The role of Engineering-to-Order machinery manufacturers in future Cloud Manufacturing supply chains: a business case and a strategic perspective

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The visionary paradigm of Cloud Manufacturing (CM) struggles to take off in the real manufacturing world. This paper develops a single-case study on one fully-operative platform we found in Europe (metal processing business) which can be regarded as representative - and maybe "revelatory" - for the future CM paradigm. The case, with an explanatory purpose, studies the platform success from a resources perspective. The findings show how an Engineer-to-Order (ETO) company, namely the manufacturer of the machineries virtualized, provided a key contribute to build such a system, thanks to its own peculiar resources and competences. Resorting to theoretical available knowledge, the paper suggests that ETO machine manufacturers should consider CM as a strategic option for their competitiveness but – at the same time - they should recognize that their internal resources and competences are not enough to build completely a CM platform on their own.

Keywords: ETO Machinery manufacturer; Cloud Manufacturing; Manufacturing-as-a-Service; value chain strategy.

1. Introduction

Cloud Manufacturing is a concept which belongs to the so-called "Industry 4.0" paradigm (Kang et al. 2016): by merging together innovations in Information Technologies (IT, as Data Analytics, Internet of Things and Cloud Computing) with advancements in Operational Technologies (OT, as Additive manufacturing, Robotics, new Human-Machine interfaces), Industry 4.0 fosters manufacturing companies to enhance the interconnection and cooperation abilities among their resources (physical assets, people, and information, both within the factory as well as distributed along the value chain), thus improving their efficiency and competitiveness (Lasi et al. 2014; (Miragliotta, Macchi, and Terzi 2015).

The first definition of Cloud Manufacturing (CM) was given by (Li et al. 2010) and it progressively attracted the attention of many authors that revised the definition, described the architecture, the expected benefits and put forward the main business challenges (X. Xu 2012; D. Wu et al. 2013). After almost 10 years, and more than 1000 journal and conference papers published, some sort of consensus on the CM definition has been reached: CM could be described as the 'Manufacturing version of the Cloud Computing', or more specifically:

> 'Cloud Manufacturing is a networked manufacturing model in which locally and globally distributed manufacturing resources for the complete product life-cycle are made available by providers for satisfying consumers demand, and are centrally organised and controlled as manufacturing Cloud services. The model supports unified interaction between service providers and consumers, for trading and usage of configurable resources/services, as well as dynamic and flexible cooperation and collaboration in multi-partner manufacturing missions. Distinct characteristics for the use of services are that they are scalable, sold on demand, and fully managed by the provider' (Adamson et al. 2017).

Cloud Manufacturing therefore represents a service-oriented model inspired by Cloud Computing technologies with the main goal of delivering Manufacturing services, hence known as Manufacturing as-a-Service (MaaS) (Zhu, Zhao, and Wang 2013; Henzel and Herzwurm 2018). In addition to pure manufacturing services, resource providers may offer additional services connected with the product / process lifecycle; for example, a company could sell through the cloud some available capacity of its designers, could sell simulations or maintenance operations (and so we have Design-as-a-Service, Simulation-as-a-Service, Maintenance-as-a-Service) (Tao et al. 2011; Adamson et al. 2017). Nevertheless, Manufacturing-as-a-Service certainly remains as the most interesting and debated target of the CM paradigm.

According to the literature, a CM service revolves around three roles: the "Resource Provider", the "Platform Operator" and the "User" (Adamson et al. 2017), where the role of "Platform Operator" and of "Resource Provider" could be played by the same actor, as it happens for example in the Cloud Computing business. MaaS also has strong links with the so-called Platform Economy which, in recent years, has strongly changed consumers' and businesses' equilibria (e.g. Alibaba.com, Uber.com and Airbnb.com); this is why an increasing number of academics has studied the implementation of the Cloud Manufacturing paradigm through the lenses of digital platforms (Hu et al. 2012).

Despite such interest within the academic community, few real life applications of this paradigm can be found, due to several issues (He and Xu 2015), both technical (virtualization of heterogeneous resources, integration of systems, tasks scheduling) and business (D. Wu et al. 2013; Adamson et al. 2017; Liu et al. 2018; Miragliotta and Tedaldi 2018). As a result, almost all cases of distributed, on demand manufacturing services developed so far are focused on additive manufacturing services (e.g. Sculpteo.com, 3DSystems.com, Shapeways.com,), which benefit from largely simplified technical issues (available formats and standards, super-simplified bill of materials).

One noteworthy exception is represented by 247TailorSteel.com: this company provides on-demand manufacturing services in the metal industry, covering a large set of machining capabilities (see Section 4 for details), thus being a very interesting instance of the CM paradigm. In a first exploratory phase of our research, around 2014-2015, we discovered that a quite important role for the success of this initiative was played by the equipment supplier, i.e. the Engineer-to-Order (ETO) company that engineered the machineries used by 247TailorSteel.com to provide the CM services.

Since the resource provider is never contemplated in the CM literature as one of the key roles, we started a more focused research stream to understand this situation, driven by the following research questions:

- RQ1. What is the contribution that an ETO machinery manufacturer could bring to the realization of a CM platform and why such contribution is needed?
  As a consequence of the question, we'll try to generalize the results to understand whether CM paradigm can see a consistent, relevant contribution coming from ETO companies such as a machinery manufacturer.
- RQ2. Is it relevant, for an ETO machine manufacturer, to consider the CM paradigm as one strategic development option?
  In case of a positive answer, we'll wonder why the ETO company did not realize the platform on its own, and whether it could happen in the future.

We conducted an in-depth analysis of the platform (history, characteristics, operating rules) and a longitudinal explorative case study about the involvement of the ETO machinery manufacturer which realized the virtualized resource layer. The collected data were then analyzed through the lenses of available literature and theoretical frameworks (Platform economics, Dynamic capabilities) to answer the above mentioned questions.

To properly illustrate our research work, the remainder of the paper is arranged as follows. Section 2 presents the theoretical background consisting in three pillars: first, state-of-the-art and open issues in the development of Cloud Manufacturing; second, the platform economy and its fundamentals; third, resource-based view as a source of competitive advantage. Section 3 introduces the methodology of the research, highlighting the sources and the methods used for the single-case study development.

Section 4 presents the case, and more specifically the analysis of the platform and of the ETO, machinery manufacturing company which designed the tube processing machines and contributed to the deployment of the CM system and infrastructure. Section 5 tries to generalise the collected evidence, and deals with the strategic implications this may have on machine manufacturers in general. Eventually, Section 6 will draw some conclusions, and provide future work recommendations for both managers and researchers in this area.

2. Previous knowledge and Theoretical background

2.1 Cloud Manufacturing: state of the art and open issues

Even older than the concept of CM was the concept of MaaS: it first appeared in literature in 1990s, when (Goldhar and Jelinek 1990) attempted to identify the characteristics of a Service for manufacturing, mentioning:

- Customer participation to the design activities of a product;
- High level of customization;
- High information content between vendor and customer;
- Fast response time and shorter lead times;
- Flexible pricing and contractual relationship;
- The relationship between vendor and customer becomes more efficient over time because they both continuously learn from the history of their transactions.

The technology available at the end of the last century was unable to ground the MaaS concept into real applications. Today Cloud Manufacturing aims to realize MaaS leveraging on distributed manufacturing resources, and resorting to a technology paradigm which has come to full maturity in the IT world, i.e. Cloud Computing. This is why the debate on MaaS gets more attention year after year.

Cloud Manufacturing, as Cloud Computing, involves three participants: Resource Provider, Cloud operator and the final User/Resource Consumer of the system (Adamson et al. 2017). There is a transaction of information and manufacturing services between the Resource Provider and the User, and the Cloud Operator is in the middle and manages the transactions (D. Wu et al. 2014). This means that in CM the User who buys services does not have any contact with the Resource Provider, but is limited to dialogue with the Cloud Operator (Fig. 1). The aforementioned feature is the major difference distinguishing CM from a B2B marketplace (e.g. like MFG.com) which simply facilitates the match between demand and offer. CM in this pure instance constitutes a two-sided platform, as we have two groups of users (Resource Providers and Consumers) and an infrastructure (managed by the Cloud Operator) which facilitates the transactions between the two entities (Eisenmann, Parker, and Van Alstyne 2006).

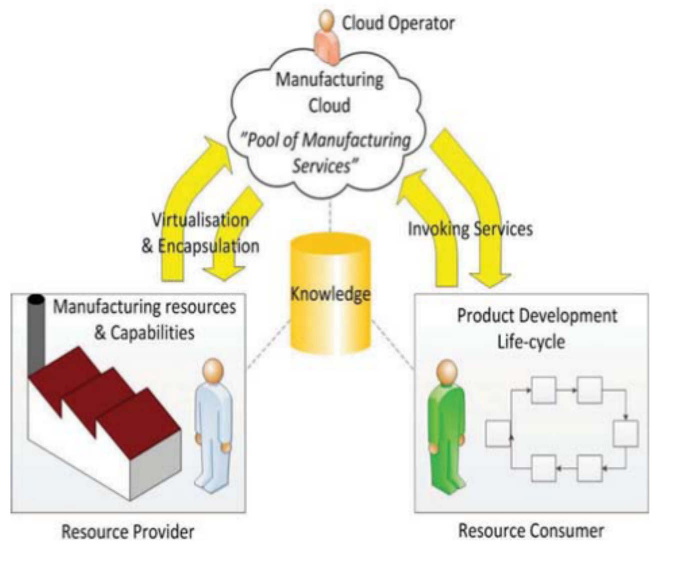

Figure 1. The CM concept and the participants (Adamson et al. 2017)

The operational process starts with the User who asks the Cloud Operator for a quotation related to a particular manufacturing service (e.g. design of a printed circuit board, or finishing of a mechanical part of a given material). The request is received by the platform (e.g. a web-based tool) which interprets and manages the manufacturing service request. The Cloud Operator is in charge of checking the feasibility of the request and the availability of the resources, and then answers to the request, providing the user with estimated delivery time, quality level and price (Fig. 2).

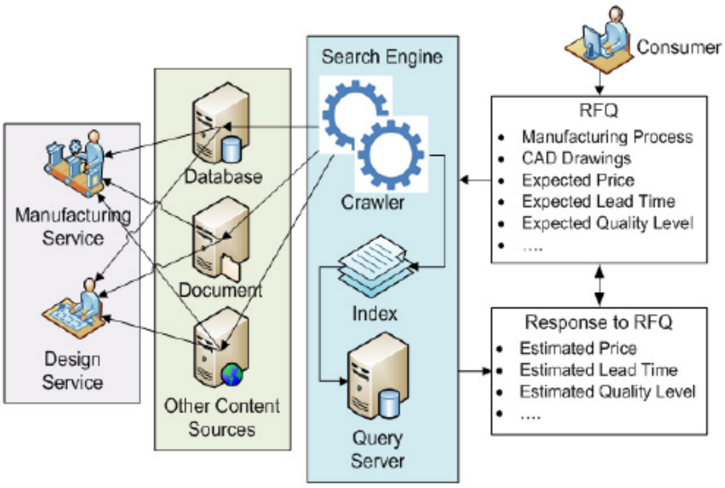

Figure 2. Operational processes of a CM system (D. Wu et al. 2014)

According to the CM literature, the answer to RFQ (Request For Quotation) should be almost in real time, and this is why most of the authors talks about a “high level of automation” of the platform’s engine (D. Wu et al. 2013) and “minimal management effort or service provider interaction” (X. Xu 2012). Once the order is confirmed, the Cloud Operator turns the requested service into tasks to be performed by the resources (Guo et al. 2010), allocates and schedules them among the Providers. Finally, the requested manufacturing service is delivered to the User.

Cloud Manufacturing Open issues and challenges

CM has been largely debated over the last 10 years but still there is not consensus about the concept, architecture and characteristics, also because empirical cases of full implementation of this paradigm are missing (He and Xu 2015). The reason why CM has not been fully implemented is twofold.

On the first hand, there are open issues related to technology, i.e. to how CM would be applied. As we said in the previous chapter, there is not consensus on how resources should be described, virtualized and how the manufacturing services requested to the platform could be converted into tasks and matched with services enabled by the resources. Manufacturing Equipment Resources (MERs) must be virtualized and encapsulated into service packages. First of all, MERs must be described. (Zhao et al. 2013) proposed a framework for defining the stationary functional capabilities and dynamic production capabilities: stationary ones describe what type of work a machine can perform, while dynamic ones tell when the resources are able to perform it (W. Xu et al. 2015). Moreover, because resources are likely to be heterogeneous, there is also a problem of interoperability and standards for the communication with the Cloud Operator. From the User side, the product/service requested should be interpreted, turned into tasks to be performed and matched with the available service packages. Other challenges in CM are represented by how tasks are split among the providers, and this leads to open issues related to the scheduling algorithms applied to CM environments (Liu et al. 2018).

On the other hand, there are gaps in literature regarding the applicability of CM from a business perspective. It’s not clear where CM could be applied (i.e. which sectors and sub-sector), and who could be interested in providing and exploiting the concept of MaaS. At a first glance, it seems that CM should not apply to businesses where MaaS characteristics (e.g. customer participation in the design of a product, fast response to RFQs, shorter lead times) are not achievable or simply not desired.

Moreover, it seems that it wouldn't apply in contexts where resource providers would not take advantage in participating to the CM environment (e.g. they don't need to saturate their own capacity). For example, it doesn't seem feasible to bring the concept of MaaS in contexts where RFQs requires high customization, hard engineering skills and the process is difficult to be encapsulated in small services (e.g. cast iron foundries). Then, CM could be very difficult to apply in contexts where the manufacturing process is performed through dedicated transfer lines, based on rigid automation and producing parts at high-volume with limited parts flexibility. Similarly, CM could be limited in those situations in which the Resource Providers are geographically dispersed: in this case, even if the needed capacity is available in the network, excessive logistics costs may prevent from finding an acceptable overall pricing for the RFQ.

With the goal of MaaS, CM aims to make easier the transactions between demand and supply, this means that CM would be successful in contexts where transaction costs represent a key-issue. Yet, from a business perspective, the User should trust the platform in terms of quality, security and share knowledge with other CM participants (i.e. the platform owner and a pool of resource providers). The transaction of information about the products and services requested represents an issue to be taken into account because the intellectual property (IP) rights are not to be managed in a single relationship customer-supplier as it happen in traditional business transactions (D. Wu et al. 2013).

Other challenges refer to how value added of the product should be split among resource providers and platform operators, because the final product could be the results of a combination of services coming from different enterprises (Adamson et al. 2017). Probably new revenue and business models will be developed to accomplish the implementation of CM, maybe shifting from traditional ones to a "share-to-gain" philosophy (D. Wu et al. 2013). For the sake of convenience, the essential characteristics and related issues of CM are eventually summarized in Table 1.

Characteristics	Definitions	Open Issues Technology / **Business**
Resource pooling / Distributed resources	Resources are pooled to serve multiple users. There is a sense of location independence in that the customer generally has no control or knowledge over the exact location of the provided resources but may be able to specify location at a higher level of abstraction (e.g., country, state).	• Description, virtualization of the resources (e.g. heterogeneous equipment and capabilities) and encapsulation into service packages. • **User's trust towards the CM environment (e.g. quality, delivery date).**
Centralized management of resources	Resources are centrally and fully managed by the Cloud Operator which answers to the RFQ and turns orders into tasks to be performed by the resources. Thus, the Cloud Operator is in charge of matching tasks with available services, allocating and scheduling the tasks among the resources.	• Conversion of manufacturing services requested into tasks to be performed. • Match of tasks to be performed with available service packages. • Logics for allocating and scheduling of services among the resources. • **Mechanisms for splitting the value added by the resources.**
Service-oriented	CM aims to transform resources and capabilities into services (e.g. Manufacturing as-a-Service). Products and services requested are highly customized according to User requirements.	• Highly automated processes in order to provide the User with highly customized products, fast response times (almost instant) and shorter lead times.
On-demand	Resources are available to produce at any time when the User asks for something.	• Platform and resources available at any time.
Ubiquitous / Broad network access	Services are anywhere available over the network and accessed through standard devices (e.g. smartphones, tablet, laptops).	• Multi-tenant Platform. • Flexible accessibility to platform services.
Dynamic with uncertainty / Rapid Elasticity and Scalability	Resources can be elastically provisioned and released to scale rapidly outward and inward commensurate with demand. To the user, resources for provisioning should appear to be unlimited and can deliver products or services in any quantity at any time.	• A critical mass of resources would be ensured to the CM system and this increases the complexity of CM implementation.

High information sharing	There is a high information content between User and Cloud Operator and between Cloud Operator and Resource Providers. From one side, the User transfers information about the product or service to the Cloud Operator who feeds him back with data about estimated cost, delivery time, quality. From the other side, the Cloud Operator monitors in real time the availability of the resources and controls the order fulfillment.	• Lack of interoperability and standards for the communications, e.g.: - Interpretation of the product or service requested; - Real time monitoring of resources, often characterized by proprietary communication protocols. • **Security issues related to the transaction of information.** • **Intellectual property (IP) rights because all the CM participants could claim them.**

Table 1. Characteristics and open issues of CM

Cloud Manufacturing early adopters

Despite the academic debate on CM started more than 10 years ago, a very low number of actual applications can be found worldwide. As a comparison with the IT world, NIST[1] definition of Cloud Computing (Mell and Grance 2011) has been coined in 2011 after several years of widely available commercial Cloud Computing solutions (e.g. Amazon WebServices, Google). Moreover, existing CM applications do not show all the characteristics presented in Table 1, but just some of them: this is why we call them "Early adopters".

From a chronological point of view, the first CM applications to appear were those offering additive manufacturing services. As a first example, Quickparts.com was born in 1999 as a provider of additive manufacturing services and in the first ten years of life developed an interesting web-based platform featured by an instant quoting engine recalling the CM concept, as Wu et al. recognized (Dazhong Wu et al. 2015). In 2010 it already had an annual revenue of $25 million and in 2011 it has been acquired by 3DSystems.com, one of the most important 3D printers manufacturers (NBC 2011).

[1] NIST: National Institute for Standards and Technology

A second example is Shapeways.com, an American startup founded in 2007, which has received a US$ 108 million funding. Shapeways.com too offers 3D printing and design services leveraging on resources distributed among its own facilities in US and Netherlands, in addition to a network of partners settled all around the world. We can fairly maintain the CM solutions for Additive Manufacturing is pretty much consolidated, as testified by (Mai et al. 2016), who proposed a framework for Additive Manufacturing service integration and application in Cloud Manufacturing.

More recently, initiatives such as the American companies xometry.com and Fictiv.com and the European one 3dhubs.com enlarged their manufacturing services from additive manufacturing to CNC machining, injection molding, urethane casting and sheet metal fabrication. All of them have been founded in 2013, and so far received funding for $118, $58, $30 million respectively (as for crunchbase.com, November, 2019). The peculiar characteristics of the platforms developed by these companies are as follows:

- they leverage on a network of distributed resources that are managed centrally by the Platform Operator;
- the platform is web-based, multi-tenant, 24/7 available;
- the platform owner manages centrally the orders and takes full responsibility for every step from the quoting phase to the final delivery;
- the User during the order journey is not in direct contact with the resource provider;
- the quotation phase is supported by an instant quoting engine which provides the final price and the estimated delivery time;
- intellectual property and quality issues are carefully faced by the Platform Operator.

Others interesting European cases are those of the Dutch company 247TailorSteel.com, the English fractory.com and the Italian weerg.com. 247TailorSteel platform serves the market of metal sheets and pipes, and it will be described in details in the next Section of the paper. Fractory is very similar to the aforementioned Xometry, but its capabilities are limited to sheet metal fabrication and tube cutting: it leverages on more than 20 manufacturing partners all over Europe, ensuring deliveries in less than 5 days. The Italian Weerg developed a platform with an instant quoting engine and makes use of its own resources (people, machineries for additive manufacturing and CNC machining services.). In such a case, when the Cloud Platform Operator is – at the same time - the one and only Resource Provider is a bit different instantiation of the CM concept, as it does not represent a distributed manufacturing model, but we are still considering these cases to be interesting MaaS models, as they may expand in multiple locations or open the platform to other Providers to become a distributed manufacturing system, as soon as scalability and elasticity are justified by an increased market demand.

Others initiatives were born with the objective of realizing some of the MaaS features but they cannot be considered as real examples of CM, as they are much closer to the concept of an electronic marketplace: there is not centralized management of the manufacturing resources, and there is no automated, instant quoting engine which guarantees a fast response to RFQs. These players simply facilitate the connection between customer and supplier and the platform usually ends its task once the match is completed. Example of these platforms are the generalist Techpilot.com, or orderfox.com, which is focused in CNC machining parts. Also freelabster.com falls within this category, but it represents an evolution with respect to a traditional marketplace because it takes care for the quality of the manufactured part, with a model that resembles the Airbnb (Airbnb.com) practice. Resource Providers (named by the company "Freelabsters"), in fact, are not paid unless the User confirms he is satisfied with the services he get. Freelabster.com offers services of 3D modelling and 3D printing, leveraging on an international network of suppliers. Users can choose the best suppliers according to their capabilities and geographical position.

2.2 Platform economy

Platform economy refers to the new economy generated by the rise of digital platforms, that changed the way we socialize (e.g. Facebook), shop (e.g. Amazon), book accommodation (e.g. Airbnb) and move (e.g. Uber) (Kenney and Zysman 2016). Also, within the Cloud Computing paradigm, we find the "Platform-as-a-Service" model (Mell and Grance 2011) which defines the capability provided by a Cloud "Operator" to a User for creating applications through the use of programming languages, libraries, services offered by the Cloud "Provider".

More in general, platforms can be studied from an economic perspective (as two-sided markets) or from an engineering design perspective (as a technological architecture) but what interests us is the first one (Gawer 2014). According to this perspective, platforms can be defined as physical or digital entities that match groups of users in two-sided networks (Eisenmann, Parker, and Van Alstyne 2006). For example, a shopping mall can be considered as a platform for a two-sided network composed of consumers and retailers. With platforms, the value has different flows with respect to traditional business, as we can have revenue and cost on both sides of the network (e.g. Salesforce.com basically sells a Customer Relationship Management (CRM) software and additional tools offered by external developers; revenues come from users but also from developers because Salesforce sells them visibility of their additional applications).

Platforms act as intermediary and represent a cost (paid by one or both sides of the two-sided market) which is justified because they reduce transaction costs for users (e.g. the search of suppliers, contractual phase, etc.). Back to the mall example, the retailer represents the traditional market while the mall is a platform because it facilitates the users for shopping. In this case, retailers are usually charged with costs for being part of the mall (i.e. administrative and operative cost, at least) while users are subsidized and not required to pay anything to the mall.

(Eisenmann, Parker, and Van Alstyne 2006) suggests that platforms operators should address three challenges in managing and designing a platform: get the pricing right (i.e. for each side of the network), cope with "winner-takes-all" competition and avoid the phenomenon known like "platform envelopment" (Eisenmann, Parker, and Van Alstyne 2010) caused by an overlapping competing platform (Bakos and Katsamakas 2008).

At the basis of these challenges, there is a great attention to the "Network effects" which characterize the deep nature of two-sided market. They refer to the dynamics appearing in these environments when users from one side increase (or lower, in case of negative effect) the number of users from the "same-side", or whether they attract (or repulse) users from the other side ("cross-side" effects) (Rochet and Tirole 2003; Eisenmann, Parker, and Van Alstyne 2006).

2.3 Sources of competitive advantage: the resource-based perspective

Some decades ago, Porter introduced an approach to strategy formulation which is known as Positioning School (M. Porter 1980). Within this thought, competitiveness of a firm is defined (or deeply affected) by external competitive forces: threat of new entrants, threat of substitute products, bargaining power of customers, bargaining power of suppliers and rivalry among existing competitors (M. E. Porter 1979). Among the authors of the Positioning School, there is a great emphasis on external factors affecting competitiveness and an orientation towards the final products of the firms fighting these market forces. A second approach leverages on product market imperfection, entry deterrence and strategic interaction.

Nevertheless, in the following years, many authors start to study limitations of the Positioning School. For a firm - resources and products are the two sides of the same coin and this is why from 1990 onwards the Resource-Based View (RBV) theory gains an increasing success. The origins of the RBV theory go back to 1984 when (Wernerfelt 1984) proposes some economic tools to provide the firms with new strategic options starting from the study of internal resources endowment. (Barney 1991) is one of the first authors to successfully contribute to the conceptualization of the theory: according to him, sustained competitive advantage roots on the value, rareness, inimitability and substitutability of internal resources, whether they are tangible or not. Indeed, one of the basic assumption of the RBV theory is that resources are heterogeneously distributed among firms and imperfectly mobile.

A complementary theory to the RBV is that one of the Dynamic Capabilities, which refines and expands the concept of “internal resources” (Wang and Ahmed 2007). The dynamic capabilities framework analyzes the sources and methods of wealth creation of firms immersed in context of rapid technological change (Teece, Pisano, and Shuen 1997), thus firms consolidate processes (organizational and strategic routines) to integrate, reconfigure, gain and release resources to match or create market changes (Eisenhardt and Martin 2000). These theories will represent our foundation to address the strategic implications of the gathered evidence from the market analysis and the case study.

3. Methodology

The small number of actual CM implementations, as stated in the previous sections, did not allow us to use any quantitative research method, hence we resorted to a qualitative approach (Glaser and Strauss 1967). The most appropriate research methodology in our situation is the case study, as recommended by (Yin 2003), especially "…when the boundaries between phenomenon and context are not clearly evident, and when multiple sources of evidence are used".

We decided to design a single-case study because we just met one case of a Cloud Manufacturing platform which resembles most of the characteristics of CM, as described in literature. This case, i.e. the Dutch manufacturing platform www.247TailorSteel.com could be considered representative - and maybe revelatory - for the future of CM, and this is one of the rationales for which we went for a single-case study (Yin 2003; Ridder 2017). In a very first phase of study, the unit of analysis was represented just by 247TailorSteel.com, which we first studied within the 2015 edition of the "Industry 4.0" Observatory at Polytechnic of Milan (www.osservatori.net/ww_en/observatories/ industry-4.0). In this very early phase, we discovered that one of the major contributions for the development of the platform was given by an external player, namely a technology provider who engineered and manufactured the machineries (manufacturing resources) to be virtualized through the platform (hereinafter we will refer to this company with the name Comp). Therefore, we decided to investigate, according to the research questions, why the platform operator needed Comp to setup the platform, and how an ETO company like Comp did contribute to build it. Moreover, we wonder why Comp agreed to get involved in this project and whether it could have been - or could be in the future – able to build and run such a platform all by itself, with its own resources.

Thus, eventually, the unit of analysis became composed of two embedded units: the Platform itself, as one of the most interesting fully operative example of CM available in Europe, and Comp, as one of the main contributors beyond it. The study of the platform was made possible by the collection of documents online, publicly available both on the company website and as deliverables of the European project "The future of Manufacturing in Europe (FOME)" (Scholten 2017).

Conversely, Comp was studied through the collection of data from the company website, economics data from online databases (e.g. https://aida.bvdinfo.com/) and a case study. Two semi-structured interviews were conducted in two rounds, in 2015 and in 2019, with the Chief Technical Officer (CTO) who leads the Research & Development department. The first round of interviews (in 2015) aimed at collecting information about the project they were working on, i.e. the building of 247TailorSteel.com. At that stage, we mainly collected technical information, useful to understand the technical contribution provided by Comp, and through which set of resources. 4 years later, after the platform successful consolidation and the opening of a new manufacturing hub in Germany, we decided to deepen the analysis of such cooperation: in this second round, we mainly collected information about the business relationship and we stimulated Comp about the strategic implication of such a collaboration.

4. A successful MaaS case

247TailorSteel.com is a very interesting case of a MaaS platform offering on-demand manufacturing services in the metal industry. In this section, we are going to describe the first unit of analysis, i.e. 247TailorSteel.com and its functioning, according to information collected by resorting to secondary sources. Subsequently, we are going to present the second unit of analyses, i.e. the ETO company which designed and produced some of the machines used to perform the manufacturing activities offered as a service.

4.1 The 247TailorSteel.com MaaS cloud platform

247TailorSteel was founded in 2007 by its owner, who had previously worked as general manager for a company in the sheet metal processing business for more than twenty years. His idea was to exploit the potential of Internet (and future technologies, that we now refer to as smart manufacturing technologies) to provide the customer with a kind of "virtual supplier" that could be convenient, fast and reliable.

247TailorSteel.com today operates in the metal industry, as a pure MaaS platform, and using CM as its reference technology architecture. It offers machining, laser cutting, bending and deburring, both on sheets and tubes of a wide variety of metal materials. The platform can be accessed using a plugin (for some functionalities) or using a software tool named SOPHIA (SOPHisticated Intelligent Analyzer): the user downloads SOPHIA, runs it and uploads the 3D drawings (in .STEP / .DXF / .DWG formats) of a metal part desired. SOPHIA is able to process 3D drawing consisting of multiple parts, as it can recognize each separate part. Then, the user selects the material, the finishing (e.g. deburring of metal processed), the desired quantity for each part (from as little as one item, to large batches) and finally submits the request for quotation (RFQ). Almost in real time, SOPHIA checks the availability of materials, machineries and capabilities of the employees, and then it elaborates the RFQ, providing a feedback about, feasibility, price and as-soon-as-possible delivery date available. If the order is confirmed, SOPHIA turns it into operational instructions to be executed by the manufacturing resources.

Behind the scenes, the architecture of the system embodies all of the features of a Cloud Manufacturing systems, with few peculiarities: SOPHIA represents a two-sided platform where manufacturing resources are made available to whomever (User). In this case, nevertheless, 247TailorSteel plays two roles: it is the only Resource Provider and it acts as the Cloud Operator: even though this situation is different from well-acknowledged two-sided platforms in the consumer market (e.g. Uber, Booking, etc.), this is a quite standard situation in B2B Cloud services, where the platform and the IT resources are provided and run by the same company (e.g. AWS, Azure).

Manufacturing resources are, currently, geographically distributed in two facilities settled in the Netherlands and in Germany, and managed centrally by the Cloud Operator; growth plans, according to (Scholten 2017), are targeting a scalable network of more than 150 manufacturing sites to be built close to customers, as soon as demand scales up. All the available manufacturing resources are pooled as it were a "cloud facility" and the User cannot distinguish which facility will be in charge to realize the requested products.

4.2 The machinery producer

Comp designs and manufactures machineries for metal tubes processing (e.g. tube, pipe and wire cutting, bending, sawing, endforming). It is settled in northern Italy and has a total income of about 250 US$ million (2018 figure). Most of its customers are big subcontractors for major larger manufacturing companies, and Comp has grown up over the years trying to meet their requirements, which are very demanding as they aim to cover all the market niches (e.g. tubes dimensions, materials) and need to saturate the machineries as much as possible. Over the years, this context forced the company to acquire knowledge to design a wide range of machineries (for cutting, bending, sawing, endforming), materials (e.g. steel, stainless steel, aluminum, copper, brass), shapes and dimensions (e.g. pipes with diameter from 1 up to 25 inches and length up to 18 meters).

Due to this pressure, Comp became a pioneer in technology innovation, starting from laser cutting machines, while increasing customization and flexibility to requests: complete working centers are engineered to order according to specific customer's requests.

As we settled the case study, these were the main topics we addressed[2]:

- What are the factors that compelled Comp to shift from selling just machineries to machineries plus software? How long it took to complete this shift?
- Which role has had Comp in the design and development phases of the 247TailorSteel.com platform?
- Which are the reasons why Comp has been able to contribute to the creation of the platform?

Factors pushing Comp beyond just selling machines

In addition to being pioneers in technology applied to production processes, over time Comp has developed strong competences in managing and building the software used by its customers to manage the manufacturing process itself. The reason for this shift was twofold. Firstly, according to the interviewee, it was clear that in the long term China and other growing economies would be able to cover the gap they had (and still have today), i.e. low reliability and quality, safety and compliancy issues, and would be able to sell machineries with comparable performance at considerably lower prices. Secondly, Comp has found that there was an important competitive advantage in mastering the machines not only at the mechatronic level, but also at the machine

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[2] The complete semi-structured questionnaire we used is available on request.

control software level.

For these reasons, Comp progressively moved from selling just machineries to selling a more complete and sophisticated solution, including Computer Aided Design (CAD) and Computer Aided Manufacturing (CAM) software, as well as simulation software to estimate the actual flow-time and to improve production management. The software suite has been very appreciated by the customer base because it allows a complete upstream and downstream integration of machineries within the design and manufacturing process of the customers. The CAD is thus allowed to send orders directly to the machinery, which turns them into technical operations to be executed, and the machinery eventually feeds back the ERP with real-time information (e.g. actual production data, failures). This enables users to better manage the production and orchestrate the operations within the manufacturing plant more efficiently.

Thus, Comp progressively went beyond the machineries (hardware) and extended its limbs in creating a middleware which enables the integration of the machineries in the manufacturing, logistics operations of the customers. This shift towards software-intensive and IT-driven machineries began more than 15 years ago, and now is boosted by the transition to Industry 4.0 of Comp customers. Finally the CTO says:

> "[…] we observed that new business models arose and our machines were sometimes used by our customers to get the same final product but with a totally different business approach (e.g. 247TailorSteel vs traditional businesses) and this is where we have to look at now".

The role of Comp in the development of 247taylorsteel.com

In 2015, Comp has been asked to interact with 247TailorSteel in the development of SOPHIA to fill the gap between the drawings uploaded and the technical instructions to be sent to the machineries. Comp contributed with a software that usually is not given to customers: that software is now part of SOPHIA and allows to pass automatically from the three-dimensional model of the part into machining programs, taking into account the whole kinematics and automation systems integrated into Comp machines. Moreover, the software provided by Comp is able to simulate the operations in charge of the machineries, and accurately estimates the time and cost of the production process. These data are extremely important for the accuracy of the instant quoting engine of SOPHIA. SOPHIA then combines them with information related to the raw materials stock, logistics data plus other business parameters and is able to assure that the requested part will be manufactured as it has been designed, with processing time and costs as expected. According to the interviewee:

> "[…] it would have been risky for the success of 247TailorSteel to develop SOPHIA without Comp's technical competences on the machineries"

Today, a strong and loyal relationship exists between 247TailorSteel and Comp: on the one hand, in the future it will be easier for 247TailorSteel to integrate new machineries developed by Comp into its processes; on the other hand, Comp will be interested in offering new features to SOPHIA and this represents a new business opportunity. As an example, Comp developed a patent for the "active marking" of the parts which can be easily absorbed by SOPHIA: according to this marking feature, the CAD/CAM system injects some meta-information into the geometrical description that are then interpreted by the machines and translated into marking codes. This enables Comp and his customers to have traceability on every single product manufactured, for instance to fight illegitimate trade issues.

Why Comp was necessary in the development of the CM platform

There are several reasons why 247TailorSteel involved Comp in building their platform. First, 247TailorSteel choose Comp because, as an ETO company, it is historically used to satisfy customer requests with flexibility. In fact, the CTO says that many of the most innovative features of Comp machineries are nothing but the result of usual partnership and co-design phases with their customers. Second, Comp has strong competences on machines software developed over the last 15 years. Comp already had experiences about the digital representation of the part to be manufactured and its translation into operational instruction for machineries. Finally, Comp already had developed machine software for the integration of the machineries within the plants of their customers (e.g. integration with Manufacturing Execution Systems and Enterprise Resource Planning) and this is what 247TailorSteel was looking for, to complete their platform architecture.

In some ways the results of the case study are not surprising. The development of the 247TailorSteel platform seemed to the interviewee, at that time, to be almost natural.

5. Evidence discussion and generalization

By means of the performed case study we have addressed RQ1, namely how the machinery manufacturer enabled the realization of the CM platform, and why its contribution was needed. In this section, leveraging on the information collected during the case study and in the light of available theoretical frameworks, we will address the remaining ones.

As regard to the generalisability of this first evidence, i.e. whether the CM technology paradigm may see a consistent, and relevant, contribution coming from ETO companies such as a machinery manufacturer. This is relevant to be investigated, as most of the literature on CM just focused on the product and process features, and on the integration between information and operational technologies as promoted by the Cloud Operator, neglecting the contribution of other players. Given the limited diffusion of CM, and the very limited empirical base that is available, the remainder of this section should be considered in the light of an interpretative research effort, to be validated as new data and evidences will become available.

The topic of ETO distinctive capabilities is crucial to address this RQ2. As we know, machinery manufacturers belong to the category of Engineer to Order (ETO) companies, which is characterised by the customer decoupling point located at the design stage (Amaro et al. 1999). Many types of ETO supply chains exist, and several authors have tried to highlight the main capabilities that are needed by companies to excel in this kind of business.

(Anderson, Fine, and Parker 2000) highlighted knowledge sharing and contractual risk management, as key competences of ETO companies, backed by (Hicks, McGovern, and Earl 1992) who remarked partnership and contractual relationship with customers. (Olhager 2003) focused on flexibility, design capabilities and speed as key factors for ETO competitiveness. (Wikner and Rudberg 2005) stressed engineering and project management competences. (Micheli, Cagno, and Zorzini 2008) highlighted that, amongst other factors, partnerships with suppliers, corporate (product and process) standardization and co-design capabilities are key competences of successful EPC companies. More recently (Gosling et al. 2015) claimed that coordination of internal and external processes and a very high technological expertise, both at hardware and software levels, are distinctive capabilities. Eventually, (Adrodegari et al. 2015) summarized a set of distinctive capabilities and peculiar operating conditions they found in the business of ETO machinery manufacturing companies.

By merging up the main elements that are acknowledged by scholars to be distinctive competences of ETO companies, we may consider: superior engineering skills, HW e SW technology expertise, product and process standardization, co-design, partnership and process integration with their customers. We confirm that all these distinctive elements were easily recognizable in the case study we performed in Comp, and were key factors for the project success.

If this is the set of capabilities supplied by ETO machinery manufacturers, abundant literature exists, as highlighted in Section 2, Table 1, to describe the set of capabilities needed in order to build a CM system, at a technical level (process abstraction, HW & SW integration and automation), at a business / technical interface level (process standardization, business interoperability) and finally at a business level (complex project management). Despite we have observed a single case, and thus we cannot claim for adequate validity, this first case study helps us in establishing a deeper connection between the observed contribution and the underlying factors that justify such a contribution: the explaining variable here is represented by the ETO company key distinctive capabilities. Fig. 3 shows this contribution: it underlines the direct contribution of an ETO machine manufacturer to the CM issues and challenges. Of course, other contributors are involved and other capabilities are necessary for the development of such a CM platform (e.g. investment capacity, IT competences) but they are out of scope of the present paper (Fig. 3).

Since these factors are deemed to characterize any (successful) machine manufacturer, we have arguments to maintain that machine manufacturers could play a relevant role in the establishment of a successful MaaS platform, and they should be considered as relevant players by researchers addressing the CM manufacturing paradigm.

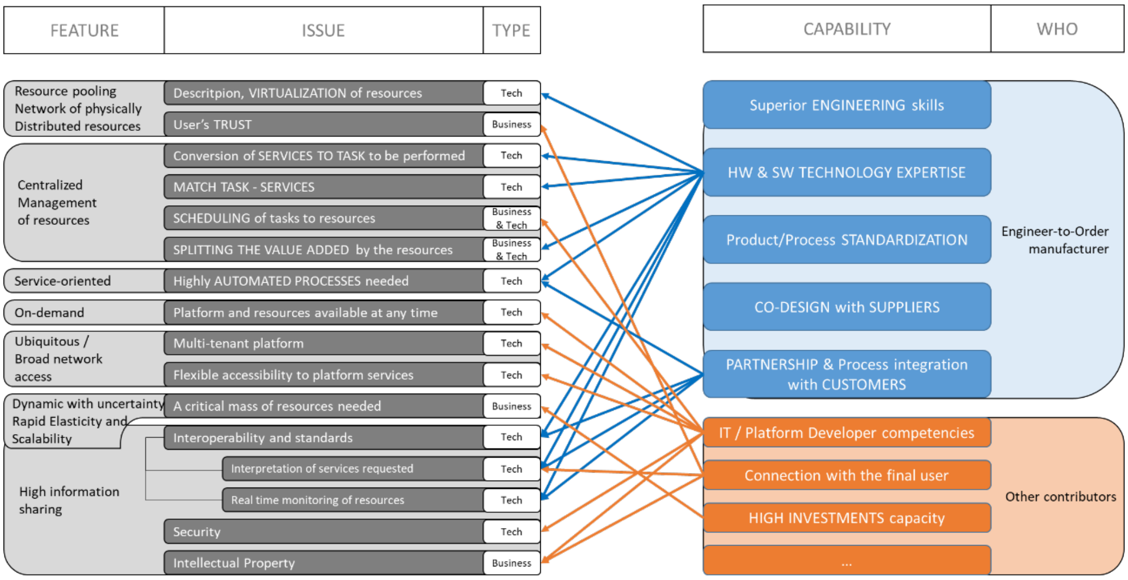

Figure 3. ETO capabilities (right side) covering CM issues / challenges (left side).

Given this conclusion, the second research question comes into play, i.e. whether machine manufacturers could consider the realization of a CM platforms as a strategic option for their growth and to which extent (RQ 2). This second research question has a strong connection with the strategic trend discussed by (M. E. Porter and Heppelmann 2014); according to these authors, the advent of smart and connected products is reshaping the competition boundaries, and is transforming competition, which is no more driven (only) by the intrinsic features of one product, rather by the performances of the system of products to which such product belongs.

This paper can be considered as the manifesto of a new competition era and, de facto, it claims that the traditional boundaries of the value chains should be rewritten in a new value perspective, where integrated business management and optimization are still the key, but focusing no more on the product rather on the system of (systems of) products (M. E. Porter and Heppelmann 2014).

By applying this view to the machinery industry, we may conclude that competition in this industry will be no more driven (only) by the technical capabilities of the machinery, but by those extra capabilities that will be enabled by a system of interconnected machines; therefore, a metal processing machine which can reach higher utilization performances because it can offer its un-used production capacity on a cloud platform will be preferred to a machine which does not have this capability. If we follow this theoretic view, then the contribution / participation of the machinery manufacturer to CM platform where to offer MaaS services for unused capacity could become a strategic priority also for machine manufacturers (RQ2).

To understand whether building their own CM platform could be a strategic option for an ETO machinery manufacturer, we may resort to the Resource-Based View (RBV) theory (Barney 1991), as introduced in Section 2. According to this theory, companies are supposed to focus on capabilities that are distinctive, in the sense of valuable, rare, difficult to imitate and well organized in processes to capture value, so as to build a sustainable competitive advantage (Rothaermel 2012). If we apply this theoretical framework to the distinctive capabilities highlighted above (when discussing the first research question) we see a big strategic gap, as to design a successful CM platform a company has to:

1) manage a whole set of production technologies, as the CM platform is supposed to act a complete virtual shop from where to get the job done;

2) manage the relationship with the platform Users (i.e. the ones that demand for the parts produced by the machines).

None of these capabilities are strong (or sometimes not even present) in the current set of core competences of machinery manufacturers, as listed above, since they are generally focused on specializing on a single (or restricted set of) manufacturing technology, and are very focused on machine buyers and their needs, not on the final users that generate the demand for mechanical parts. Moreover, to create a successful CM platform designing and maintaining appropriate a pricing strategy (Eisenmann, Parker, and Van Alstyne 2006; Bakos and Katsamakas 2008) is crucial to “get both sides of the market on board” (Rochet and Tirole 2003): in this regard, the machinery manufacturer has no complete visibility on the final user who buys the single part / tube processed, and does not know the rules for competitiveness in this “final market”. Its resources and competences are strongly related to its nature (and history) - of being an ETO company - and it can hardly switch from engineering machines to massively producing and selling the machined parts.

Therefore, in this very moment, we may conclude that machine manufacturers have strong competences that allow them to enable successful implementation of a CM platform, but are not strategically set to become CM Operators by themselves, as they have never developed a cross-technology expertise, neither the relationship with the Users as two of their core competences (RQ2).

In this regards, it could be useful to update the list of possible supply chain strategies for companies operating in the ETO business, as described in (Gosling and Naim 2009), which originally encompassed 7 different strategies (shift between supply chain structures to suit marketplaces / standardization / reduce complexity, supply chain integration, information management, business systems engineering, flexibility, time compression, new product development process improvement) by adding a new one, that is: focusing on final Users to possibly become Operators of a CM platform.

6. Conclusions

Cloud Manufacturing (CM) is the manufacturing version of Cloud Computing and it seems to be a promising answer to realize Manufacturing-as-a-Service. Although CM has been largely debated in literature, few and limited empirical examples can be found, mainly tackling Additive Manufacturing services, because of the many open issues and challenges of this paradigm.

In this paper we present a single, longitudinal case study in which a company successfully realized a CM platform for metal sheets and tubes processing. This has been possible because this player designed the platform in close contact with the supplier of the machineries (i.e. the technology provider), leveraging on the competences of the machine manufacturing company. Our paper contributes to the topic of CM in a threefold way.

First, it provides first-hand information about a case of an “up and running” CM platform involving more complex capabilities with respect to Additive Manufacturing capabilities, and it suggests that CM really has the potential to spread in other discrete manufacturing industries like the industry of CNC machining metal / wood parts. Second, we propose to move the attention from CM implementation issues to those players who own specific capabilities which can cope with them. This study shows that an ETO machine manufacturer owns distinctive capabilities which interestingly match some of CM implementation challenges. Third, the study remarks that complex ETO machine manufacturing companies could play a pivotal role in the CM scenario, if they further develop their internal competences and capabilities to tackle the business challenges, not only the technological ones.

We see two sets of practical implications. The first one is for academicians studying CM: in the future, they should monitor and address not just the key player represented by the Could Operator, but also machinery manufacturers as relevant contributors to the platform, at least from a technical point of view. The second one is for machine manufacturers, as they should focus on CM as a performance extension for their products, according to the competitive paradigm of the Smart and Connected Product. To do so, they should enlarge the scope of their supply chain strategies, by including a better knowledge of the final users of their machines, i.e. the ones that use the parts made by their machines.

We are planning to work at disseminating these results starting from the Italian Association of machine manufacturing companies (UCIMU), as Cloud Manufacturing could be an opportunity for reinforcing their competitive advantage.

Currently, future research directions are focused on enlarging the empirical base, so as to increase the reliability of these conclusions. In case of CM platforms developed with the contribution of ETO machinery manufacturer, it could be interesting to identify a roadmap for the implementation of a CM system and eventually monitor the nature of the relationship which can be established between the ETO company and the CM platform (e.g. basic customer-supplier relationship, equity partnership).

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