Early adopters of Manufacturing-as-a-Service (MaaS): state-of-the-art and deployment models

Tedaldi G.*, Miragliotta G.*

**Department of Management, Economics and Industrial Engineering*

Politecnico di Milano, Milan (Italy)

Abstract:
Purpose: Cloud Manufacturing (CM) is the manufacturing version of Cloud Computing and aims to increase flexibility in the provision of manufacturing services. On-demand manufacturing services can be requested by users to the Cloud and this enables the concept of Manufacturing-as-a-Service (MaaS). Given the considerable number of prototypes and proofs of concept addressed in literature, this work seeks real CM platforms to study them from a business perspective, in order to discover what MaaS concretely means today and how these platforms are operating.
Design/methodology/approach: Since the number of real applications of this paradigm is very limited (if we exclude prototypes), the research approach is qualitative. The paper presents a multiple-case analysis of 6 different platforms operating in the manufacturing field today. It is based on empirical data and inductively researches differences among them (e.g. stakeholders, operational flows, capabilities offered, scalability level).
Findings: MaaS has come true in some contexts and today it is following two different deployment models: open or closed to the provider side. The open architecture is inspired by a truly open platform which allows any company to be part of the pool of Service Providers, while the closed architecture is limited to a single Service Provider of the manufacturing services, as it happens in most Cloud Computing services.
Originality: The research shoots a picture of what MaaS offers today in term of capabilities, what are the deployment models, and finally suggests a framework to assess different levels of development of MaaS platforms.

Keywords: Manufacturing-as-a-Service (MaaS); Platform Economy; Cloud Manufacturing; Industry 4.0

1. Introduction

Flexibility is a key word for competitiveness in nowadays dynamic and turbulent business environment (Vázquez-Bustelo, Avella, & Fernández, 2007). Flexibility is widely accepted as one of the four operational capabilities of a manufacturing firm, among quality, dependability and costs (Ferdows & De Meyer, 1990; Brettel, Klein, & Friederichsen, 2016) and becomes fundamental for business strategy (Gerwin, 1993). Naim, Potter, Mason, & Bateman (2006) distinguish different types of "internal" flexibility of a company resulting into 4 different types of "external flexibility", i.e. product, volume, mix, and delivery.

Thus, in order to boost flexibility, manufacturers and researchers have worked in two directions: within the company and along the value chain.

Within the company, the achievements of the flexible manufacturing systems FMSs (1980s) have led to reconfigurable manufacturing systems RMSs (Bortolini, Galizia, & Mora, 2018). Along the value chain, new paradigms were sought to overcome the stiffness of traditional supply chains (e.g. Holonic and Grid manufacturing, the vision of Agile systems). These models were pointing in the right direction, as they were looking for a "radical" change to cope with the increased demand for flexibility. They were inspired by technological models dominant at the time, and greatly influenced by the advent of the Internet. Nevertheless, they pursued decentralized approaches, inspired by how the Internet network is configured and controlled, that were partially in conflict with the traditional culture and structures of the manufacturing domain, which is usually characterized by hierarchical approaches (Y. Yin, Stecke, & Li, 2018).

As a consequence, also due to other barriers such as lack of clear methodologies, lack of top management commitment, unavailability of appropriate technologies, high upfront investments required (Hasan, Shankar, & Sarkis, 2007), the number of actual implementations of such manufacturing systems is very limited still today (Tao, Zhang, & Nee, 2011).

So, inspired by the evolution of dominant technological paradigms, a new paradigm was introduced in 2010 to the scientific community by (Li et al.): Cloud Manufacturing (CM). CM takes inspiration from the success of Cloud Computing (Xu, 2012), as it is can be defined as a model to enable convenient, on-demand network access to a shared pool of manufacturing services (Y. Liu, Wang, Wang, Xu, & Jiang, 2019). It mainly differs from previous paradigms because it goes back to a centralized management of resources / services through a platform managed by a "Cloud Operator" who sets the business rules; in this regard it is closer to traditional manufacturing management and control models.

A lively scientific debate opened on the concept of Cloud Manufacturing, trying to establish a clear connection with consolidated conceptual models, as those provided by NIST (National Institute for Standards and Technology) for Cloud Computing (i.e. "Public", "Private", "Community" and "Hybrid", cfr. Mell & Grance, 2011), to conceptualize deployment variants (Design-as-a-Service, Simulation-as-a-Service, Tao, Zhang, Venkatesh, Luo, & Cheng, 2011; Y. Liu et al., 2019), to clarify in which manufacturing context this paradigm could spread (Lu & Xu, 2019) or which business interactions may facilitate the creation of such a manufacturing environment (Tedaldi & Miragliotta, 2022).

After a ten-year debate, relevant knowledge gaps are still open, such as the inherent differences of MaaS deployment models, or metrics to assess the development of such a paradigm. This is mainly due to the scarcity of empirical examples. Eventually, in recent years, several platforms have emerged that resemble the characteristics of CM paradigm as envisioned by academics, and therefore they offer the first relevant opportunity to empirically address this situation. Relying on the new empirical background, this paper presents a multiple-case study research, addressing three research gaps:

RQ1. What is the state-of-the-art of MaaS platforms (prototypes excluded) that are currently in operations?

RQ2. What are the deployment models currently used by these platforms?

RQ3. How can we measure different levels of development of MaaS platforms?

These questions are relevant, especially in the light of Industry 4.0 paradigm, as the Operations management community is looking for a clear picture about how far the current implementations are from the original concepts (RQ1), whether the different deployment models can generate different CM implementation paths (RQ2), and whether is possible today to build a framework to assess the maturity of a MaaS platform (RQ3).

The paper is therefore arranged as follows. In Section 2, a literature review of Manufacturing as-a-Service (MaaS) and CM is performed, followed by a study on the platform economy. Section 3 presents the objective and the methodology used, whereas Section 4 deeply discusses the cases. The cross case analysis is performed in Section 5 were results are illustrated. Finally, Section 6 discusses the results while Section 7 concludes with suggestions for future research directions.

2. Theoretical Background

2.1 CM as a heritage of previous manufacturing paradigms

From 1990 onwards, the research for new radical innovations was certainly justified to cope with the increasing uncertainty and turbulence of the context. Agile, Multi-agent based, Holonic and Grid manufacturing are paradigms arisen for this purpose.

On one hand, the Agile manufacturing *vision* gets to the bottom of the network configuration, where enterprises should be able to establish a network of shared resources that can be used by virtual enterprises which are born and die to respond quickly and effectively to market requests (Gunasekaran, 1998; 2019).

On the other hand, Multi-agent based, Holonic and Grid manufacturing paradigms propose agile manufacturing *control systems*. Agents or Holons (manufacturing systems that can be defined as "whole" or "part of a whole" manufacturing system) cooperate, decentralize decisions (heterarchical structure) on distributed resources by providing autonomy and intelligence to the individual parties involved. They differ from traditional control approaches because they do not have a top-down approach characterized by centralization of planning, scheduling and control function decisions. Instead, they involve a "bottom up" approach because the control is devolved to intelligent, autonomous, and integrated manufacturing components (Leita, 2009). In Manufacturing Grid, companies cooperate through the coordinated (but not centralized) sharing, integration and interoperability of a system of resources that are spatially distributed. This is possible through the interconnection of resources and the use of advanced IT and management techniques (Tao, Zhang, & Nee, 2011; Qiu, 2004).

All the paradigms previously described leverage on cooperation among enterprises where a network of resources is somehow shared. The main challenge for them is having a network of resources without centralized management. Although the Agile *vision* was clear when it was introduced, today further methodological support is still needed for agility implementation and improvement within companies (Medini, 2022). Today Multi-agent based and Holonic industrial implementations are limited to some specific contexts (Tao, Zhang, & Nee, 2011) because the investments required for them are high, they are complex *control system* to design, and manufacturers are sceptical about "local autonomous entities" (Leita, 2009).

Hence, these paradigms may not have been as successful as they aimed to, but they have certainly contributed positively to the research for new manufacturing models. Moreover, they have inspired decentralized control systems which are at the basis of the concept of Cyber-physical Systems (CPS) within the Industry 4.0 domain (Yongkui Liu & Xu, 2016; Zheng, Ardolino, Bacchetti, & Perona, 2021; Meindl, Ayala, Mendonça, & Frank, 2021).

During the last ten years, the technological evolution in the field of computing (the success of Cloud Computing, in primis), and the advent of the fourth industrial revolution (Industry 4.0) have revitalized the need for a radical innovation (Zheng et al., 2021) enabled by new digital technologies (Frank, Dalenogare, & Ayala, 2019). Therefore, in the context of the fourth industrial revolution, CM was born as a counterpart to Cloud Computing, from which it derives some peculiar characteristics. With regard to previous paradigms, CM control systems are quite different from those provided by Multi-agent, Holonic and Grid Manufacturing. Nevertheless, CM could be another important model enabling the Agile Manufacturing *vision*.

2.2 From Cloud Computing to CM

To better understand the CM paradigm this sub-chapter briefly runs through the history of Cloud Computing and its development trajectory.

During the last ten years Cloud Computing has deeply changed the way we make use of computing resources as they have been servitized: we can now get computing services on-demand, with pay-as-you-go / pay-per-performance models. This idea was not new: "creating a distributed computing infrastructure" and transforming computing as a "fifth utility" – after water, gas, electricity and telephony – was discussed already 30 years ago (Clark & McMillin, 1992; Foster, Geisler, Kesselman, & Tuecke, 1997). Grid Computing is certainly the most known distributed computing paradigm pursuing the objective introduced above. It should enable a federation of shared computing resources resulting in a dynamic, distributed environment (Foster, Zhao, Raicu, & Lu, 2008). Foster explains that Grid Computing should have these two characteristics (Foster, 2002):

1. coordinating resources that are not subject to centralized control;
2. using standard, open, general-purpose protocols and interfaces.

Nevertheless, Grid Computing shows few implementations and only in specific contexts (e.g. university research) because of the never solved issues about coordinated resource sharing and problem solving in dynamic, multi-institutional organizations (Foster, Kesselman, & Tuecke, 2001).

The history shows that among distributed computing paradigms, only Cloud Computing (Mell & Grance, 2011) broadly succeeds in delivering computing services as they were an utility, and it has been unexpectedly characterized by opposite characteristics with respect to the Grid paradigm (Mell & Grance, 2011):

1. involving computing resources which are pooled and centrally managed by the Service Provider;
2. using proprietary protocols and interface.

CM was naturally born from the concept of Cloud Computing and this is why the debate on this topic started around 2010 (Li et al., 2010) and why the interest increased over the last years. Many authors have tried to give a comprehensive definition of the CM paradigm (Xu, 2012) and to describe the architecture of such a system (Huang, Li, Yin, & Zhao, 2013). Although academics have published several literature reviews (e.g. Adamson et al. 2017; Henzel and Herzwurm 2018), today there is not a conceptualization of this paradigm which is shared by the scientific community. Nevertheless, we decide to provide the reader with one of the most recent CM definitions given by Y. Liu et al. (2019):

"A model for enabling aggregation of distributed manufacturing resources (e.g. manufacturing software tools, manufacturing equipment, and manufacturing capabilities) and ubiquitous, convenient, on-demand network access to a shared pool of configurable manufacturing services that can be rapidly provisioned and released with minimal management effort or service operator and provider interaction".

The system involves mainly three participants: the User, the Cloud Operator and the Service Provider. A CM system acts as a platform as it facilitates the relationship between two distinct group of users (we'll see better in next Chapter 2.4).

Among the advantages for Users we find MaaS guaranteed by the pool of available resources. In a CM environment, the supply chain is characterized by enhanced efficiency, increased flexibility (Wu, Greer, Rosen, & Schaefer, 2013).

Service Providers mainly benefits from CM systems as they increase efficiency of their production systems (e.g. reducing idle capacity, and getting in contact with a higher number of customers through the internet network).

According to the literature of CM we are quite far from seeing a completed implemented CM platform because of many unsolved technical and business issues (Lu & Xu, 2019). Most prominent academic authors in this field recognize we are still in a liquid phase because we do not know how CM will be successfully implemented (Y. Liu et al., 2019).

The characteristics of CM (Y. Liu et al., 2019) aiming to realize MaaS can be resumed as follows (Tedaldi & Miragliotta, 2022):

1. Centralized management: resources are centrally managed by the Cloud Operator (i.e. turning User requirements into tasks to be allocated and scheduled)
2. High-information sharing: Service Providers and users communicate a great quantity of information with the Cloud Operator;
3. On-demand: resources appear to be immediately available to provide the User with services;
4. Service-oriented: great flexibility in sourcing (high customization level for Users in product, delivery date, volumes, mix), fast response time, flexible contractual relationship;
5. Resource pooling: resources are pooled and generally the User could have no control or knowledge over the exact location of the provided resources;
6. Ubiquitous manufacturing & broad network access: services are anywhere available and accessible through standard devices (e.g. smartphone, laptop)
7. Dynamism with uncertainty, rapid elasticity and scalability: resources can be elastically provisioned (and released) to scale rapidly outward (and inward) as it is requested.

2.3 Manufacturing-as-a-Service (MaaS)

"Manufacturing as-a-service" (MaaS) is – of course – related to the concept of servitization within manufacturing sector. In general, servitization strategies refer to the business trend in which companies find a new source of competitiveness in adding services to their traditional offerings (Vandermerwe & Rada, 1988; Baines, Lightfoot, Benedettini, & Kay, 2009; Bortoluzzi, Chiarvesio, Romanello, Tabacco, & Veglio, 2022). The servitization domain is characterized by so-called product-service systems (PSSs), "an integrated product and service offering that delivers value in use" (Baines et al., 2007). With PSSs, it is more important the "sale of use" instead of selling the product. The very famous example is the following: Rolls Royce started selling working hours of their engines, instead of products. The PSS can be seen as the convergence of two trends: the "servitization of products" and the "productization of services".

The MaaS concept is related to servitization but it is focused on the relationship customer-supplier instead of the product-service.

In fact, the MaaS conceptualization first appears in literature when Goldhar & Jelinek (1990) describe the characteristics of a new flexible sourcing method characterized by peculiar features, e.g. high variety to the extent of customization of product design, customer participation in the design of the product, fast response time, flexible contractual relationship, high information content transactions where vendors and customers "learn", and transactions become more efficient over time.

During the last ten years, in the manufacturing sector we have experienced quite a big change in the servitization trend, due to the advent of Industry 4.0 and its enabling digital technologies (Paschou, Rapaccini, Adrodegari, & Saccani, 2020).

The maturity of technologies such as Internet of Things (IoT), Cloud Computing and the achievements of the Platform Economy pushed academics and practitioners to experiment solutions to enable MaaS. In particular, the success of Cloud Computing originates CM which aims to realize MaaS (Wu, Greer, Rosen, & Schaefer, 2013; Zhang et al., 2014; Rahman et al., 2018).

2.4 Platform Economy

With the term "Platform Economy" or "Digital Platform Economy" we refer to the economy generated by platforms which are dramatically changing our lives, e.g. socializing with Facebook.com, finding jobs on Linkedin.com, shopping on Alibaba.com, finding accommodations with Aribnb.com, moving thanks to Uber.com drivers (Kenney & Zysman, 2016). There is no consensus on either the definition of this phenomenon, or its name. Many authors label this economy as "Sharing Economy", others as "Creative

Economy", others distinguish "Gig Economy". Regardless of the terminology used, we should agree in recognizing that it is certainly one of the most impactful trends over the last twenty years.

The debate on Cloud Manufacturing and Manufacturing-as-a-Service has grown in recent years of deep transformations, and maybe it has attracted the attention from academics right in light of this phenomenon.

Platforms are usually two-sided and aim at facilitating the interaction between two groups of users: demand-side Users and supply-side Providers (Ardolino, Saccani, & Perona, 2016; Eisenmann, Parker, & Van Alstyne, 2008). One of the main problems of platforms is creating a business model to get both sides of the platform on-board (Eisenmann, Parker, & Van Alstyne, 2006) while taking into account network externalities which affect their success (Rochet & Tirole, 2003). In fact, we can recognize "same-side effects" when Users on one side attract other users to the same side of the platform, while we have "cross-side effects" when users from one side attract user to the other side (Eisenmann et al., 2006; Gawer & Cusumano, 2014).

In CM, the centralized management of the resources implies that, over and above users and providers, a third-party (i.e. the Cloud Operator) exists which coordinates tasks and services on a specific infrastructure; for all intents and purposes, it is a platform which connects two groups of users (Gawer & Cusumano, 2014; Eisenmann et al., 2006; Rochet & Tirole, 2003).

Platform-mediated networks can be open or closed to each of the roles involved: to the provider- and to the user-side of the system (Eisenmann et al., 2008), some examples are following. Uber.com provides mobility services for all the people interested in and it leverages on people who wants to share their spare time and cars, without many restrictions. A different case is represented by a car-sharing enterprise who offers its cars for mobility as a service: the platform is open to the user side but it is closed to the provide r one. The booking platform of the university library enable students and professors to reserve books belonging to the university, it means that is closed on both sides of the platform (Tab. 1).

Ex. Platform	Provider side	User side
Uber	Open	Open
Common *Car-sharing company*	Closed	Open
Common *University library*	Closed	Closed

Tab. 1 – Platforms: Openness and Closure at Provider vs User side

2. Methodology

Since the number of platforms implementing solutions closed to the MaaS concept are a few, we cannot perform any quantitative analysis. Qualitative research (Glaser & Strauss, 1967) is a suitable option, thus we decide to perform multiple case-studies (R. K. Yin, 2003) on enterprises which have developed platforms which increase sourcing flexibility and somehow resemble the MaaS characteristics.

In light of the emerging Platform Economy and theoretical developments on the CM topic introduced in Chapter 2, we use case studies to describe different maturity levels for each of the CM characteristics. In fact, Yin states (2003) that "existing theories are the starting point of case study research, (…) propositions provide direction, reflect theoretical perspective and guide the search for relevant evidence" (Yin, 2003; Ridder, 2017).

The selection of the cases starts with the identification of companies which are currently offering on-demand manufacturing services. We get 13 possible cases to analyze and we move forward to collect some data about their funding (if startup), main capabilities offered as a service, founding date, openness/closure to the Provider Side (Tab. 2). Among these companies presented in Tab. 2, the first 3 have been rejected because they were founded more than 15 years ago and this is too far from the phenomena in scope which arose from about 2010 onwards. Excluding them, we choose to study all the companies which seem to be "Closed" to the provider side as they are just 3 and focused on different capabilities (i.e. Tube processing, Sheet Metal processing, Additive Manufacturing). Among the "Open" configurations, we select the youngest of the sample (Orderfox e Fractory) and Xometry as it is the most funded of the sample. Fictiv, Hubs, Chizel and Fastradius have been neglected as they seem similar to Xometry but raised less in term of funding. At the end of the process 6 companies have been selected which can be regarded as representative of the heterogeneity of the platforms in this field, namely: Orderfox, Xometry, Fractory, 247Tailorsteel, Sculpteo, Weerg.

The unit of analyses is represented by the web-based platform and its users, i.e. the CM system. To answer to the research questions we collected additional information about capabilities offered, operational flow, funding, number of employees, number of manufacturing sites supporting the platform.

Moreover, we analyzed the web-based platforms making simulations of Requests for Quotation (RFQ) to better qualify the platforms characteristics from a User perspective, as well as paying attention to what happens beyond the platform, i.e. on the provider-side, and detailed the operational flows from RFQ to product delivery.

Sources of data are represented by semi-structured interviews with employees from the companies (transcribed and available on request) carried out between 2020 and March 2022, official websites of the

Company	Provider Side	Main Capabilities offered	Found. Year	Tot Funding [$ mil.]
Techpilot	OPEN	Many	1999	n.a.
QuickParts (3D Systems)	CLOSED	Additive Manufacturing	1999	undisclosed
Shapeways	CLOSED	Additive Manufacturing	2007	107.5
Sculpteo (acq. by BASF)	**CLOSED**	**Additive Manufacturing**	**2009**	**10.8**
Xometry	**OPEN**	**Many**	**2013**	**197**
Fictiv	OPEN	Many	2013	58
Hubs (acq. by Protolabs)	OPEN	Many	2013	32
Chizel (acq. by Truventor)	OPEN	Many	2014	undisclosed
Fastradius	OPEN	Many	2014	67.8
Weerg	**CLOSED**	**CNC Machining**	**2015**	**n.a.**
247TailorSteel	**CLOSED**	**Tube Processing**	**2015**	**n.a.**
Orderfox	**OPEN**	**Many**	**2017**	**n.a.**
Fractory	**OPEN**	**Sheet metal processing**	**2017**	**10.6**

Tab 2 – Companies offering on-demand manufacturing services, preliminary analysis – **Companies selected**

companies and other secondary sources available online (e.g. white papers, online video interviews and demo video). Since some of them are funded startup we have also sourced data from crunchbase.com, which collects specific info about new ventures (e.g. founders, foundation year, funding). The triangulation method has been adopted to ensure validity of data gathered. Moreover, although the research is mainly exploratory in kind, we have adopted an interpretive approach using theory in the earlier stage of the study to create a starting research framework for the empirical investigation (Walsham, 1995).

Finally, we perform a cross-case analyses to investigate the capabilities offered today by MaaS platforms and their deployment models. Moreover, the emerging differences between the platforms studied are used to inductively build a framework to assess different levels of development for each CM characteristic.

4. Case description

In this chapter we introduce the companies analysed, their capabilities and the main features of the platforms developed.

Orderfox

Orderfox (Orderfox.com) is a German company founded in 2017 and arisen to facilitate the relationship customer-supplier by creating a portal supporting the exchange of information. The platform basically offers two kinds of service: (I) suppliers search and (II) RFQs publication in a marketplace.

Users at the demand-side of the platform can register for free; it means Orderfox chooses the strategy to subsidize the demand-side of the platform also to attract user to the supplier-side. The “suppliers search” tool allows to select attributes of the desired supplier (e.g. capabilities, nationality, dimension, certifications) and shows the results on a map. As a “buyer” of the platform the User creates an RFQ and details it (i.e. adding drawing, any kind of documents and notes). After having decided whether to select specific recipients or publish worldwide, the RFQ is shared with Service Providers selected. The option of selecting specific recipients can be interesting if we are going to submit sensitive data through the RFQ (e.g. drawings).

Service Providers at the supplier-side can access the marketplace (a registration fee is required to have unlimited access) where all the RFQs are listed and detailed. In this case, we note the provider knows who submitted the RFQ and decides whether to apply or not for specific jobs; in case of acceptation, she/he answers to the RFQ.

Weerg

Weerg (Weerg.it) is an Italian company founded in 2015 and offers Additive Manufacturing (AM) and CNC machining services through a web-based platform which provides instant quoting to RFQs. The platform is open both to business customers and consumers.

To submit an RFQ the process is guided by the rules of the platform. The User uploads CAD drawings, selects the technology, the material, finishing services and instantly visualizes prices on the basis of the delivery date (the sooner it is, the higher is the cost). Eventually, the User places the order and the product is finally delivered to the customer.

Service Providers are represented by the single facility owned by the Cloud Operator, i.e. Weerg. As the founder says, their strength reckons on “transparency of prices, speed of execution, certainty of deliveries”.

247TailorSteel

This company is one of the eldest analyzed (founded in 2007), but it has started an interesting project in 2015 resulting in a platform offering metal sheet and tube processing (e.g. laser cutting, bending services). As in the Weerg case, the Cloud Operator is the same entity owning the resources providing the manufacturing services. It differs from Weerg because the platform is not web-based but works on a Software (namely, "Sophia") to be installed on a laptop. As for Weerg, the User uploads the CAD drawing and after having selected the specs she/he receives the quote, almost instantly. Even in this case, the delivery options are fully customizable and the price takes into account of that.

One of the most interesting things of this case is that Sophia is totally integrated with the production site. Once the order is confirmed, the production plan is updated and the CAM instructions are directly delivered to the machine which will realize the parts ordered (Scholten 2017). This is possible because they developed Sophia together with machinery manufacturers providing the resources owned by 247TailorSteel (Tedaldi and Miragliotta 2020).

Sculpteo

The company was founded in 2009 and it has been acquired by Basf (www.basf.com) in 2019. Sculpteo is specialized in providing Users with additive manufacturing services (i.e. design and production for several additive manufacturing technologies and materials available).

Sculpteo developed a web-based platform to provide Users with instant price and fast delivery times of parts desired. The User simply drags and drops 3D files (.stl or .obj files are suggested but others are allowed) in the window and configures the material and finishing options. It is possible to choose among three delivery options (i.e. "standard", "economic", "express") with different lead times (1-3, 7, 14 days).

Manufacturing resources are mainly represented by 20 3D printers owned by the company and distributed in 2 factories settled in San Francisco (USA) and Paris (France).

Fractory

Fractory is a startup providing manufacturing services for sheet metal fabrication (e.g. plasma, laser cutting) and CNC machining. It has been founded in 2017 in Estonia, moved in UK in 2019 and raised about $ 11 million from investors.

As other companies, they have built a web-based platform equipped with an instant quoting engine providing quotes in real time to RFQs. From the User perspective, the operational flow is quite similar to the previous cases, as it requires CAD drawings, to specify the technology and the materials desired. Deliveries are not customizable but more than 100 different colours as coating options are available (e.g. matte or glossy).

Differently from the previous cases, Fractory does not own any manufacturing facility. It sells manufacturing services leveraging on a network of more than 50 manufacturers distributed mainly in UK. The company simplifies the sourcing process as it answers almost instantly to Users RFQs, takes care about the production as well as the shipping/delivery.

Once the order is received, the algorithm finds the most suitable suppliers (among the registered Fractory providers) and the production is entrusted to the one which can respect the delivery date promised to the customer. On the one hand, the process is highly automated to the User side of the platform, on the other hand the relationships with Service Providers are managed almost manually.

Xometry

Xometry is an American company founded in 2013 and headquartered in Geithersburg, Maryland (USA). It has attracted great attention of investors and raised a total of $ 197 million of funding received. Recently it has acquired Shift, (a German company which was working on the concept of "on-demand" manufacturing), and the European expansion has officially started. It offers CNC Machining, sheet metal processing (e.g. waterjet, laser, plasma cutting), injection moulding, 3D printing services, as well as other ones like urethane casting and finishing services.

The business model and operational flow are quite similar to those ones of Fractory. The company does not own any manufacturing asset but it guarantees product quality of its suppliers through the use of employees which control parts before the final shipping to the customer (even if trusted suppliers sometimes are allowed to directly ship to users).

On one hand, Xometry can be compared to Fractory, on the other hand we observe Xometry capabilities, materials are more extended and the level of service customization is much higher (e.g. thread, part marking, inserts). Moreover, it allows to get different prices on the basis of the delivery options, which are three: "Expedite" (2 days), "Standard" (7 days) and "Economy" (12 days) but in some regions of US are available shipping in 1 day.

A network of more than 5.000 manufacturers guarantees to this platform a higher level of elasticity with respect to the other cases and, consequently, a higher flexibility to Users.

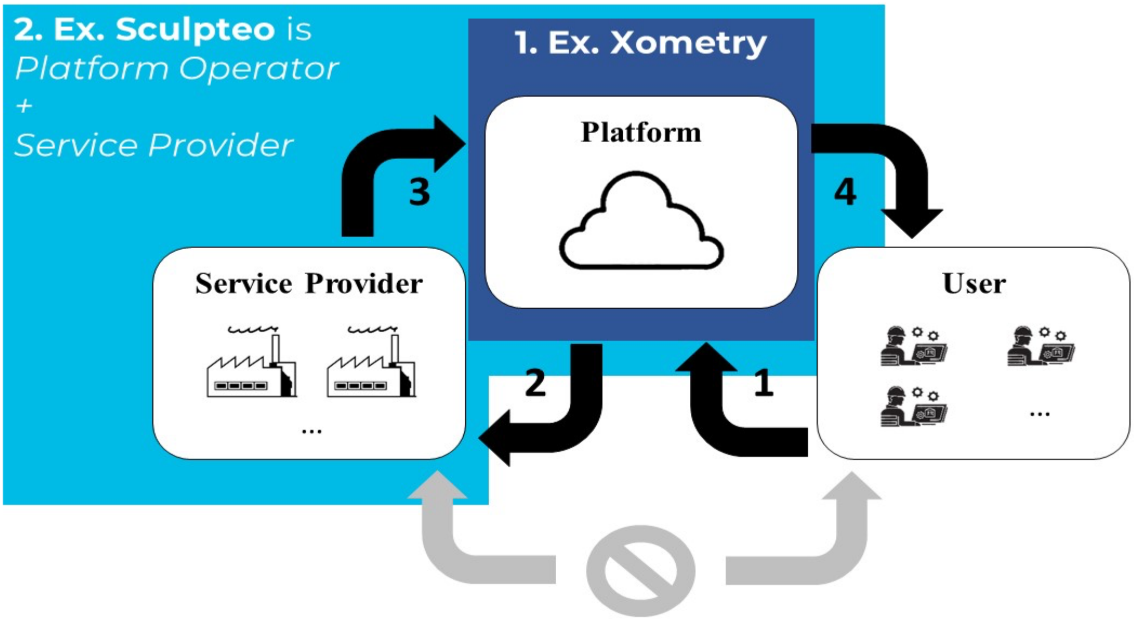

Figure 1 - MaaS Deployment models

5. Cross-case analysis

5.1 Platforms seeking MaaS benefits

First of all, we can note that the analyzed platforms can belong to the MaaS paradigm since they reflect most of the characteristics of Manufacturing-as-a-Service as envisioned by academics about 30 years ago. Orderfox is the platform farest from the MaaS concept as the responsibility of the platform operator along the users procurement journey (Ren, Zhang, Wang, Tao, & Chai, 2017) is quite limited (Tab. 4). Although this platform reduces transaction costs for users searching for manufacturing partners, the benefits in terms of responsiveness and flexibility are very limited. In all the other cases, platform operators can “read” the service requirements (published by users), and they can take care of tasks until the final delivery of the service while managing all the activities in between (Tab. 4).

The results of this research show that MaaS platforms offering on-demand manufacturing services are mainly focusing on the production of mechanical components via Additive Manufacturing or CNC machining, as well as sheet metal products (Tab. 3).

Although these Early Adopters seem quite similar to each other, they differ on the deployment models and their levels of development if we compare them to the CM characteristics described in Chapter 2.

5.2. Deployment models for CM

As from the theoretical background, platforms contemplate the “opening” or “closing” on each side of the platform (i.e. Provider and User sides). However – today - it seems that this idea cannot apply to MaaS platforms, in practice. In fact, it seems to be valid only on the Provider side, while the User side is just always open to the public. Platforms studied therefore seem to work according to just two deployment models: open (Weerg, Xometry, Fractory), and closed (Sculpteo, 247Tailorsteel, Weerg) on the Provider side, while on the User side they are all generally public, open to anyone (Fig. 1).

On the User side, these platforms probably choose to be "Public" since the development costs of the platform architecture are not compatible with a "Private" or "Community" use (reserved for a company or a small number of partner companies, respectively).

On the one hand, the "Open" platforms clearly aim for higher scalability, in the face of higher operating management costs (e.g. Xometry usually inspect parts before shipping to users). On the other hand, the closed platforms aim at the IT integration of production and logistics assets, requiring that the assets are under the strict control of the Cloud Operator (due to standards and interoperability issues). Therefore, it is not a coincidence that the Platform Operator is the direct owner of the resources and Service Provider (Fig. 1). Certainly, from a technical point of view this approach is much more challenging but it allows these platforms to maximize operational efficiency.

Company	Additive Manufacturing	Injection Molding	CNC machining (e.g. milling, turning)	Sheet metal processing	Pipe processing	Electronics	Other (e.g. Urethane casting)
Orderfox	x	x	x	x	x	x	x
Xometry	x	x	x	x			x
Fractory			x	x			
247TailorSteel				x	x		x
Sculpteo	x						
Weerg	x		x				

Tab. 3 – Cross case analysis – Capabilities offered through the platform

	CLOUD MANUFACTURING PROCESS (Ren et al., 2014)											
	1. Service publishing		*2. Intelligent matching & virtual system establishing*						*3. Service Execution*			*4. Service Rating*
	SUB-PROCESS											
COMPANY	Identification service requirements	Service customization (e.g. Design support)	Service Providers selection	RFQ submission	Quotations management	Assessment and provider selection	Negotiation	Transaction & Order Placement	Production & Order Mgmt.	Pre-shipping quality inspection	Shipping & Delivery	Rating and billing
Orderfox			P	P	"Manual"; compared in hours/days				SP	SP	SP	P
Xometry	P	P*	P	P	"Automatic"; instant quoting	P	P	P	P (SP)	P (SP)	P*	P
Fractory	P		P	P		P	P	P	P (SP)	P (SP)	P*	P
247TailorSteel	P		P	P		P	P	P	P	P	P	P
Sculpteo	P		P	P		P	P	P	P	P	P*	P
Weerg	P		P	P		P	P	P	P	P	P*	P

Tab. 4 – Cross case analysis - Platforms responsibility along the procurement journey
Legend: “”=User; P=Platform Operator; SP=Service Providers
P (SP): P centrally manages the SP --- P*Indirectly, leveraging on third parties

Company	Found. Year	Tot Funding [$ mil.]	Number of employees	Provider Side approach	Number of manufacturers
Orderfox	2017	n.a.	20-50	OPEN	17000
Xometry	2013	197	300	OPEN	5000
Fractory	2017	11	50-100	OPEN	50
247TailorSteel	2015**	n.a.	> 500	CLOSED	6
Sculpteo	2009	11	20-50	CLOSED	2
Weerg	2015	n.a.	20-50	CLOSED	1

Tab. 5 – Cross case analysis – Platforms data and their approach to the provider side “open” vs “closed”

**Company founded previously, but MaaS initiative started in 2015

5.3. A framework to assess different levels of development for Early Adopters

In this chapter we refer to the characteristics of CM presented in Chapter 2 and – from a comparison of the finding of the cases we selected – we draw different levels of development for each one, considering max 4 levels (L1, L2, L3, L4) as commonly adopted by most of the maturity models (Fraser, Moultrie, & Gregory, 2002; Schumacher, Erol, & Sihn, 2016).

Centralized Management

We identified 4 levels of centralized management.

L1. Resources are not managed by the Platform Operator. The Platform Operator just describes the Service Providers in term of capabilities. The User finds the right Provider in less time, looking at the online "providers catalogue".

L2. The Platform Operator creates a marketplace where RFQs are published. Service Providers can answer to them, connect to the Users and start a relationship.

L3. The Platform Operator directly answers to the RFQs while the Service Provider loses the contact with the final User. When the Order is confirmed, the Platform Operator select the Service Providers who would fulfil the order. The Service Provider can accept/deny the allocation suggested by the Platform Operator and it does not lose the control of its own resources.

L4. The Platform Operator turns the Order into tasks to be performed and unilaterally decides where to allocate them. Here, the Service Provider loses control of its own resources.

High information sharing

Information sharing between the platform and the other CM participants allow CM system to reach different level of automation of their processes:

L1. The Platform Operator is a traditional intermediary and just starts the relationship between customers and suppliers.

L2. The Platform is equipped with a repository of the RFQs. At this level, services are not requested by Users through standardized mechanisms, thus the response to the RFQ cannot be automated. Nevertheless, the platform centralizes the communication, supports the negotiation with web-based tools (e.g. chat tools, repository of drawings, customers categories);

L3. The services are requested through standardized mechanisms and read by the Platform Operator (e.g. drawing with specific file formats). The response to the RFQs is automated. Nevertheless, once the order is confirmed, the allocation of the tasks to the resources is managed by human interactions between the Platform Operator and the Service Providers. This happens because the Platform Operator has no visibility on the availability of the resources (i.e. resources are not connected and virtualized).

L4. The information transactions are managed almost automatically. Resources are equipped with sensors which communicate data to the Platform Operator. The RFQs are requested through standardized mechanism and the response to the RFQs is automated by the Platform. Once the order is confirmed, the Platform automatically turns them into tasks to be performed by the resources and allocates them to the most suitable ones.

On-Demand

For this feature we can simply specify whether a platform is immediately available to produce a service on request. Thus, we have only two levels:

L1. No: the platform just offers a marketplace where RFQ are published at any time but delivery of services is not guaranteed by the Cloud Operator.

L4. Yes: the Platform is available at any time and Cloud Operators guarantees the delivery of the manufacturing services whenever requested.

Service-oriented

This characteristic is focused on the relationship customer-supplier and 4 different levels of flexibility are found:

L1. The relationship with suppliers is traditional;

L2. Fast response time to RFQs, highly customized product. Users cannot change the delivery date suggested. A limited set of materials and finishing services (e.g. coating, colours) are available;

L3. Like "L2" but 3-5 delivery options are available with different pricing (e.g. "Economy", "Express");

L4. The relationship with suppliers is new (e.g. highly customized product, flexible relationship). It allows to customize materials, lead times, finishing and selecting other services.

Resource Pooling

Here we specify whether the resources are pooled and we measure the level of distribution of the resources:

L1. Resources are not pooled and it is not present a network of physically distributed resources;

L2. Resources are pooled but owned by a single Provider which manage them;

L3. Resource are pooled and owned by a group of enterprises or a group of enterprises belonging to a parent company;

L4. Resources are pooled by a great number of enterprises and the platform is open to the Service Provider side.

Ubiquitous and broad network access

Manufacturing ubiquity means the User easily access the manufacturing network and can receive the service wherever she/he is (i.e. this is related to the worldwide presence of manufacturing resources) (Chen & Tsai, 2017) :

L1. The platform runs on standard devices (e.g. web-based applications running on laptops, tablets, smartphones). Service Providers are located in one country and Users from other countries feel the distance from the manufacturer (e.g. longer lead time);

L2. Broad network access as for "L1" but here services come from an international network, even if still limited to 1 continent;

L3. As for L2 but services come from 2 continents; Users from worldwide can still suffer the distance from manufacturers of the network;

L4. As for L3 but "Ubiquitous manufacturing" here is a customer experience, because resources are dispersed in 3 or more continents (e.g. North America, Europe, Asia).

Dynamism, rapid elasticity and scalability

These characteristics depend on the number of resources beyond the platform. From the cases analysed, we can identify 4 different levels:

L1. The system is static and works with a very limited capacity. This level refers to platforms leveraging on just a couple of production facilities.

L2. The Platform responds to demand variations leveraging on a limited number of pooled resources, at the expense of the speed of response to the change. Here we find platforms leveraging on less than 10 production sites;

L3. At this level the system better responds to demand variations because a wide network of resources, but less than 50, is available;

L4. A great number of resources are available and resources appear to be unlimited to the User.

After having proposed a framework to measure different development levels of CM platforms, we can visualize on a spider chart the differences between the cases analysed (Fig. 2). As we have already noticed in chapter 5.2, companies like Orderfox are further away from the realization of a CM system, while the other ones seem to be closer but follow different approaches. 247TailorSteel aims to achieve full integration of IT systems and equipment while Xometry clearly aims at increasing the number of manufacturing providers as much as possible to guarantee full scalability.

With respect to the diffusion of innovation theory Rogers (1962) and Valente (1996) explain that in a social context when an innovation occurs, adopters can be categorized on the basis of the time of adoption. Therefore, after several years of prototypes provided by "innovators" of the paradigm, the companies we have studied could be defined "Early adopters" as they represent first real and virtuous examples (in the history) of this innovative manufacturing model, in spite of their supposed incompleteness or missed MaaS goals.

6. Discussion

6.1 The rise of a MaaS platform economy

The first research question opening our study (RQ1) aims to show the state-of-the-art of MaaS platforms (prototypes excluded) which are currently operating. First of all, we observe from empirical evidence that initiatives of MaaS platforms are not very numerous, some of these ones are quite consolidated (hundreds of employees) and offer on-demand manufacturing services which were never seen before in supply chain mangement literature (e.g. instant quoting, deliveries in 1 day). Secondly, we observe that after a debate lasting more than 10 years, the first business goal of CM seems to be achieved, i.e. realizing "a controlled service environment that offers the rapid and flexible provisioning of manufacturing resources to meet manufacturing mission's demands" (Q. Liu, Gao, & Lou, 2011).

In the literature Helo and Hao had already found empirical evidence of MaaS platforms in the context of sheet metal processing (P. Helo & Hao, 2017). This paper confirms that CM could spread through this capability, as well as through the additive manufacturing, but also CNC machining and other more exotic technologies, as we reported in the previous chapter.

The higher the number of capabilities offered, the higher is the complexity of the implementation of an integrated CM system. On one hand, Xometry realized an effective platforms without full IT integration of resources, and they can offer a wide range of capabilities (Tab. 3). On the other hand, Weerg, Sculpteo and 247tailorsteel aim to realize a full IT integration and to maximize their efficiency. For this reason they are somehow forced to be closed on the provider side, with a very limited number of machineries/facilities. However, these three platforms are succeeding in their IT integration and processes automation. This is partially in contrast with (Lu & Xu, 2019) as they wrote that "the diversity and complexity of manufacturing resources make CM impossible for the

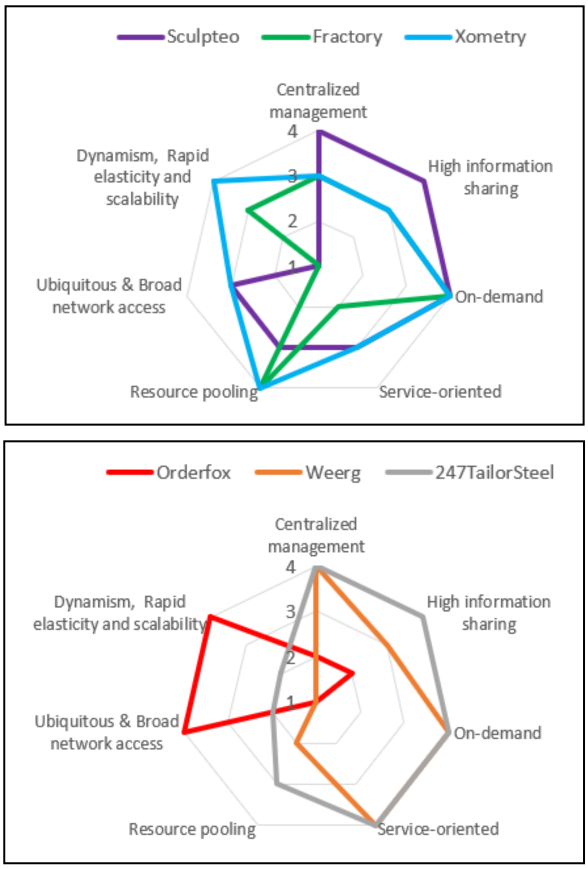

Figure 2: Cross-case analyses – Different levels of development

operator to purchase all manufacturing resources necessary for building a CM platform; […] the main function of the operator is to manage and operate providers' manufacturing resources".

6.2 Deployment models

Once we have investigated the state-of-the-art (RQ1), we move on to RQ2 to discuss the different deployment models emerged from theoretical studies and compare them to what we find from the cases. In the literature of Cloud Manufacturing most of the authors define deployment models for CM as "Private", "Public", "Community" and "Hybrid" (Y. Liu et al., 2019), mirroring the definition given by NIST to cloud computing. In cloud computing environments there is the Service Provider which is just one and it does not collaborate or partner with anyone (e.g. Amazon EC2 owns its datacenter and develops its systems, by itself). Here in CM the context is more complex, and what does in mean being "private"? Liu et al. apply the concept of "private" on both sides of the platform as they were both closed: "in private cloud manufacturing systems […] all entities are from the same organisation, and only in-house manufacturing resources are aggregated in the cloud platform" (Y. Liu et al., 2019). In the same way, they say that the public deployment model should be opened on both sides of the platforms.

Deployment models found in the literature cannot explain why we find platform like Weerg or 247tailorsteel which are "closed" on the provider side, but "open" on the user side. For this reason, we suggest to take into consideration both sides of the platform when talking about CM deployment models. This achievement is in line with the work of Helo et al., where they identify different CM "portals" in the field of sheet metal processing (Petri Helo, Hao, Toshev, & Boldosova, 2021). Their study show that some CM portals (e.g. "manufacturer-customized portal") could be closed on the provider side while being open on the user side.

6.3 Measuring different levels of development

The third research question (RQ3) of our study aims to investigate whether it is possible to identify different levels of development for MaaS platforms. The framework introduced in chapter 5.3 is based on the characteristics of Cloud Manufacturing emerged in the theoretical background (Chapter 2) and 4 different levels of development have been identified inductively on each of them, from the analysis of the cases.

This framework cannot be considered a maturity model because the word maturity usually refers to an organization or a process regarding some specific target state (Schumacher, Erol, & Sihn, 2016). In fact, within the MaaS domain we still do not know whether the two deployment models identified through this study will be sustainable in the long term.

Nevertheless, our work could be useful for researchers to build future models assessing the maturity of a MaaS platform because there are no papers in literature addressing this topic within the Cloud Manufacturing (or MaaS) domain. Jayasekara, Pawar, & Ratchev, (2019) introduced a model to assess the readiness of manufacturers (in place of Platform Operator) to adopt Cloud Manufacturing. They state that "Service Providers play the most important role in a CM environment, and the success of CM implementation depends on the readiness of manufacturers to transform their traditional business". After the present study, we may argue that manufacturers play the most important role just in the case of "Closed" environment, as in the "Open" configuration just minimal prerequisites are required to become Service Provider of the CM network.

7. Conclusions

The Cloud Manufacturing paradigm inherits challenges as well as drawbacks from the previous experiences of other manufacturing models which were born to increase flexibility in an increasingly uncertain and turbulent context. The Agile manufacturing vision seems to find in CM a new possible model enabling it.

This is possible thanks to the advent of digital technologies belonging to the fourth industrial revolution which reshape the servitization, the success of Cloud Computing and the achievement of the Platform Economy. Today we can observe several examples of platforms offering on-demand manufacturing services which we have never met in the history, and this is why we think that a Manufacturing-as-a-Service (MaaS) Platform economy is arising.

Results of the present study show that today MaaS platforms are mainly focusing on pretty simple mechanical parts through Additive manufacturing, CNC machining and Sheet metal processing. Performances in terms of flexibility offered, responsiveness, geographical coverage (and other dimensions) vary between the cases selected, nevertheless we define them MaaS Early Adopters as they share the same purpose.

With regard to the platform architecture we observe two different deployment models which both seem to work: "Open" and "Closed" to the provider side of the MaaS platform. In all cases encountered, MaaS platforms are "Public" and services are available to whomever. This is a major difference of CM with respect to the Cloud Computing paradigm where we have closed environment to the provider side while "Public" "Community", "Private" "Hybrid", to the User side.

Moreover, the cross-case analysis shows several differences between platforms studied on the basis of the characteristics of a CM platform. This point origins an inductive framework which has been proposed in this paper to assess the level of development of a MaaS platform.

The contribution from an academic perspective is threefold. First, this is one of the first papers showing real examples of companies delivering commercial

MaaS solutions. This can support academics for future studies in this field. It is important as it seems that there is an increasing gap between research and what professionals are doing (i.e. following different development trajectories). In detail, academics in this field struggle to develop a “fully integrated” CM system but it does not seem the only path possible to follow (cfr. Xometry, $ 193 million funding, now listed). Secondly, this paper focuses on the deployment models adopted by MaaS plaforms today which are different from those described in the literature (where it seems that CM can consider just “fully integrated” & “open to the provider side”). In general - on the basis of the deployment models - two development trajectories appear within the CM domain and the research should support both of them as long as they both seem to work. Thirdly, the framework proposed expand the theory as it has been inductively built from empirical cases and it could be use in the future to build models assessing the maturity of MaaS platforms.

From a managerial perspective, we show to manufacturers that MaaS platform economy is arising, and empirical evidence has been carried out in this paper. Secondly, Cloud Operators in this field could use this framework to evaluate themselves with reference to the players analyzed, or even others.

Future research directions pair with limitations of the study. First, it should be interesting to enlarge the empirical base of our results to evaluate the resilience of the framework proposed, and eventually expand it and validate it with experts in this field. Secondly, academics could monitor through longitudinal studies how these platforms evolve in order to discover whether – on the way to the CM maturity process – the deployment models identified in this study would change or which one will prevail over the other.

References

Adamson, G., Wang, L., Holm, M., & Moore, P. (2017). Cloud manufacturing–a critical review of recent development and future trends. *International Journal of Computer Integrated Manufacturing*, *30*(4–5), 347–380. https://doi.org/10.1080/0951192X.2015.1031704

Ardolino, M., Saccani, N., & Perona, M. (2016). The rise of platform economy: A framework to describe multisided platforms. *Proceedings of the Summer School Francesco Turco*, *13-15-Sept*, 257–261.

Baines, T. S., Lightfoot, H. W., Benedettini, O., & Kay, J. M. (2009). The servitization of manufacturing: A review of literature and reflection on future challenges. *Journal of Manufacturing Technology Management*, *20*(5), 547–567. https://doi.org/10.1108/17410380910960984

Baines, T. S., Lightfoot, H. W., Evans, S., Neely, A., Greenough, R., Peppard, J., … Wilson, H. (2007). State-of-the-art in product-service systems. *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*, *221*(10), 1543–1552. https://doi.org/10.1243/09544054JEM858

Bortolini, M., Galizia, F. G., & Mora, C. (2018). Reconfigurable manufacturing systems: Literature review and research trend. *Journal of Manufacturing Systems*, *49*(July), 93–106. https://doi.org/10.1016/j.jmsy.2018.09.005

Bortoluzzi, G., Chiarvesio, M., Romanello, R., Tabacco, R., & Veglio, V. (2022). Servitisation and performance in the business-to-business context: the moderating role of Industry 4.0 technologies. *Journal of Manufacturing Technology Management*, *33*(9), 108–128. https://doi.org/10.1108/JMTM-08-2021-0317

Brettel, M., Klein, M., & Friederichsen, N. (2016). The Relevance of Manufacturing Flexibility in the Context of Industrie 4.0. *Procedia CIRP*, *41*, 105–110. https://doi.org/10.1016/j.procir.2015.12.047

Chen, T., & Tsai, H.-R. (2017). Ubiquitous manufacturing: Current practices, challenges, and opportunities. *Robotics and Computer-Integrated Manufacturing*, *45*, 126–132. https://doi.org/https://doi.org/10.1016/j.rcim.2016.01.001

Clark, H., & McMillin, B. (1992). DAWGS—A distributed compute server utilizing idle workstations. *Journal of Parallel and Distributed Computing*, *14*(2), 175–186. https://doi.org/https://doi.org/10.1016/0743-7315(92)90114-3

Eisenmann, T., Parker, G., & Van Alstyne, M. W. (2006). Strategies for two-sided markets. *Harvard Business Review*, *84*(10). https://doi.org/10.1007/s00199-006-0114-6

Eisenmann, T., Parker, G., & Van Alstyne, M. W. (2008). *Opening Platforms: How, When, Why?*

Ferdows, K., & De Meyer, A. (1990). Lasting improvements in manufacturing performance: In search of a new theory. *Journal of Operations Management*, *9*(2), 168–184. https://doi.org/10.1016/0272-6963(90)90094-T

Foster, I. (2002). What is the grid? a three point checklist.

Foster, I., Geisler, J., Kesselman, C., & Tuecke, S. (1997). Managing multiple communication methods in high-performance networked computing systems. *Journal of Parallel and Distributed Computing*, *40*(1), 35–48. https://doi.org/10.1006/jpdc.1996.1266

Foster, I., Kesselman, C., & Tuecke, S. (2001). The anatomy of the grid. *International Journal of Supercomputer Applications*, *15*(3), 200–222. https://doi.org/10.1177/109434200101500302

Foster, I., Zhao, Y., Raicu, I., & Lu, S. (2008). Cloud Computing and Grid Computing 360-Degree Compared. In *Grid Computing Environments Workshop, GCE*. IEEE. https://doi.org/10.1109/GCE.2008.4738445

Frank, A. G., Dalenogare, L. S., & Ayala, N. F. (2019).

Industry 4.0 technologies: Implementation patterns in manufacturing companies. *International Journal of Production Economics*, *210*(January), 15–26. https://doi.org/10.1016/j.ijpe.2019.01.004

Fraser, P., Moultrie, J., & Gregory, M. (2002). The Use of Maturity Models / Grids as a Tool in Assessing Product Development Capability. *Proceedings of IEEE International Engineering Management Conference (IEMC)*, *1*, 244–249. https://doi.org/10.1109/IEMC.2002.1038431

Gawer, A., & Cusumano, M. A. (2014). Industry platforms and ecosystem innovation. *Journal of Product Innovation Management*, *31*(3), 417–433. https://doi.org/10.1111/jpim.12105

Gerwin, D. (1993). Manufacturing Flexibility: A Strategic Perspective. *Management Science*, *39*(4), 395–410. Retrieved from http://www.jstor.org/stable/2632407

Glaser, B. G., & Strauss, A. L. (1967). *The discovery of grounded theory: strategies for qualitative research*. Aldine Transaction.

Goldhar, J. D., & Jelinek, M. (1990). Manufacturing as a service business: CIM in the 21st century. *Computers in Industry*, *14*(1–3), 225–245. https://doi.org/10.1016/0166-3615(90)90126-A

Gunasekaran, A. (1998). Agile manufacturing: Enablers and an implementation framework. *International Journal of Production Research*, *36*(5), 1223–1247. https://doi.org/10.1080/002075498193291

Gunasekaran, Angappa, Yusuf, Y. Y., Adeleye, E. O., Papadopoulos, T., Kovvuri, D., & Geyi, D. G. (2019). Agile manufacturing: an evolutionary review of practices. *International Journal of Production Research*, *57*(15–16), 5154–5174. https://doi.org/10.1080/00207543.2018.1530478

Hasan, M. A., Shankar, R., & Sarkis, J. (2007). A study of barriers to agile manufacturing. *International Journal of Agile Systems and Management*, *2*(1), 1–22. https://doi.org/10.1504/IJASM.2007.015679

Helo, P., & Hao, Y. (2017). Cloud manufacturing system for sheet metal processing. *Production Planning and Control*, *28*(6–8), 524–537. https://doi.org/10.1080/09537287.2017.1309714

Helo, Petri, Hao, Y., Toshev, R., & Boldosova, V. (2021). Cloud manufacturing ecosystem analysis and design. *Robotics and Computer-Integrated Manufacturing*, *67*(March 2019), 102050. https://doi.org/10.1016/j.rcim.2020.102050

Henzel, R., & Herzwurm, G. (2018). Cloud Manufacturing: A state-of-the-art survey of current issues. In *Procedia CIRP* (Vol. 72, pp. 947–952). Elsevier B.V. https://doi.org/10.1016/j.procir.2018.03.055

Huang, B., Li, C., Yin, C., & Zhao, X. (2013). Cloud manufacturing service platform for small- and medium-sized enterprises. *International Journal of Advanced Manufacturing Technology*, *65*(9–12), 1261–1272. https://doi.org/10.1007/s00170-012-4255-4

Jayasekara, D., Pawar, K., & Ratchev, S. (2019). A Framework to Assess Readiness of Firms for Cloud Manufacturing. In *Proceedings - 2019 IEEE International Conference on Engineering, Technology and Innovation, ICE/ITMC 2019*. https://doi.org/10.1109/ICE.2019.8792648

Kenney, M., & Zysman, J. (2016). The Rise of the Platform Economy. *Issues in Science and Technology*, *32*(3), 61–69.

Leita, P. (2009). Engineering Applications of Artificial Intelligence Agent-based distributed manufacturing control : A state-of-the-art survey, *22*, 979–991. https://doi.org/10.1016/j.engappai.2008.09.005

Li, B.-H., Zhang, L., Wang, S.-L., Tao, F., Cao, J.-W., Jiang, X.-D., … Chai, X.-D. (2010). Cloud manufacturing: A new service-oriented networked manufacturing model. *Jisuanji Jicheng Zhizao Xitong/Computer Integrated Manufacturing Systems, CIMS*, *16*(1).

Liu, Q., Gao, L., & Lou, P. (2011). Resource management based on multi-agent technology for cloud manufacturing. In *2011 International Conference on Electronics, Communications and Control, ICECC 2011 - Proceedings* (pp. 2821–2824). https://doi.org/10.1109/ICECC.2011.6067811

Liu, Y., Wang, L., Wang, X. V., Xu, X., & Jiang, P. (2019). Cloud manufacturing: key issues and future perspectives. *International Journal of Computer Integrated Manufacturing*, *32*(9), 858–874. https://doi.org/10.1080/0951192X.2019.1639217

Liu, Yongkui, & Xu, X. (2016). Industry 4.0 and Cloud Manufacturing: A Comparative Analysis. *Volume 2: Materials; Biomanufacturing; Properties, Applications and Systems; Sustainable Manufacturing*, *139*(March 2017), V002T04A016. https://doi.org/10.1115/MSEC2016-8726

Lu, Y., & Xu, X. (2019). Cloud-based manufacturing equipment and big data analytics to enable on-demand manufacturing services. *Robotics and Computer-Integrated Manufacturing*, *57*(November 2018), 92–102. https://doi.org/10.1016/j.rcim.2018.11.006

Medini, K. (2022). A framework for agility improvement projects in the post mass customisation era. *International Journal of Production Research*. https://doi.org/10.1080/00207543.2022.2146228

Meindl, B., Ayala, N. F., Mendonça, J., & Frank, A. G. (2021). The four smarts of Industry 4.0: Evolution of ten years of research and future perspectives. *Technological Forecasting and Social Change*, *168*(November 2020). https://doi.org/10.1016/j.techfore.2021.120784

Mell, P., & Grance, T. (2011). The NIST Definition of Cloud Computing Recommendations of the

National Institute of Standards and Technology. *Nist Special Publication*, *145*, 1–7. https://doi.org/10.1136/emj.2010.096966
Naim, M. M., Potter, A. T., Mason, R. J., & Bateman, N. (2006). The role of transport flexibility in logistics provision. *The International Journal of Logistics Management*, *17*(3), 297–311.
Paschou, T., Rapaccini, M., Adrodegari, F., & Saccani, N. (2020). Digital servitization in manufacturing: A systematic literature review and research agenda. *Industrial Marketing Management*, *89*, 278–292. https://doi.org/10.1016/j.indmarman.2020.02.012
Qiu, R. G. (2004). Model.
Rahman, M. N. A., Medjahed, B., Orady, E., Muhamad, M. R., Abdullah, R., & Jaya, A. S. M. (2018). A review of cloud manufacturing: Issues and opportunities. *Journal of Advanced Manufacturing Technology*, *12*(1), 61–76.
Ren, L., Zhang, L., Wang, L., Tao, F., & Chai, X. (2017). Cloud manufacturing: key characteristics and applications. *International Journal of Computer Integrated Manufacturing*, *30*(6), 501–515. https://doi.org/10.1080/0951192X.2014.902105
Ridder, H. G. (2017). The theory contribution of case study research designs. *Business Research*, *10*(2), 281–305. https://doi.org/10.1007/s40685-017-0045-z
Rochet, J.-C., & Tirole, J. (2003). Platform competition in two-sided markets. *Journal of the European Economic Association*, *1*(4), 990–1029. https://doi.org/10.1109/SISPAD.2008.4648258
Rogers, E. (1962). *Diffusion of innovations*. (Free Press of Glenco, Ed.). New York.
Schumacher, A., Erol, S., & Sihn, W. (2016). A Maturity Model for Assessing Industry 4.0 Readiness and Maturity of Manufacturing Enterprises. *Procedia CIRP*, *52*, 161–166. https://doi.org/10.1016/j.procir.2016.07.040
Tao, F., Zhang, L., & Nee, A. Y. C. (2011). A review of the application of grid technology in manufacturing. *International Journal of Production Research*, *49*(13), 4119–4155. https://doi.org/10.1080/00207541003801234
Tao, F., Zhang, L., Venkatesh, V. C., Luo, Y., & Cheng, Y. (2011). Cloud manufacturing: A computing and service-oriented manufacturing model. *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*, *225*(10), 1969–1976. https://doi.org/10.1177/0954405411405575
Tedaldi, G., & Miragliotta, G. (2022). The role of Engineering-to-Order machinery manufacturers in future Cloud Manufacturing supply chains: a business case and a strategic perspective. *Production Planning and Control*. https://doi.org/10.1080/09537287.2020.1837942
Valente, T. W. (1996). Social network thresholds in the diffusion of innovations. *Social Networks*, *18*(1), 69–89. https://doi.org/10.1016/0378-8733(95)00256-1
Vandermerwe, S., & Rada, J. (1988). Servitization of business: Adding value by adding services. *European Management Journal*, *6*(4), 314–324. https://doi.org/https://doi.org/10.1016/0263-2373(88)90033-3
Vázquez-Bustelo, D., Avella, L., & Fernández, E. (2007). Agility drivers, enablers and outcomes: Empirical test of an integrated agile manufacturing model. *International Journal of Operations and Production Management*, *27*(12), 1303–1332. https://doi.org/10.1108/01443570710835633
Walsham, G. (1995). Interpretive case studies in IS research: Nature and method. *European Journal of Information Systems*, *4*(2), 74–81. https://doi.org/10.1057/ejis.1995.9
Wu, D., Greer, M. J., Rosen, D. W., & Schaefer, D. (2013). Cloud manufacturing: Strategic vision and state-of-the-art. *Journal of Manufacturing Systems*, *32*(4), 564–579. https://doi.org/10.1016/j.jmsy.2013.04.008
Xu, X. (2012). From cloud computing to cloud manufacturing. *Robotics and Computer-Integrated Manufacturing*, *28*(1), 75–86. https://doi.org/10.1007/978-3-642-35197-6_34
Yin, R. K. (2003). *Case Study Research: Design and Methods*. (Thousand Oaks, Ed.). SAGE.
Yin, Y., Stecke, K., & Li, D. (2018). The evolution of production systems from Industry 2.0-4.0.pdf. *International Journal of Production Research*, *56*(1), 848–861.
Zhang, L., Luo, Y., Tao, F., Li, B. H., Ren, L., Zhang, X., … Liu, Y. (2014). Cloud manufacturing: a new manufacturing paradigm. *Enterprise Information Systems*, *8*(2), 167–187. https://doi.org/10.1080/17517575.2012.683812
Zheng, T., Ardolino, M., Bacchetti, A., & Perona, M. (2021). The applications of Industry 4.0 technologies in manufacturing context: a systematic literature review. *International Journal of Production Research*, *59*(6), 1922–1954. https://doi.org/10.1080/00207543.2020.1824085