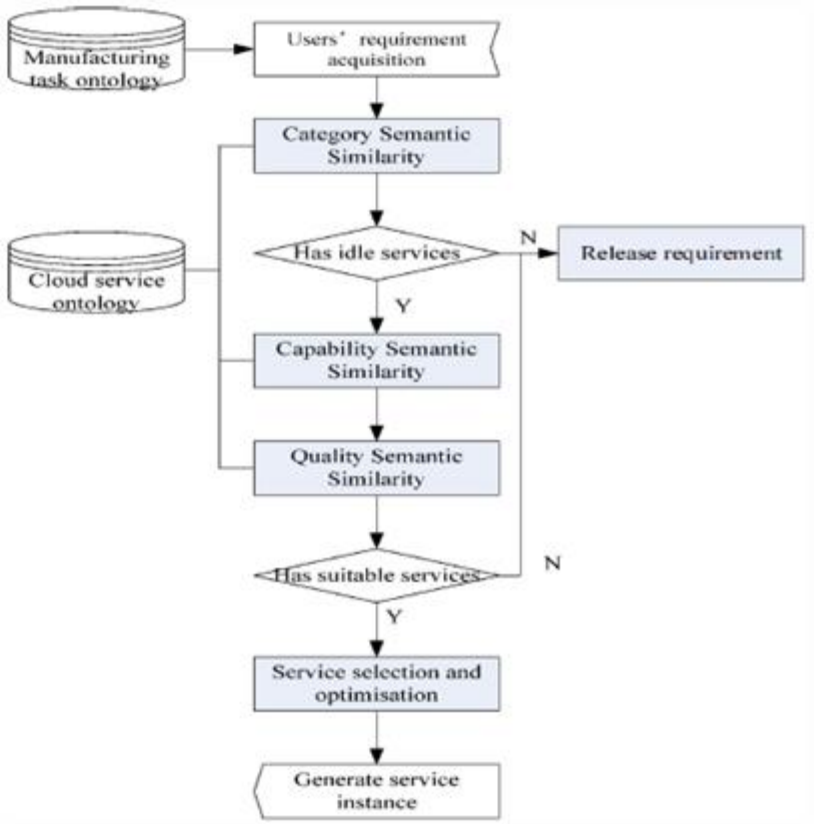

Fig. 2.13 - *Matching process example (J. Xinjuan, L, Quan, "Research on the On-Demand Service Mode in Cloud Manufacturing", 2017).*

It is possible to notice that it is possible to obtain a successful matching when the matching degree meets the service requirements. Then it provides the candidate services. As seen before, if the task is divided into many subtasks, each sub-task has a candidate set of manufacturing services, and then the service optimization should be adopted.

2.2.1.7. Service evaluation

Evaluations of resource services (Quality of Service (QoS) evaluation, trust evaluation, and utility evaluation) are very important to the allocation of manufacturing resources and services.

Considering the trust problems existing in the resource service transaction between demanders and providers, the concept of resource service trust-QoS is introduced into the resource service scheduling with the aim to provide high credible resource service abilities and results to the user (F. Tao, Y. F. Hu, Z. D. Zhou, “Application and modelling of resource service trust-QoS evaluation in manufacturing grid system,” 2009). In addition, a trust model based on feedback evaluation is proposed (X. L. Xie, L. Liu, Y. Z. Cao, “Trust model based on feedback evaluation in Cloud Manufacturing environment”, 2011). The model proposed a set of evaluation indicators of CM services properties, introduced the dynamic trust mechanism for attenuation by time, established the feedback evaluation and incentive mechanism given by the user, and improved the dynamic adaptability (F. Tao, L. Zhang, Y. Liu, L. Wang, X. Xu, “Manufacturing Service Management in Cloud Manufacturing: Overview and Future Research Directions”, 2015).
During the product development process, the product information should be exchanged between customer and provider, so they should have mutual understanding of that exchange information. Consequently, they can trust each other in information contents.

Quality-of-Service should provide a guarantee of performance, availability, security, reliability and dependability.
QoS requirements depend on end-user and provider: due to this “Service Level Agreements” (SLAs) are an effective means for ensuring QoS.
QoS is related to the monitoring of resources, storage, network, virtual machine, service migration and fault-tolerance.

At the end, to be noticed, a service evaluation matrix proposed by Y. Lu et al. (Y. Lu, X. Xu, “A semantic web-based framework for service composition in a cloud manufacturing environment”, 2016), that highlights two stages composing the service mapping process: retrieval of feasible resources for a project (stage A) and adaptive service generation based on real-time availability information (stage B).
Focusing on stage A, it uses semantic web reasoning to retrieve possible manufacturing resources. In this process, the domain ontology, resource capability descriptions and access rules from service providers, recommendations from third-parties, and regional regulations are all integrated into a knowledge graph.
To have a quantitative evaluation QoS, three indexes were introduced:

- Service Coverage: this first index refers to the proportion of unique workpieces that a service provider can assign specific manufacturing resources to. It can also assess the capability of a service provider for developing a project.

- Lead Time: represents the latency between the placement of a service order and delivery of the requested service.
- Service Reliability: this last index is used to evaluate ability to deliver the required service in a fixed time.

2.2.1.8. Service selection and composition

The purpose of Cloud Manufacturing is to move from production-oriented manufacturing processes to service-oriented manufacturing process networks by modelling single manufacturing assets as services and provide them to the variable demand of customers. The fundamental issue of providing on-demand manufacturing services in the cloud is the mapping of distributed manufacturing resources with personalised service requests; this process is called service composition (Y. Lu, X. Xu, "A semantic web-based framework for service composition in a cloud manufacturing environment", 2016).

With the goal of mapping service requests and distributed resources in the cloud, few factors need to be considered in the service composition process. These factors include delivery time, cost, quality, etcetera. Instead the non-functional factors are converted into a QoS attribute.

In the process of virtualizing manufacturing resources into services, mapping plays a critical role.
Based on Xu (X. Xu, "From Cloud Computing to Cloud Manufacturing", 2011) and Adamson et al. (G. Adamson, L. Wang, M. Holm, P. Moore, "Cloud manufacturing: a critical review of recent development and future trends", 2017), the process of virtualizing a manufacturing resource can be viewed as an encapsulating process, which can be carried out using three different mapping methods:

- one-to-one
- many-to-one
- one-to-many

One-to-one mapping is the simplest situation, which applies to manufacturing resources that can only provide a single function and can therefore directly be encapsulated into one service. The CAD and CAE data formats exchange service are two of the common types of such resource.

In this case, the process of mapping service requests with manufacturing services is a simple matching process, from the aspects of functional requirements and non-functional requirements.

Note: functional requirements include what type of products the customer wants and the customized requirements on the products such as adding a product module or a slot. Each manufacturing task is transformed into a subtask directed graph according to its task type and customized requirements.
The individualization of non-functional requirements reflects preferences of service demanders among multiple task completion indicators. The diversity of users' preferences towards time, cost and quality results in the diversity of optimal objectives of task scheduling (L. Zhou, L. Zhang, C. Zhao, Y. Laili, L. Xu, "Diverse task scheduling for individualized requirements in cloud manufacturing", 2017).

In one-to-one semantic distance is usually used to measure the similarity between a service requests and services available. In the cloud, there are a lot of services with similar functional characteristics. It is important to select the optimal resource combination, based on non-functional characteristics or QoS. However, QoS attributes are not easy to measure, due to their complexity.

In a many-to-one mapping, multiple resource (each providing a specific function) may be combined to create a more powerful or functional resource form. At the user end, such combination of multiple resources is invisible.
This scenario is very useful when no single manufacturing service in the cloud can fulfil a complicated request from a consumer. In this case, it requires the cloud environment itself to compose an optimal set of service units as a more powerful service.
In a many-to-one mapping, advanced optimisation algorithms are used to combine optimally the services for a complex service request.

The one-to-many mapping concerns with a single resource that appears to a client as a multiple resource. The client interfaces with the virtualized resources as though he is the unique consumer. In fact, the client is sharing the resource with other users.

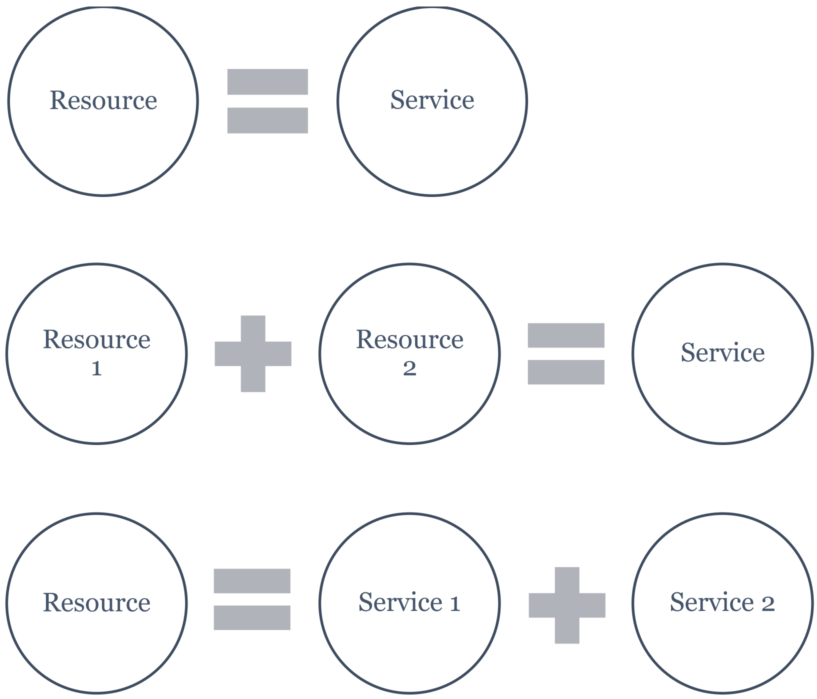

Fig. 2.14 - *Three main types of services composition.*

X. Xu et al. (Y. Lu, X. Xu, "A semantic web-based framework for service composition in a cloud manufacturing environment", 2016) stated that the service composition process in general consists of two phases:

1. Capability assessment, which is to find feasible resources for a given task, based on the characteristics of the job and the capability of each unique resource.
2. Service recommendation, where economic analysis and sustainability analysis are carried out, after which an optimal set of manufacturing resources is recommended.

The process of mapping manufacturing jobs with an optimal set of manufacturing resources is a knowledge-intensive activity. This process often requires a manufacturer to reuse existing knowledge (such as drawings, assembly instructions, manufacturing processes and resource capability) to compose a sequence of activities, subject to specified constraints.
There are two main tasks to be undertaken:

1. Generating a representation scheme for manufacturing knowledge
2. Creating a mechanism to allow smooth knowledge integration and utilisation in any decision-making activities.

A manufacturing resource is in a constant status of switching between being in use and idle. It is, therefore, necessary to consider the actual capacity and availability of a manufacturing resource during service composition. In other words, Cloud Manufacturing needs to consider the actual resource capability instead of nominal resource information.

In summary, industry implementation of Cloud Manufacturing imposes special requirements on service composition because of the knowledge-intensive, collaborative, and web-based nature of Cloud Manufacturing.
Service composition for Cloud Manufacturing needs systematic knowledge utilisation, dynamic event handling and posteriori articulation of service preferences.
(Y. Lu, X. Xu, "A semantic web-based framework for service composition in a cloud manufacturing environment", 2016).

At the end, practical engineering knowledge has not been utilised to a desirable level in service composition. In a practical engineering environment, decisions on production management and scheduling often rely on accumulated know-how from experience.

2.2.1.9. Service scheduling

In Cloud Manufacturing when the authors talk about multi-task scheduling, they refer to process of allocating services over time to perform a set of tasks while satisfying constraints in terms of time, cost, QoS, and service availability.
This is a very important aspect and it is considered an intrinsic part of a Cloud Manufacturing system, and has a major impact on system performance. Effective task scheduling methods are capable of significantly enhancing system performance. Different from the scenario in cloud computing, task scheduling in Cloud Manufacturing is usually accompanied by logistics.

It is possible to classify task scheduling, based on existing literature, in two categories (L. Zhou, L. Zhang, C. Zhao, Y. Laili, L. Xu, "Diverse task scheduling for individualized requirements in cloud manufacturing", 2017):

1. COMPUTING TASK SCHEDULING: to support the execution of manufacturing tasks the computing resources are virtualized as service. In a CM environment, the computing services do not only support the execution of computing tasks but they also provide a supporting the entire environment for manufacturing services. When a computing tasks are executed (e.g. design tasks and simulation tasks) there is a

frequent interaction between distributed computing clusters. According to the interdependent relationships between tasks, the computing task scheduling problem can be divided into scheduling of independent tasks and scheduling of dependent tasks.

2. MANUFACTURING TASK SCHEDULING: the interactive interfaces, availability and operational environment of manufacturing services are more complicated than computing services: and consequently, the manufacturing task scheduling is more difficult than computing task scheduling. To solve the scheduling problem of manufacturing tasks some various optimization algorithms have been applied.

Task categories

MaaS tasks can be classified into nine big categories:

1. Design tasks (DT)
2. Manufacturing and processing tasks (MPT)
3. Assembly tasks
4. Maintenance tasks
5. Test tasks
6. Logistics and inventory tasks
7. Consulting task
8. Computing and simulation tasks
9. Other tasks (OT).

Each big category contains many subcategories following different task demands and conditions. For example, design task (DT) is generally viewed as product or process design (T. Wang, S. Guo, C.G. Lee, "Manufacturing task semantic modelling and description in cloud manufacturing system", 2014).

Wang et al. (S.L. Wang, W.Y. Song, L. Kang, Q. Li, L. Guo, G.S. Chen, "Manufacturing resource allocation based on cloud manufacturing", 2012) described customers' requirement tasks at four different levels:

- Products
- Parts
- Processing technology

- Machining procedure (or process)

Accordingly, manufacturing resources can be categorized into four different levels:

- Enterprise level
- Workshop level
- Cell level
- Device level

A task has a certain subtasks structure, which is usually a combination of the four basic structures, including sequential, parallel, selective, and circular.
Furthermore, there are two types of tasks: those whose subtasks' execution processes can be interrupted (i.e. subtasks' execution may span discontinuous periods), and the other type of tasks are those whose subtasks must be performed within a continuous period until their completion.
To schedule the tasks, it should be considered the service costs and the logistic costs.
The challenge issue is that, given the production time and production cost of each task in a production process, how to schedule tasks to minimize the total cost and time.

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Scheduling methods

Liu, Xu et al. (Y. Liu, X. Xu, L. Zhang, L. Wang, R. Y. Zhong, "Workload-based multi-task scheduling in cloud manufacturing", 2016) differentiate between "Random Scheduling" and "Workload-based scheduling":

- Random scheduling: tasks are scheduled in the order of their numberings irrespective of their workloads. This method acts as a benchmark for comparing the results obtained with different methods.
- Workload-based scheduling: tasks are processed in a descending (i.e. tasks with a larger workload are handled with a high priority) or an ascending order of workload (i.e. tasks with a smaller workload are handled with a high priority).

A critical aspect that can characterize different type of scheduling scenarios is the presence or not of time constraint, and so the authors consider:

- Without time constraint: the detailed steps are as follows: (1) a task is scheduled for execution, (2) a Cloud Manufacturing platform searches for all matching services (including the occupied ones) for each subtask to obtain a service set, (3) all the possible service composition solutions are calculated, (4) the overall QoS utilities of all the possible composition solutions are calculated, (5) the composition solution with the highest overall QoS utility is selected, and (6) the corresponding services and their occupying periods are recorded. This steps above cycle until all tasks have been executed.
- With time constraint: when time constraint is considered, some change needs to be made to step (5) for the scenario without time constraint. In this case, the optimal service composition solutions should be selected among the ones that satisfy the time constraint. If no solution could meet the time constraint of a task, then the task is regarded as being unsuccessfully executed. An unsuccessfully executed task does not occupy any services. That is why failure rate needs to be introduced for the scenario with time constraint.

The main metrics used to evaluate the system performance with the scheduling methods are the following:

- Total completion time (TCT).
  The total completion time is the time from the arrival of the first task until the completion of all tasks.
- Service utilisation (SU).
  Service utilization is defined as the ratio of the number of the total service occupying periods to that of the total periods within the total completion time.
- Failure rate.
  This index is specially introduced for the case with time constraint. The failure rate is the ratio of the number of the tasks that are unsuccessfully executed to that of all tasks.
- Average completion time.
  Average completion time is the ratio of the total completion time of all tasks to the number of tasks.
- Average cost.
  Average cost is the ratio of the total cost of all tasks to the number of tasks.
- Average reliability.

Average reliability is the ratio of the total reliability of all tasks to the number of tasks.

(Y. Liu, X. Xu, L. Zhang, L. Wang, R. Y. Zhong, "Workload-based multi-task scheduling in cloud manufacturing", 2016).

There are mainly two different task scheduling objectives.
According to the task scheduling method, when a certain task is scheduled for execution, it is possible to consider only the QoS utility of task, or not considering only the QoS utility but also the effects of scheduling that task on system performance such TCT and SU.
In the former case, the objective is to achieve the optimal execution of the single task, thus users' requirements can be best satisfied. In the latter case, the objective is to achieve the overall optimization of the entire system (i.e. not only satisfy users' requirements, but also shorten TCT and increase SU) (Y. Liu, X. Xu, L. Zhang, L. Wang, R. Y. Zhong, "Workload-based multi-task scheduling in cloud manufacturing", 2016).

Scheduling process main steps

Zhou et al. (L. Zhou, L. Zhang, C. Zhao, Y. Laili, L. Xu, "Diverse task scheduling for individualized requirements in cloud manufacturing", 2017) individualize five steps in the process of diverse task scheduling, including task submission, task decomposition, scheduling decision-making, schedule execution and product delivery:

Step 1: task submission
In this step, the service applicant submits their manufacturing orders with specific functional requirements and non-functional requirements to CM platform.

Step 2: task decomposition
Received tasks are decomposed into a series of subtasks with specific precedence for execution considering their functional requirements (e.g. task types and customized requirements).

Step 3: scheduling decision-making
Subtasks of each task are mapped to appropriate services according to their types. Then the scheduling system will select the optimal services for all subtasks from the possible service sets according to the non-functional requirements of tasks and

information of services. Finally, the optimal task scheduling solutions are generated for all tasks based on the optimization objective.

Step 4: schedule execution
The matched subtasks are dispatched to service providers thanks to Internet. Once received, service providers execute the allocated subtasks in their local manufacturing systems.

Step 5: product delivery
Once all subtasks in the subtask directed graphs are completed, the final products are delivered to the related service demanders.

2.2.1.10. Service transaction

In a typical Cloud Manufacturing environment, the main goal of Cloud Service Transaction (CST) is to find appropriate services to execute and complete a task with high-quality to meet and satisfy the requirements of customers and improve the utilization and sharing of cloud service, and at the end to arrive at the final payment. This process contains the complex relations between the information flow, logistics and capital flow owning to the particularity of various Cloud Service in CM.

About service transaction, several results exist with the aim to solve this issue.
Cheng et al. (Y. Cheng, Y. Zhang, L. Lv, J. R. Liu, F. Tao, L. Zhang, "Analysis of Cloud Service Transaction in Cloud Manufacturing", 2012) described briefly cloud service transaction of the tripartite users (i.e., provider, operator, and consumer) and provided the detailed transaction flow. There are also other quantitative researches on the utility modelling, equilibrium, and coordination of resource service transaction. The comprehensive utility models consider the revenue, time, and reliability for the three sides in the resource service transaction process, faced with uncertain factors under decentralized decision-making conditions.

2.2.1.11. Logistic Services

The logistics services serve for the specific processes and results of some kinds of manufacturing services.

Due to different requests of the tasks implementation, the logistics could be the transportation of the results after service execution, or the transportation of the materials in the process of service execution.

Currently, in logistics, there are many company-defined service networks that are based on fixed and/or dedicated logistics plans. For example, the logistic service network between a supplier and the retailers it supplies, or yet the logistics network of an express carrier, are mostly dissociated from other networks and each actor in these networks works independently from the others.
The new logistics concept can be examined after proposes an analogy with the internet network that was able to develop a global system of data transport (datagrams). This is the physical internet, and this is expressed through collaborative work during the "Physical Internet NSF Workshop" at Georgia Tech (Atlanta, USA) in May 2010 expressed it vividly as the evolution and integration of container standardization and intelligence, broadband communication, cloud computing, and deregulation in transport, catalysed by new logistics business models.
The main objective of the "Physical Internet" is to achieve locally focused systems with global reach that are more economically, environmentally, and socially efficient and sustainable than contemporary systems. The idea of the "Physical Internet" (PI) is that to interconnect these logistic service networks through the transposition of the principles of the Internet. Therefore, the aim is the universal interconnection of logistic networks (R. Sarraj, E. Ballot, S. Pan, B. Montreuil, "Analogies Between Internet Network and Logistics Service Networks: Challenges Involved in the Interconnection", 2014).

2.2.1.12. Service fault-tolerance

As in cloud computing, fault tolerance is an essential and must have feature of MSM. In the CM environment, manufacturing cloud services are more complex, dynamic, and diverse. Apart from the traditional characteristics of web service such as I/O, preconditions, and effects of invoking, more attributes should be considered such as the running status and the complex business relationships among enterprises. As a result, CM services are complicated. In CM, service status, service QoS, etc., are changing all the time such that manufacturing cloud services are dynamic. As CM platform aggregates services that are required during the product development life cycle, CM services are various. Due to the above-mentioned characteristics, the invoking of resource services has the characteristics of long lifecycle, high complexity, and so on (F. Tao, L. Zhang, Y. Liu, L. Wang, X. Xu, "Manufacturing Service Management in Cloud Manufacturing: Overview and Future Research Directions", 2015).

So, it’s possible that the execution and the composition of cloud service may undergo some sort of failure. It therefore has a strong need to manage the failure pertaining to cloud services and their compositions.
Although failure management is critical for the actual application of CM, few studies have been conducted to investigate it probably because the research of CM is still at early phase.

2.2.1.13. Service execution and monitoring

Advanced monitoring techniques consisting of smart sensor networks and seamless communication procedures can provide the required awareness to decision making process (D. Mourtzis, E. Vlachou, M. Doukas, N. Kanakis, N. Xanthopoulos, A. Kountoupes, “Cloud-based adaptive shop-floor scheduling considering machine tool availability”, 2015).

Monitoring techniques have been widely investigated in literature, where applications have been reported for tool condition monitoring and monitoring for maintenance. However, monitoring on a higher level, i.e. monitoring of the machine’s availability, is still in its infancy. Machine monitoring techniques utilize various methods for data retrieval and data transfer. Among other, sensory systems, operator input, and direct communication with machine tools controllers are frequently used. Widely used sensory systems consist of accelerometers, acoustic emission, force, and temperature sensors. Yet, for the purpose of high-level machine availability monitoring, current and power measurements seem to be the most proper signals to identify the status and operating mode of a machine tool ((N. Tapoglou, J. Mehnen, M. Doukas, D. Mourtzis, “Optimal tool path programming based on real-time machine monitoring using IEC 61499 function blocks: a case study for face milling”, 2014); (N. Tapoglou, J. Mehnen, A. Vlachou, M. Doukas, N. Milas, D. Mourtzis, “Cloud based platform for optimal machining parameter selection based on function blocks and real-time monitoring”, 2015)).
In addition, the influx of monitoring data streams from heterogeneous data sources requires data, sensor, and information fusion techniques to derive to meaningful information (D. Mourtzis, E. Vlachou, M. Doukas, N. Kanakis, N. Xanthopoulos, A. Kountoupes, “Cloud-based adaptive shop-floor scheduling considering machine tool availability”, 2015).

The cloud service begins from the monitoring service for up-to-date machine availability and utilisation to guarantee that decision making for planning and optimisation become resource-aware and well informed.

The service monitoring supports the collection and display of state information of manufacturing services to their consumers, so that users can track the progress of task executions. Advanced users would develop their own manufacturing platforms, software or applications that contain the decision-making modules based on the monitoring service (C. Yang, W. Shen, T. Lin, X. Wang, "A hybrid framework for integrating multiple", 2016).

2.2.1.14. Safety and security

Corporate information often contains sensitive data of customers, consumers and employees, business know-how and intellectual properties (A. Mokhtar, M. Houshmand, "Introducing a roadmap to implement the universal manufacturing platform using axiomatic design theory", 2010).
Security is one of the major issues which hampers the growth of CM industry.
Securing sensitive data and the ubiquitous availability of requested applications in the Cloud are of major concerns for potential users of Cloud services. Manifestations of these concerns regularly appear in many existing CC services, as a profound unwillingness and anxiety of letting sensitive and important data escape outside the boundaries of the physical company premises (K. Popovic, Z. Hocenski, "Cloud computing security issues and challenges", 2010).
Few works have performed researches on the security issue of CM: a security framework for CM was proposed, which includes four levels: infrastructure security, identity and access management, data protection and security, and cloud security as a service (F. Tao, L. Zhang, Y. Liu, L. Wang, X. Xu, "Manufacturing Service Management in Cloud Manufacturing: Overview and Future Research Directions", 2015).
The service models (SaaS, PaaS and IaaS) require different levels of security in a Cloud environment. IaaS is the base of all CC services, with PaaS built upon it and SaaS in turn built upon PaaS. Just as capabilities are inherited, so are the information security issues and risks (X. Xu, "From Cloud Computing to Cloud Manufacturing", 2011).
But the research on security and privacy management in Cloud Manufacturing is still at an early stage, because things are more complicated in a cloud environment than typical web environment. Research on information security has been one of the pillars of advanced IT systems.
One proposal about this issue comes from T. Kim, et al. (T. Kim, C. D. Cera, W. C. Regli, H. Choo, J. Han, "Multi-level modelling and access control for data sharing in collaborative design", 2006) proposed a multi-level modelling technique, based on feature-based modelling and mesh simplification, to enable information protection in computer-aided collaborative design. It's very helpful when a team of designers works collaboratively on a 3D assembly

model, a component of the assembly is presented in full detail to those who have full access privileges to the component, but at an abstract level of detail to those who have fewer access privileges. Such levels of detail are in two phases:

- Volumetric feature removal, achieved through interactive feature recognition on the CAD model.
- Multi-resolution mesh construction, which is based on polygonal simplification. Appropriate representations of the assembly are extracted by direction of access matrix, and then presented to the users participating in collaborative design.

Research on information security has also extended to the cyber-physical environment, with more focus on security mechanisms for prevention, detection and recovery, resilience and deterrence of attacks in a cyber-physical environment (A. Cardenas, S. Amin, B. Sinopoli, A. Giani, A. Perrig, S. Sastry, "Challenges for Securing Cyber Physical Systems", 2009).
Results from this research could provide general implementation guidelines for Cloud Manufacturing. However, there are more specific privacy and security requirements in a Cloud Manufacturing environment. Xu (X. Xu, "From Cloud Computing to Cloud Manufacturing", 2011) pointed out that manufacturers are very concerned about the confidentiality and privacy of their data.
In a more recent research (Deng et al. X. Deng, G. Huet, S. Tan, C. Fortin, "Product decomposition using design structure matrix for intellectual property protection in supply chain outsourcing", 2012) proposed an original approach to decompose product structures, to controlling IP leakage risk in supply chains using a design structure matrix. A design structure matrix is employed to study the potential risk of IP leakage, and considered different types of interaction between product components. Based on such a matrix, a clustering algorithm is developed to decompose and allocate the product components, having regard to IP protection issues. This methodology could be considered like a decision support tool to help the manufacturer select a set of optimal suppliers, while minimising information leakage risks and manufacturing costs. To protect IP information in product design files in a Cloud Manufacturing environment, an innovative partial encryption approach was proposed to represent a CAD model into different granularities of information, for different users with different access rights (X. Cai, W. Li, F. He, X. Li, "Customized encryption of computer aided design models for collaboration in cloud manufacturing environment", 2015).
In this method, a CAD model can be flexibly encrypted to realise partial sharing of features and safe protection of the rest of the model, according to collaboration requirements. Meanwhile, during encryption and decryption, the CAD model is always manifold, no matter which feature is encrypted or decrypted, to ensure the user friendliness, model validity, and

robustness of the approach. Data protection in a collaborative engineering environment is a significant issue that has received an increasing amount of attention in recent years.
The data encryption for sensitive data exchange was analysed with much attention in previous studies. To protect core IP information within a product design, the authors still need more systematic technological solutions to protect sensitive data from all parties involved in the network, even though the reported encryption technologies have demonstrated some good applicability in a Cloud Manufacturing environment. The needs of service consumers and service providers need to be valued. Thereafter, a set of business processes that are equally secure for any stakeholders can be constructed. In this process, the main challenge is to balance the need to share manufacturing information and product data for successful service provision with the strong desire to keep proprietary information.

2.2.2. Business point of view

Moving to a more business considerations and evaluations, there is not much work about in literature, due to the fact the new paradigm of MaaS, in these years, is undergoing a study more from the technical point of view.
Anyway, with a possible adoption of Cloud Manufacturing, due to the globalization and increasing offshore sourcing, "Global Supply Chain Management (GSCM)" can be considered, of course, as a main problem for most of the companies (H. Akbaripour, M. Houshmand, O. F. Valilai, "Cloud-Based Global Supply Chain: A Conceptual Model and Multilayer Architecture", 2015).
Comparable to traditional supply chain management, the key goals of GSCM are mainly reducing the cost of manufacturing and procurement and decreasing the risks related to purchasing activities. As a main difference, while GSCM aims to involve a company's worldwide opportunities, interests, and suppliers, the traditional one simply considers a local or national orientation. Because global supply chain usually implicates trading with a lot of countries, it also usually includes many new difficulties that should be dealt in an efficient manner. First, for precise decision-making, companies need to determine the overall costs. Although local labour costs may be potentially lower, companies must also consider many other kinds of costs as costs related to logistics, space, transportation, tariffs, and other related expenses for doing their activities across the globe. Without to forget that the companies need to factor in the exchange rate. Companies must develop a complete analysis of every aspect of financial operations regarding all the aforementioned differences as part of their global procurement program.

Another big issue that should be addressed when dealing with a Global Supply Chain it's the time.
There's the necessity to consider any kind of time that could can influence the performance of the company. Also, the company's lead time can be variable and it can be decreased or increased by transportation times and productivity of the overseas employees. Therefore, it is also necessary for the company to depict its overall outsourcing plan, developing critical criteria to have a successful GSCM.
For whatever reason, the company may prefer to use local manpower (as shown before potentially less expensive) and keep some aspects of supply chain closer to home. On the other hand, the company may find services from an outsource provider are more desirable.
So, the supplier evaluation and selection process becomes another aspect that must be evaluated. Assessing and comparing several vendors within the company's home-country can be challenging enough, but comparing vendors from globally distributed suppliers can be even more complex.
Moreover, companies who desire to ship their manufacturing overseas could meet some additional problems as well. The number of plants that are needed, besides the locations for those plants and hub-and-spoke network design, can create difficult logistical concerns for companies.
Also, the optimal number of suppliers is a very critical aspect, because with fewer suppliers the company can manage or evaluate each part appropriately, but it could also cause some difficulties if one vendor fails to deliver as expected or if one vendor has bargaining leverage to obtain price concessions.
A new and relevant consideration that can born thinking about the application of MaaS, is the possibility to share the resources between different providers that could bring many advantages for example related to the setup, both time and cost, the level of utilisation of the resources and the availability and maintenance of the plant machineries.
Talking about the share between companies it is important to do a precise specification: in fact, a collaborative manufacturing is not implied using Cloud Manufacturing, but the use of this last can bring relevant advantages to the cooperation between companies. In fact, it is important to remember that the authors can talk of Cloud Manufacturing if there is a service, in the case of MaaS a manufacturing service, available in a cloud platform, but a situation in which some companies help themselves and collaborate between themselves does not mean Cloud Manufacturing.
All the above-mentioned issues permit to light up the complexity of the globalization. It is intensely changing how manufacturers can operate, and at the same time is exposing companies to tight competition.
Additionally, the relationship between manufacturer and supplier should be integrated and handled on a global scale. In fact, globalization has created new opportunities for companies

to reach different customers in the global market as a potential source of sustainable growth. Just as there are both major costs and major benefits to the globalization, there are similar pros and cons of a Global Supply Chain. Therefore, companies need to trade off its risk and rewards to make appropriate decisions.

Chapter 3
Model construction

To answer the first questions born at the beginning of the work explained in the previous chapters, the authors thought to create, starting from the literature, a model that permit the authors to do, in a completed and a clear way, all needed considerations to reach the goal. The main core of the model is a matrix, with specific rows and columns, that the authors are going to analyse below.

3.1. Matrix

The model can provide two main outputs: the model itself, created to evaluate the status of a company with a view to applying MaaS, and the results obtained by the model application with the companies to do some considerations about the MaaS applicability.
The model is a matrix that provides three kinds of information, and it is composed by an objective part and a quite subjective one: the former is composed by the main aspects, to evaluate, involved in the process starting from RFQ to delivery service and the respective possibilities that can benefit or not the MaaS application.
The latter refers to the different importance of each row, also relating to different cloud environments.

Now the authors analyse more in detail each part of the model.

First, it is very important to underline that the matrix is pointed towards the provider point of view.
The consumer requires to use a service, without paying attention to its production process (technical and business problems).
The consumer can be everyone, from a civil, to a generic company or a manufacturing factory.

In fact, considering for example both service provider and consumer as manufacturing companies, the consumer does not have to work in cloud to require a service to a provider, who, instead, must use the MaaS paradigm to provide a service. The only requirement for the consumer is the accessibility to the cloud system, in fact the production process of the consumer's company does not have to use the cloud.

The authors divided the rows of the model in two parts, the technical and business point views, called technical and business level.

The rows of the matrix represent the main steps (necessarily evaluable for the MaaS application) involved in the process starting from the request to the delivery of a service, and these compose the first kind of information that the model provides.

To each row is associated a range of possibilities, related to that specific aspect, which refers to the solution that a company can use. This is the second output of information of the model. The range of scoring utilised is from -1 (limit to the cloud applicability) to +1 (best solution to be able to apply MaaS), passing from 0 (that means this step can be improved aiming to apply MaaS).
As explained above, these two parts represent the objective part of the model, where the related considerations are not or very little questionable.

Considering then the last part of the matrix, understanding logically that is the third and last kind of information that the matrix can provide, it is possible to note that for each row is assigned a weight, called Factor of Importance, to highlight the different importance of each row and, more in detail, this value can vary in each row depending on the kind of cloud environments.

At this point it is however important to make some precisions.
The MaaS has three different kinds of provider solution: Single Company, Group of Companies and Any Company. So, inside the column of the Factor of Importance, the authors evaluate all these kinds of providers to have a complete analysis, and to indicate the best solution for the company analysed.
Moreover, only in the Group of Companies sub-column, it is important to distinct the "Service Provider Only" (SPO) company case and the "Dual-role" case: in the first case, the group can be composed by companies making different services, all necessary to provide final services more complex or complete, so they will be always SPO.
In the second case, the group can be composed by companies making the same services, so a company of these can be both service provider and service consumer when it is not able to

provide the service for some reason (e.g. full capacity production in a certain period), so they will be Dual-role companies.
The authors do not do the same consideration for the sub-column Any Company because it is not possible to decide and foresee the type of companies participating that platform, being an environment without any boundaries.
Referring the Group of Companies and the Any Company, it's very important to notice that a collaborative manufacturing is not implied using MaaS. In fact, when the authors talk about Manufacturing-as-a-Service, being an application of Cloud Manufacturing, the authors should start that everything is considered a service, and that service is available on cloud. But, of course, the MaaS application, like in these cloud environments, can bring relevant advantages to the cooperation between companies.

The authors chose to do all these specifications, within the objective of evaluating the applicability of MaaS, because they believe it is important to specify in the final phase also the type of cloud environment most appropriate for the company examined.
This because an aspect can be different, for example, for a Single Company service provider with respect to an Any Company service provider.
Finally, it is possible to consider the range of values of the Factor of Importance from 1 to 5; the highest value indicates the higher importance of that aspect for the related kind of service provider, and conversely for the lowest value and so thinking on a follow model application the highest value indicates that the company should apply that type of cloud work environment.

Basing on the most cases, to help giving a score, implicitly, the authors considered the following consumer environments, that is the most common possible situation: the Private Cloud to the Single Company, the Community Cloud to the Group of Companies and the Public Cloud to the Any Company solution.
With the goal to obtain a conclusive result through the application of the model, it is necessary to multiply, for each row, the score for the respective Factor of Importance, and then to sum each row's result, for each kind of provider (column).
The higher the final value, higher the probability of being able to apply MaaS in that company, and then, after subsequent and considerations, in the respective industrial sector.

It follows a deeper explanation of the model.

		Score			Factor of importance			
		-1	0	1	Single	Group of companies: SPO	Group of companies: Dual-Role	Any
RFQ ANALYSIS	RFQ format		mail / meeting	uploaded on website	1	1	1	1
	% year of reply to RFQ	low	medium	high	1	1	1	2
	% of regular customers	low	medium	high	4	3	3	2
	Check of feasibility of the service: who	personnel interchangeable	fixed expert team	software	5	5	5	5
	Check of feasibility of the service: how	knowledge and experience		validation on website	5	5	5	5
	Formalization of the process from RFQ to start production process	impossible	hard	easy	4	4	4	4
	Formalization of the process from RFQ to list of resources involved	impossible	hard	easy	4	4	4	4
	Decomposition of the request in a task list: who	personnel interchangeable	fixed expert team	software	5	5	5	5
	Decomposition of the request in a task list: how	knowledge and experience		software decomposition	5	5	5	5
	Quote Service: who/how	personnel interchangeable	fixed expert team	software	4	4	4	4
	Period of the quote service release	long	variable	short	3	3	3	3
	Formalization of Quote Service	impossible	hard	easy	4	4	4	4
RESOURCE IDENTIFICATION	Types of manufacturing machines	completely manual	quite automated	fully automated	2	2	2	2
	Complexity of capabilities, Know-how	high		low	5	5	5	5
SERVICE COMPOSITION	Range of services offered	not constrained		constrained	5	5	5	5
	Number of different kind of machines involved for each service type	high	medium	low	1	1	1	1
	Kind of processes involved for each type of service	depend on client request specifications	quite standard	fully standard	5	5	5	5
SERVICE QUALITY	Quality standard of service offered	organization standard	national standard	international standard	3	4	4	5
	Rejection rate of services offered	high	medium	low	4	4	4	4
	Repair rate of services offered	high	medium	low	4	4	4	4
SERVICE-TASK MATCHING	Matching between service and task: who	manufacturer employee	expert team	software	5	5	5	5
	Matching between service and task: how	knowledge and experience		software algorithms	5	5	5	5
	Formalization of service task-matching process	impossible	hard	easy	5	5	5	5
TASK SCHEDULING	Production scheduling: who	manufacturer employee	expert team	software	3	3	3	3
	Production scheduling : how	knowledge and experience		software algorithms	4	4	4	4
	Formalization of task scheduling process	impossible	hard	easy	5	5	5	5

		Score			Factor of importance			
		-1	0	1	Single	Group of companies		Any
						SPO	Dual-Role	
LOGISTIC	Complexity of value chain (subcontractors, more own factories etc...)	heavy sequence	few companies involved	no sequence	4	4	4	4
	Overall costs (transportation, space etc..)	high	medium	low	2	2	2	2
	Coordination complexity	high	medium	low	4	4	4	4
	Coordination costs	high	medium	low	2	2	2	2
PLANT	Utilisation level	high	medium	low	3	3	4	5
	Costs	high			4	4	2	3
				low	3	3	3	3
FLEXIBILITY	Setup time	high	medium	low	4	4	4	4
	Setup cost	high	medium	low	4	4	4	4
	Possible introduction of new resources and/or capabilities	no		yes	4	4	4	4
DATA SENSITIVITY	Sharing of the process information	unique technology			1	3	3	5
				standard technologies	3	3	3	3
WORKFORCE	Specialization	low skilled	skilled	very skilled	1	1	2	2
SUPPLIERS	Complexity of the supply chain	high	medium	low	2	2	2	2
	Procurement criticality	niche market		common market	5	5	5	5
	Location	far		close	1	1	2	3
	Costs	high	medium	low	1	1	2	1
CUSTOMERS	Quantity and kind of information provided about the service	general features of service	drawings	drawings + BOM	2	2	2	2
TRANSACTION	Interaction level between consumer and provider	during the process		only at the beginning	4	4	4	4

Tab. 3.1 – *Matrix.*

3.1.1. Matrix elements

3.1.1.1. Technical level

For the technical level, the authors considered five main criteria (developed in detail) between the fifteen ones mentioned in the previous chapter, which summarize in a completed way the steps most important to analyse, from the customer's request to the delivery of the product:

- RFQ analysis
- Resource identification
- Service composition
- Service-task matching
- Task scheduling

RFQ analysis

The first step is about request for quotation by the client, that it is considered, very often, the most crucial and critical phase between all technical steps, because the output of this step includes all information necessary for the company to start with the production, and all information for the customer to accept the company condition.
The authors wanted to consider RFQ analysis divided in two parts:

- The former part concerns more a general point of view: so, the authors considered, for example, how the client presents his request to a company, if it is already a quite automated process or not, and consequently closer to MaaS application.
  Also, the percentage of answered RFQ and the percentage of usual customers are considered interesting points to evaluate the applicability of MaaS, because if a company has many usual customers it’s more probable that it already knows the all range of services requested and what the most of customers want, so it can reduce the time to start to manufacture, that could decrease using MaaS.
- The latter part is related to a more technical point of view: the authors started from the check of the feasibility of the product, considering the service that a company can offer, analysing how this check is conducted and who oversees this.

The authors guess that is a very hard point for the applicability of MaaS, because it is very important and mostly necessary make an evaluation based on the knowledge and the experience of some expert teams, especially of an engineering team.
The authors can enlarge the same consideration also for another point that they evaluated, that is the matching between the request of the client and the task needed for the production.
To permit the above matching between service and task, it is necessary the decomposition of the tasks needed, to identify the simplest processing required, according to the resources owned. Considering the request of a new product, this phase is impossible to be done only by a software. The human action is irreplaceable in this phase.
Obviously, to use MaaS it is essential the formalisation of the processes involved from the request to the service delivery.

Resource identification

To identify completely the resources, the cloud needs to understand the types of machines, the types of capabilities and the know-how related to the operators, so once resources are identified, they can be virtualised.
The types of machines and the know-how are related to the manufacturing resources, both soft and hard form.
For the object of the thesis is not mandatory to understand all the manufacturing resources involved in the plant and to know about their virtualisation. The authors delegate this deeper analysis for a future work.

Service composition

Concerning to service composition, the authors looked for understand how the company decides which machines, processing and employers are involved for each kind of good. This is the starting point to understand if the service (internal and external to the company) can be composed in a formalised way and to be upload on the cloud.
The authors also analysed the range of the services offered by the company, namely what a company can offer like the entire final product, and/or a part of the final product, and/or multiple processing, and/or single processing. The range can be well defined or not. In the latter case, due to the possibility to customise its, it will be very difficult to identify the resources needed for a new request.

Another interesting consideration is that a high number of services would be very useful in a cloud with more providers participants because it would give to the company more job possibilities and opportunities. On the other side, this situation would be, however, more complex and difficult from the virtualisation point of view.
For the kind of processes involved for each type of service offered the authors associated the standardisation or not of themselves. This aspect is probably the most important factor to predict the applicability of the MaaS, because a complex service depending on client request specifications lead to change the processes needed to provide it, so it cannot be earlier defined, so then virtualised. It is quite impossible to describe a service that is the direct consequence of a complex designing work and so it is quite impossible to write an algorithm to program its informatically.
On the other side, if the service provided by a company is quite standard or even more completely standard, it will be more useful and smart to apply MaaS.
Finally, considering the single service, the authors focused on the number of different machines involved for each service, to evaluate mainly the complexity of the service provided.

Service quality

Also, the quality of the service could be a not insignificant point because if the performance of the company is low, the authors suggest it to not use a cloud system. This can be measured through the quality of the output.
Because of the bigger market, the quality standards used by the company are fundamental to participate in a cloud environment.
About the quality of the service provided, the authors also decided to evaluate the percentage of rejection and repaired service that the company has.

Service task-matching

How and who matches the tasks, needed for product manufacturing, with the services, provided by the company, is important to individualise which are the appropriated algorithms to run the matching. In fact, the pure action of matching is a problem only for the selection of the best algorithms (or for the writing of the new one), because what a company really needs to reply to customer's request has already been during the check of the feasibility previously.
In literature there are many algorithms, many proposals about how to do selection, or some basis to create a software to do this.

Task scheduling

The scheduling does not need a new model, because if it is quite formalised, it could not be difficult to make it digitalised. It is only programming.
To understand if the scheduling can be formalised is necessary to evaluate who plans it and how.
Linking to a business point, like logistic, the authors also analyse not only the scheduling between the machines in a same company, but the scheduling between different manufactures or different factories. For this situation, the application of CM could be very helpful because, referring for example to a community environment like a Group of Companies, thanks to a cloud, the operator has an overview to all manufacturers, and so he can reach the choice of the best producer who could be faster and more appropriate.

In respect with the technological steps individualised in the previous chapter, the authors don't consider the conversion of the customer request format, the resource virtualization and the service fault-tolerance.
For the first two aspects, the reason is that the common gaps individualized are problems only from the informatic-programming point of view: they can be solved in the future research works, and they will be different for each sector.
Then, the authors decided to not consider the last aspects because some methods to evaluate the fault-tolerance, in a production process, already exist, as well these methods do not change too much in a cloud-based system.
Furthermore, the authors do not consider the resource virtualization because it's an aspect secondary about the applicability of MaaS. In fact, the resource virtualization is not a critical step, because the virtualization of capabilities and machineries depends only on the computer programming (so it is a future research area, specialized for each kind of company).

3.1.1.2. Business level

For the business level, the authors considered the main parameters and aspects basing on authors' background and knowledge of the industrial realities, gathered as follow:

- Logistic
- Plant
- Flexibility
- Data sensitivity
- Workforce

- Suppliers
- Customers
- Transaction

Logistic

If to make the finished good is necessary a sequence of companies (excluded raw material providers), own or not, the logistic costs, like a transportation for example, will increase and accordingly the coordination will be more complex and expensive, because there will be the necessity to have an employer (or many employers) dedicated and this could complicate the use of MaaS.

It becomes fundamental to consider the value of the final product. In fact, it does not make sense to work applying MaaS to provide a final service very poor, that it requests a very complex value chain, long and hard transportations and consequently high cost, because the gain would be too low, and then the application of MaaS will lose its meaning.

But if the authors consider a collaboration between companies, delimited in a very narrow geographical area, for a poor final product some cloud environment could be very helpful.

For these reasons, as the complexity of chain and coordination increases, the difficulty to apply MaaS increase as well.

Plant

About the utilisation, in the case the capacity of the plant is not totally used, some resources available can be shared with other companies to make other products. In this way, there is a twice advantage, both for who "rent" the resource in terms of resource utilisation and for the resource users in terms of production and capital saved (it can happen that a company needs a resource just for only job, so it could be not affordable to get one).

The costs of the equipment, of the machineries and so more in general of the plant lead to be open or not to new resources. MaaS cannot be applied in a capital-intensive plant.

The high costs of the equipment, of the machineries or of the plant lead a company to share them, so it could be affordable to Group of Companies and Any Company solutions.

So, depending of the cost of the machinery, there will be advantage to share it.

Flexibility

First, to apply the MaaS, a company must be open to new resources or capabilities, just think about the interconnection, e.g. with Wi-Fi connection, between each machine or between

company software and machines, that nowadays most companies do not understand the utility and then they do not use.
Talking about flexibility the authors also refer to setup time and costs, and, as explained for the logistic, this can be influenced by the value of the final product, because high set up time and cost for a very poor product could limit to the applicability of the cloud.
Thinking of heavy setup times and costs, a company must consider them and must plan the production process blocked around them, so maybe the process is saturated at 100%.
High upfront investment of time and cost for setting up a manufacturing facility is an obstacle for manufacturing companies to become more flexible in the dynamic market. That's one of the selling points of MaaS. In fact, a company with high setup costs and time should be Single Company because of the decreasing of the demand unpredictability, but it should be in a cluster because it could delegate the unfulfilled demand.
With manufacturing activities being auto-configured in the cloud and manufacturing activities being carried out by service providers in the cloud, a company has great potential in adapting to market changes.
In the end, having setup time and costs high decreases the advantages using cloud, but this doesn't limit the applicability of cloud.

Data sensitivity

If the data of the process, or some aspects of that, are unique and so secret, it could be difficult to share to others partners some steps of the process to make the finished good: it could be very hard to use of shared platforms between more providers.
Otherwise, the secrecy of data is maintained in a Single Company cloud environment, commonly developed for a Private Cloud.

Workforce

The skilled workforce can be both an advantage and a disadvantage.
An advantage because is more required in a Group of Companies or everyone cloud environments (see later how can change), and that brings to be more specialised into the market.
A disadvantage when a company requires to reply to a customer request too heavy for itself and it needs some subcontractors, who could not have the skills needed.
Another consideration is that a too skilled workforce usually means niche product manufacturing and then very specific and accurate process. And to represent in a cloud

platform these kinds of process could be a problem. Anyway, due to the low knowledge about this aspect, the authors don't do any conclusion.

Suppliers

The complexity of the supply chain is an obstacle to the MaaS. This is since the higher the number of companies, the more difficult it would be to manage and collect data. Certainly, an easier procurement to manage and then a clearer manufacturing process would be simpler to have in cloud.

It would be ideal to have an optimal number of providers, not too high that can cause management difficulties but not too low to avoid lack of materials.

Anyway, it is fundamental the position of the company inside the value chain. Probably just only a part of the chain can use MaaS, but this could bring a lot of benefits to entire value chain.

Another important aspect to evaluate is the providers geographical location: if the suppliers of raw materials are very far from the company, this entails a more complex value chain and moreover, different government and different social environments lead to different motivations and give different incentives to use cloud.

But at the same time the application of a cloud between more participants located far from each other would be useful because permits to share and communicate in a faster and more reliable way.

The geographically distributed companies involved in a Group of Companies or in a public cloud would promote a specific material procurement that can be a problem for some of them.

Another important point to consider is the criticality of raw materials, because if there is a need of very special and critical material, e.g. diamond, the use of cloud is more complex than an expert, who, thanks to his know-how, can move into a specific market, independently by the types of cloud ambient.

The last aspect considered is the cost related to the supply, that it could find specific advantages for providers organised in group especially for the Dual-role company. In fact, if more companies collaborating each other have the same raw materials and so the same suppliers, the price of the materials needed will be lower because amortized between all companies involved.

Customers

A quite important point is about the product information provided by the customer because many times the clients are not so expert about the specifications and about the characteristics of the product, so could happen that they present a request very poor of technical information.

This could cause a very long time of comparisons between customer and company that extends the product lead time.

Transaction

The MaaS is a gain for the possibility by the customer to monitor the product's state, for all manufacturing.

Otherwise, with the use of the cloud, it can be more difficult to interact once process is started.

3.1.1.3. Scoring

As explained before, this part of the model offers the possibilities that a company can use for each step, both operational and business, from the RFQ to the delivery of the service.

For this part of the model some ranges of possibilities could seem quite vague or few defined, like "high-medium-low".

It is very important to notice that this model is not created for everyone, so the person who is going to use this model to evaluate the status of a company regarding his MaaS applicability, should be an expert of Cloud Manufacturing, able to evaluate, with a company, the single situations for each step. This is since, being the Maas not applied yet, some parameters or well-defined criteria to evaluate some aspects (time of quotation, set up time, rejection rate…) do not exist. So, it will be up to the expert and the company to examine each single aspect and draw the most appropriate considerations from it: the current solution is a limit or an advantage?

Considering the subjective rows having for example "high-medium-low" as possibilities, the Score must be assigned first considering the different kinds of business. Only in a second analysis, considering different factories belonging the same kind of business, the Score could change. This is a fundamental rule using the model.

Below, the scores for each aspect analysed.

RFQ analysis

RFQ format

From the responses of the companies, the authors individualised two possibilities: the former is via mail, calls and meeting, privileging the negotiating, the latter is uploading the requests, considering drawings, BOM and anything required by the provider. Obviously, the last one is the nearest to the concept of digitalisation and MaaS.

% year of reply to RFQ

Valuation provided by the company.

% of regular customers

Valuation provided by the company.

Check of feasibility of the service: who

Depending on the kind of product, a team is composed to evaluate the feasibility of the customer request. Moreover, the team can be also fixed, considering a group of experts in different area of the company. Another possibility is the use of a software, possible mainly only in the case of very standard products.

Check of feasibility of the service: how

Currently, in most of the companies the feasibility of the product is evaluated and analysed through the knowledge and the experience of the team in charge of it. In an ideal case, it can become possible to evaluate the feasibility through a software and to show the results on the web, modifying the features not manufacturable in the company.

Formalization of the process from RFQ to start production process

The chances of this point depend on the response of the company and on the personal evaluation of that process.

Formalization of the process from RFQ to list of resources involved

The chances of this point depend on the response of the company and on the personal evaluation of that process.

Decomposition of task list of service to find the right tasks: who

As the check of feasibility.

Decomposition of task list of service to find the right tasks: how
As the check of feasibility.

Quote Service: who/how
As the check of feasibility.

Period of the quote service release
Depending on the response of the company (who knows the markets' period to release the quotation) and the personal knowledge concerning the industrial sector considered.

Formalization of Quote Service
The chances of this point depend on the response of the company and on the personal evaluation of that process.

Resource identification

Types of machine
In nowadays there are three main kinds of machines that the authors found during the visits, the machines completely manual, another kind of machines that needs a little human support, and the last one that is fully automated, considered the most near to MaaS applications. This because the CNC machines have already a lot of information described and "explained".
Considering the machines of the company, it will be easier virtualise them if they are more automated, like CNC machine tools. In fact, it means that more information concerns the machine are already identified and described, resulting in available data.

Complexity of capabilities, Know-how
The authors considered the extreme highs, considered a low level of know-how and a high level one.
The higher is the know-how of the company, more difficult is to identify and describe it. So, this kind of resource can be impossible to virtualise. The same for the complexity of capabilities.

Service Composition

Range of service offered

The range of services offered can vary from an unlimited pool of services to a constrained possibility to choose, two different situations that can bring advantage or disadvantage illustrated hereafter.

Number of different kind of machines involved for each service type

Higher the number of machines more complex it will be the composition of them, because the number of things needed to evaluate is higher. Nevertheless, it is not a limit to the applicability of the cloud.

Kind of processes involved for each type of service

The kind of processes needed to compose a service can depend on client request specifications or can be standard.

If the types of processes involved for a service depend on the product specifications it will be quite impossible to apply the cloud, because, as written previously, more standard is the process easier is the applicability of the cloud.

Service Quality

Quality standard of service offered

The quality standard can be valid inside only the organisation, the country or the world. This is one of the most relevant row because if the quality standard used by a company are valid for itself only, surely the quality required by the customer will be different. If the customer requires a higher quality, it will be not satisfied, in the other case, in which the customer requires a lower quality, the service provider pays more money and time than necessary.

Moreover, the customer can reject the service because it requires specific standards legislation.

Rejection rate of services offered and repair rate of services offered

The rejection rate and the repair rate of the service offered have the same score possibilities: high, medium and low. The authors wanted to consider the last one as the most suitable situation to apply MaaS, since if a company responds appropriately to client requests, a hypothetical MaaS application could bring advantages more in more in terms of reliability and innovation in the market.

Otherwise, if a company does not have a good quality trend of responses, it does not make sense to pass to apply MaaS.

Service-task matching

Matching between service and task: who

Commonly, in a company, this important step is conducted by the personnel. The first case is that the manufacturer employee takes this decision, without any comparison with any expert. Another case is that there is a team of expert people responsible to combine the right task to the right service. The authors also had to consider the most difficult case but closer to MaaS in which a software, evaluating the requested task and needed service, makes and finds out the decision automatically.

Matching between service and task: how

This is very related to the previous point, because if the people is in charge to take a decision, the choice is based on his knowledge and experience. Otherwise, in the software case, it is necessary the use of some informatic algorithms.

Formalization of service task-matching process

The chances of this point depend on the response of the company and on the personal evaluation of that process.

Task scheduling

Production scheduling: who

As mentioned above for the task-service matching, there are three main possibilities of the scheduling of the work: it can be done by an employee, by a team if it is more complex or by a software if it is quite standard and simple.

Production scheduling: how

To schedule the processes, referring to previous point, for the first two possibilities the responsible can base his choice on the knowledge and on the experience, otherwise for the last possibility it is helpful and necessary the use of some algorithms.

Formalisation of task scheduling process

The chances of this point depend on the response of the company and on the personal evaluation of that process.

Logistic

Complexity of value chain (subcontractors, more own factories, etc...)

Reminding the exclusion of raw material suppliers in this step, the main consideration is about the subcontractors needed to provide the finished good, because the company is not able to process all the features required by the customers. This can lead from a heavy sequence of companies to the absence of sequence (all manufacturing in a unique factory).

In this point, it is not considered the possibility to delegate part of the capability to other companies because the saturation of the leading company.

Overall costs (transportation, space, etc.)

From the considerations of the company and the personal experience and knowledge.

Coordination costs and Coordination complexity

From the considerations of the company and the personal experience and knowledge.

Plant

Utilisation level

Valuation provided by the company.

Costs

From the considerations of the company and the personal experience and knowledge.

Flexibility

Setup (time and cost)

The result comes out from the comparison between the response of the company to questionnaire and the personal experience and knowledge.

Possible introduction to new resources and/or capabilities

The score reflects the response of the company.

Data sensitivity

Sharing of the process information

The possibility to share some processes data depends on the market in which the company is inserted and on the technologies used in the factory. Every company uses some unique process or technologies, but the authors considered the potential consequences in the sharing of same resources between more companies.

Workforce

Specialization

This analysis very interesting has permitted the authors to divide the workforce in three different kind, considering the very skilled employees, e.g. for a unique and very specialized product, and more and more towards a standard process the skilled and the not skilled manpower.

Suppliers

Complexity of the supply chain

From the considerations of the company and the personal evaluation and knowledge.

Procurement criticality

The authors taken in considerations the two extreme cases: niche market and common market. If the raw materials come from a niche market, it is a heavy limit to the applicability of MaaS, because it is impossible to identify and describe how experts of the company move into that market, knowing where is a specific raw material, the rules of different countries, etc. (e.g. diamond).

Location

It indicates the distance of the suppliers from the company. More far is the supplier more complex is the cloud applicability to each one, because of the different government, of different technologies' state of the art or because of the costs follows the increasing of the cooperation between them.

Costs

The range comes out from the comparison between the response of the company to questionnaire and the personal experience and knowledge.

Customers

Quantity and kind of information provided about the product (geometry, tolerance, roughness etc...)

The customer can provide only the main features of the products, explaining its final use, because of the not-knowledge about the product; otherwise, the customer can supply the drawings and the main raw material or, in the case that he has the know-how about the product required (but he doesn't have the capability to process its), can provide also the completed BOM.

Transaction

Interaction level between consumer and provider

Considered two main situations: when the customer can interact with the company at the beginning (before start of the process) or when an interaction between the parties is also possible during the process.

3.1.1.4. Factor of Importance

Technical level

From the technical point of view, the authors hold to be true that the level of difficulty to apply CM and so the factor of importance do not change depending on the three different possibilities to manufacture (Single, Group of Companies, Any), or on the possibility between the companies to collaborate or on any kind of environment (Private, Community, Public); for this reason, the authors assigned for each row the same value for each scenario. The only exception is about the percentage of regular customer, which, according to us, it is an aspect that can vary depending on the environment, because if a company works alone, like in a Private Cloud, this point is more relevant.

Of course, a company that cannot supply a service, exploiting for example the collaboration with other companies, can make up to that lack, but, as mentioned below, it is very important not confuse collaborative manufacturing with Cloud Manufacturing in a Group of Companies environment.

RFQ analysis

Working with the regular customers will be easier because many steps are already approved. Due to having less potential customers, for the Single Company point of view this step is more important than others.

The importance of the service information does not depend on the way with which the information is sent. In fact, in the worst case (mail/meeting), the possibility to use cloud for the all production processes is not avoided because if a company receives the completed BOM about the product by email, it can however put all data needed in an alleged software, able to decompose in sub-tasks and evaluate the feasibility of the request, and then to start with the manufacturing processes. This could be the more ideal case of MaaS application.

Similar reason for the percentage of reply to the number of requests in the year. Anyway, if the percentage is very low, it can be a problem for Any Company cloud because not foreseeing the demand is more probable to not reply to all requests.

The possibility to formalize the process starting from the RFQ and to start with the production process is very important, because it involves a time acceleration in the production and consequently a reduce of costs and an increase of profits.

The authors assigned the highest value of importance to the check of feasibility and the decomposition of client request to obtain the tasks list to manufacture, because the authors think that is one of the crucial and key steps to evaluate because it is on the basis both quote service and mostly of the service composition and matching.

Anyway, the authors consider this process quite unlikely to do by a software (this is a topic for the future research) because also in the case the customers' requests are usually standard, any required modification lead to a new evaluation of the feasibility. So, the authors consider the participation of skilled engineers necessary for every case in which the customer requires a new or quite customise service.

The process to provide the quote service and the consequent possibility to formalize it are fundamental for every kind of environment, regardless of the number and type of providers and consumers.
For the same reasons, it could be relevant the period needed to release the quotation. Anyway, the use of cloud for the quote service decreases the time to release the quotation.
The provision of a more customised service needs of knowledge, experience and evaluation of experts. The engineering phase needs of human intellect, and it can be supported by a software, but it cannot be substituted.

Resource identification

Considering the types of machines, ideally and theoretically, every machine can be virtualised, the problem is the complexity of the processing that the machine is able to do, but this is an aspect concerned informatic and software experts.
Another speech for the identification (and consequently the virtualisation) of the know-how, that is the base for many aspects: check of feasibility, scheduling of the task and matching between tasks and services. So, virtualise its can be a limit, because of the potential inability to do it.

Service composition

Once identified and virtualised the resources, the authors move on the service composition and two of the most difficult points are the range of the services offered by a company and the type of process involved for each kind of service. In fact, in the case the production process changes heavily, because it depends on the possibility to customise without boundaries the product, it will be very hard the use of the cloud, because, as mentioned previously, it is the result of the engineering analysis.
So, these two aspects have the same maximum importance for all the environments, as opposed to the number of different machines involved for each service type, that it has less weight related only the complexity or not of the work.

Service Quality

The quality standard used in the company can be a heavy problem to apply MaaS, especially for Any Company, where the customer can be anyone; so, it could happen that a company does not have the quality requirements wanted by the client. This consideration is not valid for a

Single Company cloud where the company provider and the client would have to know well each other, quality provided included.
The rejection rate and the repair rate can be a useful parameter to understand if the service that the company is offering are adequate and reliable in the market.

Service-Task matching

As explained previously, the matching between task and service is solved by an algorithm, but it is certainly relevant if the matching is formalized or not: in the latter case, it will be impossible to find an algorithm. This phase is strictly related to the feasibility check, in fact, due to this, the authors decided to give it the same importance, because for any service request modification is needed a decomposition of tasks and an assignment to available resources. Probably, a software should not able to decompose a new kind of task, because obviously it has computing constraints.
For this step, as for the follow (Task Scheduling) there is no difference between types of provider, because they are needed requirement for Any Company to any cloud environment.

Task scheduling

The scheduling is fundamental to evaluate the availability of the production, to provide a quotation in terms of time and cost and to have an optimal manufacturing. Its digitalization can reduce the time to evaluate all the previous aspects. For these reasons, all aspects analysed are important, especially the formalisation.
For the different kinds of providers, the authors refer to the same considerations done in the previous analysed step.

Business level

Logistic

Considering the logistic, the cloud applicability is quite important related to the complexity of the value chain and consequently of entire coordination, because all companies involved would have to use cloud to take advantage completely of all benefits that MaaS can bring, and a more complex chain of companies would need the presence of some people, considered in a cloud platform like the operator figure, able to manage all problems from the beginning to the end.

The economic aspect related to the supply chain is not properly a limit to the use of cloud, instead the use of cloud can decrease the costs of coordination.

Plant

In a cloud environment, the plant utilisation is one of the most important factor, mainly concerned the sharing of the available resources.
This row has an increasing importance, from Single Company provider to Any Company provider, because of the increasing of the pool of potential customers (both providers and consumer of the platform), consequently the increasing of the probability that someone use the resources of the company.
Then, a company will not have the own machines engaged only by the its client's requests, but maybe there could be the possibility that other providers, who for different reasons have their plant full, can use the service provided by the company considered.
From these considerations born the high value for the last kind of environment.
If the costs of the plant are heavy, the company is more interested to share the resources, to increase the profits. Especially in a Group of Companies Dual-role because the probabilities to find the same business is maximum. On the other hand, if the cost for a company are low the value of importance is considered the same for all types of environments, because no reasons would exist to choose a specific cloud environment.

Flexibility

In the case the setup time is high, like days (as in a case of painting industry), it will be very difficult to respect the concept of rapid scalability, agility and speed response that characterize the MaaS. The same explanation for the setup costs. There is no difference between the cloud environments.
Anyway, a company with high setup costs and time should be Single Company because of the decreasing of the demand unpredictability, but it should be in a cluster because it could delegate the unfulfilled demand, this is the reason of the equal weight for each environment.
The opening to new resources is quite important to the application of MaaS, because it is necessary to acquire new technologies to move towards cloud, and it is probable the opening to new markets or to customisation production.

Data sensitivity

This step could be very critical, mainly for the cloud ambient with the services shared with many other participants. If a company has a unique technology it will be unlikely that it wants to share some specific information. Due to this, Any Company has the higher value and Single Company lower, because in the latter case the company know well who uses the services.
Factor of Importance changes in the case in which the technologies are quite common, in fact it is equally important for any kind of applications.

Workforce

The considerations for this step are very similar to those done for the utilisation and the set-up cost and time. They are based, in fact, on the concept of the sharing, and so the possibilities to share own workforce can increase in a cloud with more participants, mainly for a very skilled workforce. In fact, there could be a twice benefit, both for those who rent the resource (in terms of utilisation and cost) and for those who use the resources (e.g. in terms of training cost saved).

Suppliers

Certainly, more complex is the supply chain more difficult is to apply the cloud to all the companies involved.
But the main aspect to consider in this phase is the procurement criticality, about the presence of a niche market or not, aspect that remains very critical for every kind of cloud environments. In fact, the difficulty of obtaining highly sought raw materials (often suitable for a niche market) does not depend so much on the number of companies involved, but often on environmental, political, government, wars, etc.

In the Any Company more than in Dual-role company, it is more probable to find suppliers of other companies participating the MaaS closer to the company.

About the costs, the consideration is very simple and based on scale economy, in fact in a Group of Companies, Dual-role case, the participants can have more possibility and are surer to have the same raw material need, so it possible to pay less the orders.

Customers

An important row is the quantity and kind of information provided by the customer. In fact, if the customer does not have knowledge regard the product, the company will do a design phase, together with the customer approval, and a negotiation. These are not feasible in a MaaS system.

Transaction

This last step is reputed more important, equal for any types of providers, because the lack of possibility to have an interaction only at the beginning will carry out quite impossible the entire MaaS use, due to the impossibility to stop the production once uploaded the request.

3.1.1.5. Matrix glossary

Terms	*Explanation*
DATA SENSITIVITY	Secrecy of some information about products' realization.
DECOMPOSITION OF TASK	It happens when the complexity of the service requested is high and consequently also the task is complex. So, it needs to identify the sub-task (sub-process) easier composing the entire task.
FEASIBILITY OF A SERVICE	Refers to the situation where the company is able to do the requested service.
FORMALIZATION OF X	The process considered can be defined clearly, describing each step (the sum of the steps composes the whole process). Thanks to this, the authors generalize how the process can be performed.
LEVEL OF TRANSACTION	Refers to at which production step there could be a comparison between company and client.

LOGISTIC	Includes all material, equipment and product movements/transportations and aspects of space organization.
MANUFACTURING CAPABILITY	Specific production function/process of a machine.
MANUFACTURING RESOURCE	Refers to the resources that are required during the product development life cycle.
QUOTE SERVICE	Service that provides a prevision about mainly the cost and time delivery of the service.
RESOURCE VIRTUALIZATION	Translation, in informatic language, of the characteristics and capability of a machine.
RFQ	"Request for Quotation": phase that starts with the customer order and terms with the emission of the quotation (time and cost).
SERVICE	Manufacturing product or process that a company can provide.
SERVICE COMPOSITION	The mapping of distributed manufacturing resources with personalised service requests.
SERVICE-TASK MATCHING	Identification of the service that answers completely and rightly to the task requested.
START PROCESS	Beginning of the production process.
TASK	What (production process) the company should do to answer the customer's request.

TASK SCHEDULING	Process of allocating services over time to perform a set of tasks while satisfying constraints in terms of time, cost, QoS, and service availability.
UNSATURATION LEVEL	Refers to the capacity range of the plant.

Tab. 3.2 - *Matrix glossary.*

Chapter 4
Model validation

To validate the model and, simultaneously, to understand in which kind of business MaaS could be primarily applied, the authors used a method divided in two parts.
To complete the model, the authors compared themselves with experts in Cloud Manufacturing area and with companies aiming to understand all the steps involved in the process starting from RFQ to delivery of the service.
So then, to validate the model, the authors compare the “upstream considerations” with the results obtained by the model. If the results obtained, by applying the model, confirmed the “upstream considerations”, the authors could say that the model make sense and it is validated, otherwise if the results obtained were abnormal, it means that the model was not reliable and should be reviewed.
It is important to notice that the “upstream considerations” derive from personal considerations coming out from the visits of the companies and from authors’ knowledge and background about the kinds of business. The authors call them “upstream considerations” because the authors point out them before to apply the model to the company.

Below, the authors can analyse more in detail these two main steps.

4.1. Input

4.1.1. Industrial cases

4.1.1.1. Introduction

To develop the project, the authors been in New Zealand, and the authors had the opportunity to work with the IIMS research group (Intelligent and Interoperable Manufacturing Systems). As mentioned above, to reach the objectives of the work, one of the main steps has been to meet some companies. Due to this, the authors tried to contact, study and then analyse some of the main industrial manufacturing sectors here in NZ, considering the food, textile, packaging, pharmaceutical, constructions, chemical, electrical, plastic processing, metal processing, machine manufacturing industrial sectors. The authors did not consider, for example, the automotive sector because is based on the importation from oversea. Then, the authors limited the research mainly in Auckland (most important New Zealand industry pole), and the authors analysed the companies that made themselves available to collaborate with authors and that considered the MaaS concept a good opportunity for themselves.

Before moving on to the companies met, the authors consider that it is important and interesting to give an overview of the local industrial situation in New Zealand, analysing the main aspects.

4.1.1.2. Social environment

To better understand the local work is very important to consider the social environment in which the industries can work here in NZ, that for some aspects is unique in the manufacturing world.

The New Zealand industry is main based on the SMEs and, as mentioned above, the main sectors (from the manufacturing point of view) in New Zealand are: chemical, polymer, and rubber products, transport equipment, beverage and tobacco products, non-metallic mineral products, printing, wood products, textile, seafood processing, metal products, food, electrical (basing on Stats NZ, New Zealand's official data agency).

The New Zealand government is leading a strong campaign to support the digital innovation in the industries.
The final object of the government's campaign is the achievement of "maximum impact onshore as we'll as through our shared offshore network. Working together like this is consistent with the Government focus on collaboration to deliver better public services to New Zealanders".

New Zealand is currently enjoying an economic upswing and, in the last few years the productivity growth has improved. This is a great news, but the country has a long way to go if it is to close the productivity and average per capita income gaps with other advanced OECD (Organisation for Economic Cooperation and Development) countries (today, there are 35-member countries span the globe, from North and South America to Europe and Asia-Pacific. They include many of the world's most advanced countries but also emerging countries like Mexico, Chile and Turkey).

Another important aspect that characterized New Zealand in the last decades (since the early 1990s), is that it is a country has enjoyed strong employment growth and this has drawn many low-skilled workers into the labour force. While clearly beneficial, this detracts from measured productivity compared with countries that have lower employment of the low-skilled.

The productivity gap can be explained through the weaknesses in New Zealand's international connections and an underinvestment in knowledge-based capital.
Expanding markets via international trade enhances productivity through specialisation and scale.
The competitive pressures are the consequence of the openness to trade and investment.
Thanks to the trade, and especially to the foreign direct investment, new technologies can be diffused.

Moreover, because global value chains (where production activities are spread across countries) typically require intensive interaction and just-in-time delivery, they tend to be regionally based. For New Zealand, international transportation costs for goods are about twice as high as in Europe. This reduces access to large markets and the scope for participation in global value chains.

To reach the returns to specialisation and investment in new ideas the access to large markets is crucial and fundamental. In this regard, New Zealand is penalised twice: the physical distance to external markets and the limited scope for internal agglomeration. With small domestic markets, New Zealand would benefit from greater integration into global value chains in innovation-intensive industries with fast-moving technological frontiers. This would be a great advantage because it allows to New Zealand firms to exploit global demand without having to develop a whole supply chain and a full set of underlying capabilities.
Of course, this is a hard situation to realize, and moreover the countries are increasingly competing for knowledge-intensive activities within global value chains, rather than for specific industries.
The degree of interconnectedness to the world permits also to capturing the benefits of lower trade costs and investment in knowledge-based capital. This investment has a double advantage because is also likely to affect the ability of New Zealand firms to exploit agglomeration and internal scale benefits within New Zealand. Although New Zealand has made good progress in this area, there is scope for further gains.

The Global Value Chains (GVC) consist of a wide range of value creation beginning from the development of a new concept to basic research, product design, supply of core material or components, assembly into final goods, distribution, retail, after service and marketing (including branding). Participating in these segments of a GVC allows firms to capture world demand without having to develop a whole supply chain and full set of capabilities.
From an economic point of view, this means that countries can deploy export competitiveness in specific GVC activities without developing a full set of supporting industries.
The involvement in GVCs often leads to a growing in trade, which enables countries (e.g. China) to develop industries and narrow the technological gap with respect to the world frontier over a short period of time.

To minimise the impact of the position, authorities could ensure that regulation tend to reduce the transportation costs.

In addition, a look at bilateral trade patterns suggest that New Zealand could benefit more from closer, fast-growing markets by shifting its trade flows towards emerging market economies in Asia.
Recent estimation of bilateral trade shows that New Zealand's exports are biased towards Australia, Northern Europe and advanced East Asian countries, in a sense that the shares of those regions in New Zealand's exports are larger than the distance to those markets and other

stylised determinants of trade flow would predict (A. de Serres, N. Yashiro and H. Boulhol, “An International Perspective on the New Zealand Productivity Paradox”, 2014).

4.1.1.3. Cases study

The authors visited eight companies, belonging to different industrial sectors.
To simplify the following analysis, the authors call the companies visited with letters A, B, C...

A and B are two companies related to Electrical industry, specifically PCBA manufacturers (the second one has a larger kind of products than only PCBA); the main machines are pick-and-place and thermal process ones.

C is a workwear specialist company, included in the Textile industry. C receives customer requests, it develops samples and, after the customer approval, it starts the seamstresses work.

D can be considered as Chemical industry, and it is able to provide both standard products (on the website) and customised products, which require a long phase of study in the laboratories.

E is a foundry factory, which has also some CNC machines to a post-casting processing.

Another important industrial sector analysed is the Machine Tools industry. This company does not make CNC machines, but it utilises only CNC machines for its production.
The authors had the opportunity to visit and interview two companies, called F and G, not so big and mainly both owners of different kinds of machine tools like lathes, millings, grindings etc. They were very similar companies with the possibility to manufacture any type of product without any specific constraints, so they have a large range of services that can be provided.

The last company studied has been a metal cold machining industry, called company H, where the unique and main product is roofing metal structure.
Starting from metal coils, the company cut them into metal sheet and then gives the final and right shape through bending machines. So, the steps are very clear and standard.

4.1.1.4. Considerations about different kinds of business

As explained at the beginning of this chapter, thanks to the companies met and after their visits, the authors understood better and more in detail which are the main steps between RFQ and delivery of the service and so, thank to this, the authors made the model more complete. Moreover, the authors tried to obtain, detaching themselves from the model and basing on the previous literature study and authors' personal background, some general considerations and sensations about the applicability of MaaS for each business, a step very helpful for the validation of the model.
For the following part, authors refer as "upstream considerations", because these are considerations before the application of the model.

PCBA manufacture

From the visits of the two PCBA manufacturers the importance and the significance to have standard process to apply MaaS have been highlighted. To support this, the authors identified many aspects.
If the authors consider the company A it is possible to note that the fact to manufacture just only one specific kind of product (PCBA) is an advantage for the standardisation: due to this, in fact the authors knew that all the types of machines in that company are involved for every process and every product, without the necessity to understand which kind of processes or resources are needed to answer to client's request.
Moreover, also the quality service and the procurement are standard because the material and the quality target do not vary depending on the requests.
So, the client can ask different PCBAs, and it means that the main structure of the work to do is the same.
About the other PCBA company, B, it has a range of possible products larger than company A, including some other electrical components in addition.
This fact implies that not all machines are always involved and that the processes of choosing the necessary resources are not always so automatic and therefore scarcely able to be formalized.
MaaS can be used only for the PCBA production, and not for another electrical devices' production, more customisable than PCBA.

This lead us to make a distinction between the only PCBA production and the whole production, so the authors think that the authors will have two different results related the two different markets.

Also, the presence of a software, already in use in company A supporting the matching and the scheduling of the processes, is another important aspect that puts this kind of business near to MaaS, because it makes easier the opportunity to formalize entirely or partially the process.

It does not seem that the procurement can be a limit to use cloud, in fact this kind of raw materials is not a niche market. The procurement can change basing on the components required in the PCBA, but the components are standard and common. This facilitates the use of cloud in the procurement phase because raw materials and providers are well identified.
Anyway, the supply chain is quite complex, so it is more difficult to virtualise the entire system.

There are processes developed by the company, but don't exist technologies unique in the world. This is an advantage for the sharing of the resources with others possible partners.
Consequently, the authors consider this kind of business, the PCBA manufacture, as privileged to apply MaaS.

The main limits are the high setup time and costs. This will be a limit to share resources, and to the rapid scalability.
Currently, another aspect that can be a limit for the use of cloud is the impossibility to inter-connect all the machines involved in the production process: e.g. the pick&place machines cannot be connected with the thermal process machines.

The authors cannot extent these considerations to the whole Electrical Industry, because it includes too many kinds of business. For example, the authors interviewed a company that designs any kind of electrical circuit: for this kind of business is impossible to identify the resources needed for new services, so it could be impossible to apply a cloud system.

Textile industry

The company visited provides working clothing and uniforms. Starting from a standard model, the customer can customise the garment as he prefers, adding some elements, and maybe this element could bring some difficulties to formalise entirely the process starting from the RFQ to the manufacturing process.

The most relevant consideration is that for any products the processes involved are quite the same. Due to this, it could be very interesting to upload the services provided in a cloud system. Linked to this, a possible aspect, in this business, that can bring a relevant advantage to MaaS application is the fact that, despite the product is customisable, the production of this company is related to a range well defined of clothes. The authors think, in fact, that other kinds of clothes, for example suits, the kind of resources needed could be different.

The feasibility phase is quite simple, so this cannot be a limit to apply MaaS.

Otherwise, the machines are fully manual, being unavoidable the human skills to produce a garment, so, it could be very difficult to identify and describe the human work involved in the process, and, moreover, it would be very hard to have a real-time monitoring during the process. The authors think that this point could be a limit but not a total constraint to apply MaaS.

In the end, the authors think that the Textile industry can be an interesting case study to apply partially MaaS.
Anyway, the services provided must "start" from a standard model, because the range of clothes are too wide (e.g.: hats' manufacturers have completely different resources with respect to a safety clothing manufacturer).

Chemical industry

This is one of the few industrial sectors in which, according to authors' impressions and considerations after the literature study, it would be impossible to apply MaaS. Otherwise, the main characteristic that brings advantage to this business visited is that this company offers a well-defined and limited range of products. As mentioned before during the model explanation, this is a very crucial aspect to the MaaS applicability, especially in some steps involved in the process from RFQ to service delivery.
This leads to have a very high percentage to regular customer, consequently a deep knowledge both by the customer point of view and the provider point of view, that is an advantage both for the company and for the clients concerning the quotation service.

For any products the processes involved, consequently the resources, can change, but being a product offered by a company it will be surely a set of processes known by the company. The main problem is when a customer asks to a company a new product, because any new products require studies in the laboratory, giving too importance to the prototyping.

For example, the requests for new products need a development which is carried out in lab based trials along with the customer to solve the customer's challenge. It is possible to note that this point needs a high know-how of chemical processes and reactions.

Finally, also the high setup times and costs represent a problem to MaaS applicability.

Foundry

It is not so easy to have a right and precise foreseen about this kind of business. In fact, during the visit, the authors noted that the main manufacturing steps, inside the company, are always the same, from the beginning to the end, so it could be easy to say that the manufacturing processes sequence is quite standard.
On the other side, there are several aspects that bring a lot of difficulties to MaaS application. First, thinking about the metal casting, like in chemical company analysed above, there are a series of chemical studies and considerations to do every time, that can be different depending on the type of the metal worked.
Also regarding the final phase of the business process brings with it some interesting considerations. This is in fact made up of CNC machine tools, and, depending on the final product desired by the type of customer, the various machining shaving operations must be studied and differentiated, like the authors analysed deeper later.
It is possible to note that for both two aspects, the engineering phase is fundamental, that could represent an obstacle to MaaS application.
An advantage of this company is that the customers are usually regular customers, so that at the beginning of the relationship between provider and user, a great engineering job is needed, but this will be not so necessary later. Of course, the problem occurs if the customer requests the production of new types of products.

Furthermore, the fact that this kind of plant should run continuously is a great impediment to the sharing of the resources, especially for some cloud environments like Group of Companies, but about this point the authors have some difficulties to avoid to the other types of cloud, like Private
and Public.

Machine tools industry

This sector is perfect from the “resource sharing” point of view, because the factories usually have usual idle times.

By the way, in these companies are very relevant the design and engineering phases. Due to these considerations, the potential applications are Group of Companies and Any Company, but limiting the services provided only (SPO), without the possibility to customise too much the request. So, it is easy to us could imagine that this kind of companies is perfect in a precise position inside a more complex and long manufacturing chain.
For example, a company could have the possibility to do not make a whole product, but just only a part of the all manufacturing processes, as turning or milling, needed to do the entire product.
Otherwise, more machine tools companies can provide different kinds of service in a group, in order to provide more complicate, or complete, services to a Community Cloud.

As advantage, this is the sector in which the theoretical study is more developed, in fact, the machines tools are subject of many studies to virtualise them and there is already the possibility to interconnect the machine inside a company or between the companies and collect some manufacturing data through wi-fi connection.

Metal cold machining industry

The authors visited a roof metal structure manufacturer, who use only metal cold processing to make a product.
The customisation of the product is limited, in fact the roof metal structure is quite standard. Moreover, the processes involved for different products are quite the same. So, this kind of business is suitable to MaaS application.
The know-how, the workforce and the machines are well identifiable and descriptive, so these resources can be easily virtualised, if someone is able to informatically describe them.

Having resources very specialised, and a utilisation low, it can be useful to share them. This aspect is very useful in MaaS paradigm. Also, the plant costs are very high, another reason to share the resources.

Moreover, the procurement is quite simple, so it could easily use in cloud and the setup times and costs are low, so it could not be a problem to apply MaaS.

The main aspects that could be a problem to MaaS application are the hard formalisation of the RFQ and the not connected machines. In fact, this company is structured in a way that is quite hard to have a total formalisation of all processes from the request of quotation to the

quote service delivery and then to start the production processes, mainly because the technology used is unique and the know-how needed to manufacture is quite high.
Moreover, as analysed for the PCBA manufacturers, even if the machines are standard and simple, there is no connection between them, and this is a problem about the virtualisation and the following monitoring.

The authors expect a high value resulting from the matrix.

4.1.2. Expert evaluation

The authors compared with the research group (Intelligent and Interoperable Manufacturing Systems) in which the authors had the opportunity to work, both with the people working nowadays and with the people worked past years.
Moreover, the authors contacted and discussed with some international experts of Cloud Manufacturing, in the academic area, this was a very important step because it has been very helpful and interesting: prof. X. Xu, Dr, X. V. Wang, etc.
This has allowed authors to make reliable and complete model even more.

4.1.3. Preliminary considerations

First, it is important to consider and highlight that no company knew the Cloud Manufacturing paradigm, so it was impossible to compare about it in different aspects related to the company. Someone knew some applications related to a cloud system, but at a too low level to discuss. Also, nobody was interested to go in deeper in the Cloud Manufacturing concept.
Then, the authors visited the companies and the authors confronted the experts in the Cloud Manufacturing area, to validate and strengthen the model. At first impact, the authors can say that the model seemed quite completed and reliable but, anyway, some aspects are deleted and others added.
For example, initially, the authors gave importance to the parameters characterizing the scheduling choices, in accordance to authors' background, in fact the authors did not find correspondence in the literature. Anyway, from the companies' answers, the authors did not find any potential utility to consider the applicability of MaaS, in fact, the choices mainly

depend on the customer relevance in the company view, an aspect clearly not so fundamental to consider for the use of a cloud system evaluation.
In the other side, the authors added the "Quality Service" rows, thanks to an expert suggestion, due to two reasons: it is important the rejection rate of the services (if the service is bad, it could be a limit to upload it) and the standards used for the services (different organisations or countries can use different standard, so it is very relevant when a company wants to offer a service in cloud).
By the way, the goal is to validate and reinforce more the model with its application considering the companies visited, analysed and interviewed, in order to understand if the authors have given, for example, too much or too less importance to some aspects and moreover, with the support of the values by the model quantitative evaluation results, if in general is rather reliable as the authors thought it.

4.2. Application

At this step of the work, the authors run the created model with the industrial cases analysed to verify if the upstream considerations are reasonable and right, and, thanks to the model support, more reliable.
This is also part of the model validation: in fact, if the results obtained were abnormal, it means that the model is not reliable and should be reviewed.

Then, to complete the matrix and so run the model, it is role of the expert to evaluate if the current solution used by the company is a limit or an advantage. This can be difficult considering the rows having "high-medium-low" as possibilities.
Due to this, the model should be completed and be run by an expert in the MaaS area, who can match the personal evaluation of the company interviewed with his knowledge about MaaS.
Being the Maas not applied yet, some parameters or well-defined criteria to evaluate some aspects (time of quotation, setup time, rejection rate, etc.) do not exist.
So, it will be up to the expert and the company to examine each single aspect and draw the most appropriate considerations from it: the current solution is a limit or an advantage?

Considering the subjective rows having for example "high-medium-low" as possibilities, the Score must be assigned first considering the different kinds of business. Only in a second analysis, considering different factories belonging the same kind of business, the Score could change. This is a fundamental rule using the model.

4.2.1. Questionnaire

To meet the local companies and to gather the complete and appropriate data for the application of the model, the authors created, starting from the topics (rows) of the matrix, a questionnaire that would allow us to have all the information necessary to understand in detail how those companies work.
It was a dynamic job because the authors had to deal with the different knowledge and different way to work of the companies, so the authors continuously updated the questionnaire to make it more and more clear, precise, and compatible to all kind of companies for each sector.

Technical Level	
RESOURCES IDENTIFICATION	
1)	Which types of machines do you have?
2)	Which types of processing do you have?
SERVICE COMPOSITION	
1)	Which types of services do you offer?
2)	How many machines are involved for each type?
3)	Which types of process are involved for each type?
RFQ ANALYSIS	
1)	Which format can the customer use to do a request?
2)	Which kinds of information do you ask to the customer? (geometry, tolerance, roughness...)
3)	How many RFQ do you receive in a year? At how many do you reply? Which is the percentage of regular customers?
4)	How much the description of the request of the service is clear, objective and complete?
5)	Once received the RFQ, which are the next steps?

6)	How do you understand which resources are involved for the product realization?
7)	How does the feasibility of the product is checked? Who oversees the feasibility of the product?
8)	Do you think that is possible to formalize the process from RFQ to start process? So, the resources' list?
9)	Decomposition of the service in sub-tasks: who and how this process is done
10)	How is the Quote Service in terms of time?
11)	Can the Quote Service be formalized?
SERVICE QUALITY	
1)	The quality standard of services offered is based on organization standard, nation standard or international standard?
2)	Reject rate of services offered? (How many units are rejected by the customer?)
3)	Repair rate of services offered?
SERVICE-TASK MATCHING	
1)	Who is the responsible to match the tasks with the services? A team of experts or a software?
2)	How does the matching between product more customized (specific requests) and task be done? Is this process done by an expert planner or is formalized?
3)	How do they/it do it?
4)	Can this process be formalized?
TASK SCHEDULING	
1)	Who is the responsible to schedule the tasks with the services? A team of experts or a software? Is it already automated?
2)	Can that process be formalized?
3)	How they/it do it?
4)	Which parameters characterise the scheduling choices? Just only machines availability and due date?
Business Level	
LOGISTIC COST	

1)	To make the finished good, it is necessary a sequence of companies (excluded material suppliers)?
2)	Are the logistic costs high?
3)	Coordination costs and Coordination complexity
UTILISATION	
1)	Which is the utilisation level of the plant?
FLEXIBILITY	
1)	Are the setup time high or low?
2)	Are the setup costs high or low?
3)	Are you open to new capabilities? And to new resources?
PLANT COSTS	
1)	Are the machinery costs heavy?
2)	Are the equipment costs heavy?
3)	Are the plant costs heavy?
DATA SENSITIVITY	
1)	Considering a possible collaboration with other manufacturers, are the process information sharable?
WORKFORCE SPECIALIZATION	
1)	Do you need of very specialized workforce or does your process be mechanized?
SUPPLIERS	
1)	Is procurement of raw materials difficult?
2)	How many suppliers do you need? How is complex the value chain?
3)	Where are located the suppliers? Near or far?
4)	Which are the main aspects which increase the procurement costs?
TRANSACTION COMPANY-CLIENT	
1)	At which levels the customer interact with the company?

Tab. 4.1 - *Questionnaire.*

4.2.2. Results

As explained in the previous chapter, the final results are obtained summing all the multiplications between each row value (-1, 0, +1) and the respective weight.
The model application is made for every kind of business provider (Single Company, Group of Companies Single Provider Only, Group of Companies Dual-role and Any Company), so each company has four final results.

The final results are reported in the following table:

Industry	**Company**	**Kind of providers**			
		Single	Group of Companies		Any
			SPO	Dual-role	
PCBA	A	70	71	72	73
	Bc	40	41	43	44
	B	-16	-15	-13	-12
Textile	C	-17	-16	-16	-17
Chemical	Dc	-14	-16	-14	-15
	D	-41	-43	-41	-42
Foundry	E	-31	-31	-32	-33

Machine Tools	F	0	0	2	5
	G	-4	-4	2	3
Metal cold machining	H	46	42	47	44

Tab. 4.2 - *Results from model application for each company analysed.*

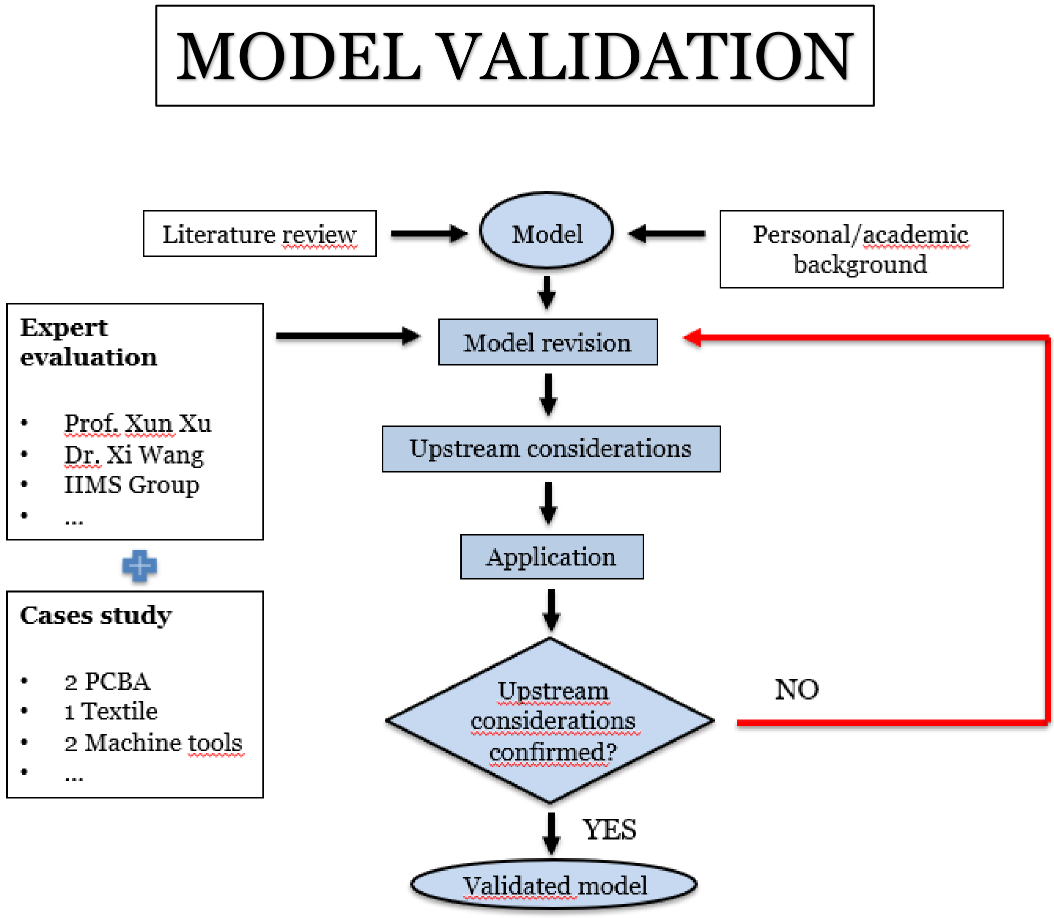

Fig. 4.1 - Model validation scheme.

Chapter 5
Conclusions and future work

Model conclusions

The application of the model leads authors to double outputs: in fact, not only, through the results obtained, the authors can foresee the suitability of the kinds of business analysed, but evaluating the similarity between the qualitative considerations and the matrix results, the authors can see both the suitability of each kind of business to MaaS, and the validation of the model, in the case in which these results reflect the upstream considerations, helping and strengthening the model itself.

Looking at the matrix results, the authors can say that the model is validated. In fact, the results confirm the upstream considerations, based on authors' background, knowledge and the companies' visits.

First, it is important to notice that the results for each kind of provider (Single Company, Group of Companies and Any Company) are different each other but this difference is related to the specific factory studied and it is not a theoretical difference.
At the end of the research study, the authors can say that there is no a specific cloud environment better than others for a specific kind of business. Indeed, the type of environment depends mostly on the position of the analysed factory in the related value chain.
Due to this, the authors will not analyse in detail the different results for the kinds of business, but the authors look at the trend of the environments' results comparing with the first considerations.

Following, the authors analyse each company results.

PCBA manufacture

The company A achieves the highest values between the all businesses studied, according to the upstream considerations done previously.
The standard processes and the constrained range of services offered are the main aspects that permit to this company to be in the best position to apply MaaS.
These considerations are in the same way valid for company B, considering only his PCBA market. In fact, as explained before, the company B offers more services than A, and this induces some complications about the formalisation processes, especially about the check of feasibility, the matching between tasks and services. For this reason, the authors decided to analyse this company B from both point of view, the only PCBA manufacture and his entire possible production solutions. As expected, making this distinction is very interesting, in fact the authors obtained different results for these two different scenarios, anyway both suitable to MaaS application, but higher for a production limited to PCBA. This confirms the importance to not have an unlimited number of kinds of products possible to manufacture.
Anyway, as explained previously, even the PCBA manufacturing is not the perfect application without limits, because the setup times are high and the machines are not interconnected.
Analysing more in detail the results it is possible to notice that the trend of the values is increasing to Any Company, especially due to the low utilisation and the high plant costs, because in this kind of environment there is more possibility to find a similar business to share the resources.
Moreover, also referring to the standard an Any Company platform can take advantage, being a public form of cloud.

Textile industry

The results are quite negative because the range of products are too heavy. Of course, the production is limited to workwear clothes, but a lot of types and combinations are possible. The company C provides samples to the customer, who customises them. Then C must understand how to produce the customer request, especially looking at the procurement and the scheduling of the work. It is possible to imagine the all these steps make that the period of the quote service release becomes always longer.
Moreover, in this kind of business, the jobs are all manual, requiring a heavy part of the employer work, and an actual difficulty for the virtualisation of the resources.
At the end, the authors think that the Textile industry analysed could apply cloud in a partial way, not for every operational and business step from the beginning to the product delivery.
Indeed, the standard processes and the easiness to check the feasibility of the request lead to be a perfect candidate to use a cloud system, but on the other hand, the long period of the quote

service release and manual machine would be a problem. About this last aspect, the authors leave to future study the capability to virtualise the manual work.
Considering the values of the results it seems that, theoretically, for this kind of business, there is not a specific kind of cloud environment better than the others.

Chemical industry

Considering the effective method of work of the company visited, thanks to his bounded range of products available, the conclusions are better than the authors thought about a generic Chemical industry that can manufacture whatever the customer asks to the company. This confirms again the hypotheses made previously.
Anyway, the results are negative because a great and important limit remains: the limit to identify, define and virtualise the chemistry involved in the process. This inevitably weighs heavily in the global MaaS appraisal. Moreover, if the authors consider the production of new products requested by the clients, it is quite impossible to apply MaaS because of the laboratory phase necessary to provide new chemical substances.
The authors can say that it will be quite difficult that MaaS will be able to establish itself in companies of this type.
Because this company is a hard condition to apply MaaS and a clear trend does not exist, it is difficult to obtain considerations about the results values.

Foundry

This is perfect example where it will be impossible to find MaaS application: the chemistry involved in the process, the 24/7 utilisation of the plant, the unlimited kind of products offered, the processes depending on the product specifications, the complexity of the value chain, the importance of the engineering for the feasibility study are all aspects that lead the applicability of MaaS to be impossible.
Referring to results, it is possible to notice that all values are negative, but it is particularly negative for the Any Company because due to the high utilisation it is hard to share any type of resources.

Machine tools industry

This kind of business has intermediate results in the considered scenarios.
The main strength for the MaaS applicability is the possibility to share the resources because of their multiple production functionality, and this can be optimal in a specific situation like

when a company has a low utilisation level of its plant or machines. Moreover, CNC machines are the most developed in the virtualisation state of the art: during literature study the authors found a lot of papers regarding the goal to virtualise all kind of capabilities of this type of machine.

Nevertheless, the range of services offered is unlimited (the company visited could manufacture everything), so also the value chain and the supply chain are variable, mainly heavier than other industries. As mentioned previously, the engineering phase is always fundamental because of the manufacturable range of products by the companies, and as already explained, the authors think that this step will remain task of engineers.

So, these aspects prevent the MaaS applicability.

Basing on all these considerations, the Machine tools industry is an interesting field to apply partially the use of cloud. They lead to consider Machine tools industry suitable for a Group of Companies cloud environment, specifically as Single Provider Only because it is suitable to be in a value chain, but it is unable to be at the end of the chain, so directly contacting the end user.

About the specific results, the trend of the values is increasing to the Any Company platform and this point is justified by the fact that this kind of business is featured by a low utilisation of the resources, high plant cost and a type of machines with general features suitable for a lot of different production. So, in a public environment like the Any Company, it is much more likely to answer to all these needs.

Machining metal cold

From the results of model application, the company studied in this kind of manufacturing has one of the highest values.

Considering the manufacturing of simple products, through metal processing, this area is very suitable to apply MaaS because the process starting from RFQ to service delivery is quite standard.

The applicability of this company is completed by the fact that has only one customer: this strengthens the applicability, because it permits both to company and to client to know each other perfectly and brings a lot of advantages in the formalisation of each steps.

Anyway, the services provided are very specific, related to a specific market, so also the know-how is higher than other kinds of business.

The machines and technologies are unique for the same reason, so it will be difficult to share them with others.

The low utilisation lead to consider Any Company as the perfect environment for this kind of business, but the unique technology and the service quality standard based on enterprise decision suggest the Single Company as the best solution.
Finally, the high cost of the plant makes the Dual-role solution with the highest value.

Cross conclusions

Customisation-Standardisation

One of the most important consideration is about the dualism standardisation-customisation.

At the beginning of the work, the authors explained that the new paradigm of Manufacturing-as-a-Service, but more in general the progressive development of Industry 4.0, was born from the necessity to go towards the maximum customisation (in the last years the goal was the maximum production).
During the model creation, the authors understood that to apply MaaS, a company should offer a bounded range of services; otherwise a new service could require a step out of the process formalised, like a feasibility study or a tasks' decomposition, which requires an engineering analysis, for example.

At the end, it is important to make a distinction for the provider point of view and for the consumer point of view.
From the provider point of view, the company should provide a constrained range of services, to manufacture in a formalised way.
Thanks to the availability of many different services in cloud, the consumer should have the possibility to combine services from different providers, to receive a more customised service than nowadays.
This is the right optic to focus on customisation.

Moreover, relating to this topic, the authors think that the future direction will be the offering less complete products, considering a provider point of view, but the companies will offer processing and resource, aiming to permit to the customer to compose service, to response to his totally customised requirements.

Benefits coming from MaaS

To summarize the benefits coming from the literature and the ones from the research work, the benefits brought using MaaS are:

- **Globalisation**: it is possibility to not limit the own market (both from the suppliers' point of view and from the customers' point of view) to a narrow and close geographical area. Thanks to the technologies on which is based the MaaS, there is high possibility to interconnect, to share and compare themselves rapidly and easily.
- **Pay-as-you-use**: it is mainly the possibility to pay only the service that you need and that you decide to use. In this way, it is possible to select only a service available in a cloud environment, that could be also only a simple manufacturing process. This can bring a lot of advantages also from an economic point of view, because a company that needs an expensive resource for a few services, does not have to buy that resource with a big investment, but it can use, and then pay, that resource only the times it needs.
  The pay-as-you-go solutions, with low cost for usage and maintenance, eliminate economic barriers such as extensive investments for IT-systems, and manufacturing equipment rapidly depreciating. By requiring just the service interested, many of the costly on premise-related expenses, like software, hardware and maintenance, can be reduced or even eliminated.
- **Ubiquitous network access**: this benefit is a direct consequence of one of the main needs to work in cloud. So, if a company decides to work in a cloud environment, a network access to every part involved (provider and consumer) is available.
- **Rapid scalability**: the MaaS allows enterprises to quickly scale up and down, where resources can be added, removed, and modified as needed to respond quickly to changing requirements.
- **Resource sharing**: permits to increase utilisation of the plant, to process and manage large datasets, to connect individual service providers and consumers in a networked design and manufacturing setting.
- **Process monitoring**: having the resources in cloud, it will be easier to monitor the steps involved in the process starting from RFQ to service delivery.
- **Speed of reply**: thanks to the formalisation of every step from the beginning to the end needed to apply MaaS, the response to the customer's request is faster and so the customer lead time is shorter.
- **Agility**: having a bounded range of services offered, it will be more rapid the response to changing customer demands through the ability to invoke different combinations of manufacturing and product design services, made available from the provider.

At this point, the authors found it interesting to try to understand and foresee, for each kind business analysed, which benefits could be more relevant and easier to reach, by applying MaaS.
It follows an analysis for each kind of business.

PCBA manufacture
Also considering the main benefits selected that the MaaS use can bring, the PCBA manufacture is reconfirmed the best kind of business.
The authors think that this is a kind of business that can exploit every advantage.

Thanks to the fact that the machines involved are always the same for every type of PCBAs production (e.g. pick and place machines, thermal processes machines…) the authors believe that it is a manufacture suitable to a rapid scalability and a resource sharing. This machineries' feature combined with the international standard that each company in this sector should provide, permit to be a kind of business very suitable in the globalisation direction to which this industrial revolution is leading.

Moreover, as shown before, the types of the process are very standard and this make possible and easy to have a process monitoring from the beginning to the end.

As the authors could see during the visits in this type of business, since these companies do not have a plant that it should work 24/7, it is possible to use the logic of pay-as-you-use, even if the authors think that hardly it will can happen because this is a market where the request commonly is the final product itself, and not a part of all process.
Finally, the authors can find some advantages also about a response to client's requests faster, thanks to the great possibility to formalise the entire process, both RFQ analysis process and manufacture process.

Textile industry
The machines in this kind of business are quite the same for any company, so it leads to share easily the resources (machines or workforce), that could bring to change rapidly the production volume.
This is also appealable to the pay-as-you-use way of work.

Anyway, the work is usually manual, so it will remain difficult to monitor the production process, because it would involve a harder collection of work data.

Linked to same consideration done for the machine tools, the speed to response to customer request will not be advantaged from the use of cloud, because of the need of samples first to the starting of production process.

Considering the tailoring, the authors think that the agility will increase using MaaS.

Chemical industry

This is one of the businesses that the authors believe quite difficult to take advantage from the MaaS application.
Just think of the high know-how needed for every chemical process and of the experiments in the laboratories to test new products. These things limit the possibility to share resources or to monitor on cloud the entire process.

Because of the high setup time and costs needed for a new product, the agility will not change using cloud.

Considering a bounded range of products that a company decides to offer to its customers, it is possible to notice that only a rapid scalability is possible, due to a possible quantity variation of the same product available.

The “pay-as-you-use” and the resource sharing remain very hard because of the secrecy and difficulties about the chemistry.

Foundry

The international quality standard used in this kind of business favours the globalisation.

Moreover, using cloud, for the same reasons explained for the Textile and the Chemical industry, it is hard to monitor step by step the production process.

Anyway, the high level of utilisation makes impossible to share resources on cloud.
Due to the 24/7 process, it will be difficult to take advantage from the pay-as-you-use.

Machine tools industry

The fact that the machines tools are very common in the metal manufacture, and their capabilities are quite common and the same, leads this kind of business to take advantage in the globalisation point of view and the ability to increase or decrease the production volume in a faster way.

For the same reason, and for the range of products that a CNC machine can work, the resources will be shared in a larger way than nowadays.

At the end, thanks to the previous reasons and the usual intermediate position of this kind of companies in the value chain, one of the main benefit will come from the pay-as-you-use. In fact, in a Cloud Manufacturing scenario, the user requests for the service from a computing device rather than owning the device. The user is billed only on the usage of the resource. This pay-as-you-use model greatly reduces capital expenses and allows enterprises to plan acquisition and releasing of resources as and when required.

The facility to connect the CNC machines each other permits the facility to monitor the production process.

An advantage that the authors do not believe possible for this kind of business is the response speed.

As explained in the previous chapters, they do not have a defined product to provide to the customer, and being able to manufacture everything, a great engineering phase is fundamental and requested, so it quite impossible to formalise it and take advantage to this benefit.

Considering the high flexibility of the companies in this kind of business, the business agility is a heavy advantage using cloud.

Machining metal cold

Analysing the last company, a roof structure maker, the possible benefits go hand in hand with the MaaS applicability. In fact, a globalisation of this business is possible thanks to use of the international process standard.

Due to specific tasks of the own machines (suitable for this specific production), a pay-as-you-use situation and a resource sharing have a limited applicability.

On the other hand, due to the standard and simple processes, a process monitoring is feasible.

A well-defined range of services offered allows a possible rapid scalability, and, like a consequence of easy formalisation, a very high speed of response.

Finally, it is quite hard to talk about the benefits to specific kind of business without an actual application. The considerations, that the authors try to do, are based on the literature study, authors' evaluations and the possible scenarios into the companies analysed.
The authors draw considerations and conclusions about the possibility to have some benefits or not, but the authors are currently not able to analyse and to comment the magnitude and the potentiality of single benefit for each kind of business.
Considering the use of the model for a specific company, in any kind of business, the potential benefits written previously will affect the revenue of the company according to that specific case, so a benefit could be more relevant than another one.

Future work

At the end of the research work, the authors think that can be useful summarize several future research opportunities identified that would merit future developments.
As checked in the literature review, Manufacturing-as-a-Service is still a relatively new concept that needs to be further researches.

First, it needs to understand which kinds of business can apply MaaS. This is the implementation of the work, using the model to all kinds of business. In fact, due to the amount of work needed to apply MaaS, it is fundamental to focus the area of interest.
Consequently, of the research work, it could be useful to understand if the company analysed can use MaaS partially (e.g. Machine tools industry) or totally (e.g. PCBA manufacture). It will result from a complex matching both in the market point of view, between the participants in the business, and the company point of view, relating to the departments in the factory.

Once evaluated the interested parties, it is necessary a heavy communication to them about the benefits brought using cloud in the manufacturing process. Nowadays, nobody knows the MaaS paradigm, so nobody is interested to use it.

At the end, it will be needed to identify all the resources of the company, so as to virtualise them. In this point, the informatic engineers will understand how to virtualise each resource, also basing on the state of the art in the literature review (the CNC machines are mainly cited in the literature).
Surely this is the heavy step to apply MaaS in a company, maybe the main one.

As consequence of these, it will be useful to understand if it exists a link between MaaS applicability and benefits brought by MaaS, for each kind of business.
Probably each "kind of MaaS benefit" has a different potential weight in the company's revenue. In fact, as written in the previous chapter, it is fundamental to evaluate the potential benefit for each kind of business, and only then it will be possible to evaluate the potential benefit for the specific company.

Nomenclature

AA	Advanced Automation
AM	Additive Manufacturing
BOM	Bill Of Materials
CC	Cloud Computing
CM	Cloud Manufacturing
CNC	Computer Numerical Control
CPS	Cyber Physical System
CST	Cloud Service Transaction
DT	Design tasks
GSCM	Global Supply Chain Management
GVC	Global Value Chain
HMI	Human Machine Interface
IA	Industrial Analytics
IaaS	Infrastructure-as-a-Service
IoT	Internet of Things
IP	Intellectual Property
IT	Information Technology
MaaS	Manufacturing-as-a-Service
MPT	Manufacturing and processing tasks
MR&C	Manufacturing Resources and Capabilities
OT	Operation Technology
OWL	Web Ontology Language
PaaS	Platform-as-a-Service
PCBA	Printed Circuit Board Assembly
QoS	Quality of Service
RDF	Resource Description Framework
RDFS	RDF Schema
RFID	Radio-Frequency IDentification
RFQ	Request For Quotation
RIF	Rule Interchange Format
SaaS	Software-as-a-Service

SCO	Service Consumer Only
SLA	Service Level Agreements
SME	Small-Medium Enterprises
SOM	Service-Oriented Manufacturing
SPO	Single Provider Only
STEP	Standard for the Exchange of Product Data
SU	Service utilization
SWRL	*Semantic Web Rule Language*
TCT	Total completion time
URIs	Uniform Resource Identifiers
XML	eXtensible Markup Language

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