Cloud Manufacturing: applicability domains of a new manufacturing paradigm(*)

Gianluca Tedaldi - Politecnico di Milano*

*Giovanni Miragliotta** - Politecnico di Milano*

Abstract

Information and digital technologies are penetrating the manufacturing world allowing enterprises to be more flexible, efficient and effective towards the market. Such a transformation has been named "the fourth industrial revolution" and it has become a prominent trend worldwide. Among these enabling technologies, cloud computing is one of the most interesting: the evolution of this paradigm (from the traditional Infrastructure, Platform and Software served on demand) has brought some authors to start talking about Cloud Manufacturing (CM), the manufacturing version of Cloud Computing where also manufacturing services can be encapsulated and served on-demand.

In literature, several studies have been published, showing architectures, benefits and models for CM mainly focusing on technology issues, while it is hard to find reports on empirical examples. The objective of the study is to build a model to assess the applicability of Cloud Manufacturing, in order to understand which sector or sub-sector may be receptive to this new paradigm in the future.

Starting from the literature the authors have created a qualitative model that answers such research question. The model consists in a matrix: on the rows it includes the requirements for CM in all the main steps from the RFQ (request for quotation) to the delivery of the product/service while on the column a system of scores is presented. To validate the model several companies belonging to different sectors have been interviewed. These interviews helped to retune the model and, following the opinions and suggestions provided by experts, the model was calibrated and the overall process validated.

The model has been finally applied to some companies. The results reported in this paper shows that companies interviewed are not yet ready to apply the concept of CM because of some requirements not respected, but some industries are closer than other.

Keywords: Cloud Manufacturing; Manufacturing as-a-service; Service-oriented manufacturing; Distributed manufacturing; Collaborative manufacturing.

[*] Ph.D. Student, Department of Management, Economics and Industrial Engineering, Politecnico di Milano, (gianluca.tedaldi@polimi.it), corresponding author

**Associate Professor, Department of Management, Economics and Industrial Engineering, Politecnico di Milano, (giovanni.miragliotta@polimi.it)

1. Introduction

In the last decades, manufacturing has been moving from maximizing production to maximizing customization and from a product-oriented approach to a service-oriented one. Companies in the last years need to be more responsive to customer demand and dynamically adjust the entire production network trying to survive to an increasing turbulent context. In the last years, both academics and practitioners started to look for forms of collaboration on manufacturing activities in order to be more competitive on a global marketplace. According to Adamson et. al., sharing resources, knowledge and information between geographically distributed manufacturing entities could make enterprises more agile and cost-effective, with higher resources utilization, leading to a competitive edge, in a win-win scenario for all participants (Adamson et al. 2015). In the Industry 4.0 era new technologies become available and many enterprises progressively adopt solutions that change the approach they used to have. One of the most interesting technologies is Cloud Computing (CC): the evolution of this paradigm from the traditional IaaS, PaaS and SaaS have brought some authors to start talking about Manufacturing as a Service, or Cloud Manufacturing (CM). According to Xu, CM is the manufacturing version of Cloud Computing where distributed resources are encapsulated into cloud services and managed in a centralized way (Xu, X., 2011). The main objective of this paper is to understand in which manufacturing context the Cloud Manufacturing could be effectively applied. Thus the authors presents a model to assess the applicability of CM, in order to understand which sector or sub-sector may be receptive to this new paradigm in the future.
In order to address this concern, this paper proceeds as follows. Section 2 introduces the theoretical background: definitions, architectures, key characteristics and benefits of CM. Section 3 underlines the gap found in literature presenting the research questions arisen and later describes the methodology applied to address them (model construction and validation). Section 4 introduces the structure of the model and its operating parameters. Section 5 is devoted to illustrate the results given by the model tested on two different manufacturing industries. Eventually, Section 6 draws some conclusions and suggests future research concerns that could be addressed.

2. Theoretical Background

Current market challenges push competition towards more efficient, faster and more sustainable production processes. Customer needs must be a focal point for any department within a company, with a steady attention for the fulfillment of customized requirements and for the engagement of the customer. Furthermore, markets and industries have become extremely dynamic, asking firms to flexibly adapt the volume and the mix of their production. In view of these challenges, the new paradigm of Cloud Manufacturing seems promising from several perspectives (efficiency, customization, innovation, scalability). Since 2010 a growing debate about Cloud Manufacturing has been emerging in literature and meanwhile practitioners from all over the world show attempts of CM solutions in different manufacturing sectors.

The first definition of Cloud Manufacturing (CM) is given by Li (Li et al. 2010), and it progressively attracted the attention of many authors that revised the definition, described the architectures, the benefits and the challenges of this new interesting manufacturing paradigm.

CM is strongly related to the concept of Cloud Computing and, on the basis of the work of NIST (National Institute of Standards and Technology), Wu proposed the following definition: "Cloud Manufacturing is a customer-centric manufacturing model that exploits on-demand access to a shared collection of diversified and distributed manufacturing resources to form temporary, reconfigurable production lines which enhance efficiency, reduce product lifecycle costs, and allow for optimal resource loading in response to variable-demand customer generated tasking" (Wu et al., 2013). The architecture of CM is described by many authors in literature but all of them are similar: it is a multilayer architecture composed by Application layer, Service Layer, Virtual resource layer and Manufacturing resource layer as described by Xu in 2011 (Xu, X., 2011) and revised by Esposito et al. (Esposito et. al., 2016) (fig.1). The Application Layer serves as an interface between the user and manufacturing cloud resources: the user can define and construct a manufacturing application through the virtualized resources. The Service Layer is mainly responsible for locating, allocating, free-calculating and remote monitoring the manufacturing resources (the hardware providers are still responsible for executing the manufacturing task and ensuring the quality of the job). The key functions of the Virtual Resource Layer are to identify manufacturing resources, virtualize them and package them as cloud manufacturing services, while the Manufacturing Resource Layer encompasses the resources that are required during the product life cycle (development, manufacturing): these resources may be physical resources (e.g. machineries, equipment) or manufacturing capabilities (e.g. operators skills, machineries capabilities).

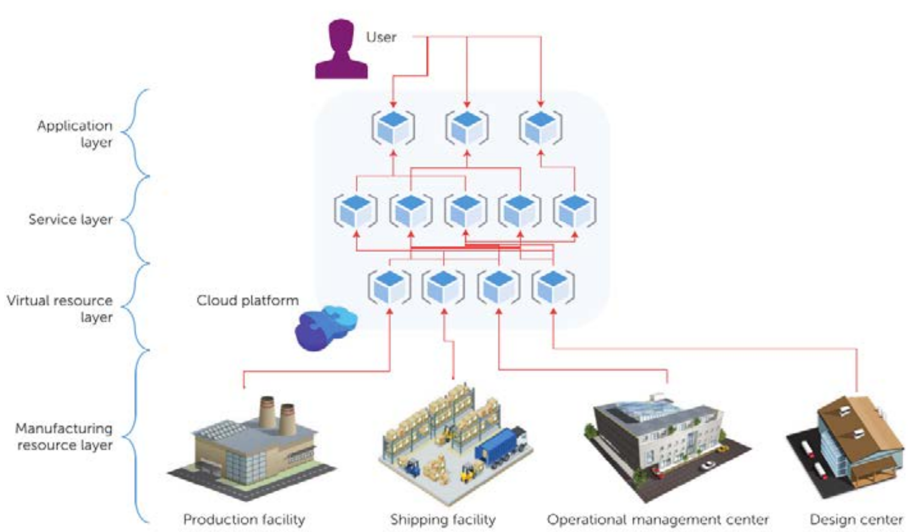

Fig. 1 – *Cloud Manufacturing architecture (Esposito et. al., 2016)*

Customer-centricity is one of the key characteristics of Cloud Manufacturing. Traditional supply chains, based on the hierarchical flow of requirements from suppliers

to sub-tier suppliers, are very rigid; CM links users and their needs to resource providers so that the user could be allowed to specify key requirements of a desired product (e.g. cost, lead time, and quality) and different alternatives that respect those requirements would be provided for consideration. Another key aspect for CM is the ability to match the specific needs of the users with resource providers able to satisfy those requirements while meeting cost, schedule and quality objectives. The resulting benefits are enhanced efficiency, reduced cost, increased flexibility and improved capabilities for the user. These benefits are actually achievable thanks to the pooling of resources that enable the creation of flexible manufacturing sequences. CM production lines are designed to be temporary, quickly reconfigurable and dynamic. In addition, the quick re-configurability of the system has an important side effect because also production in small lots becomes economically viable.
Moreover, the CM environment is meant to be demand intelligent, meaning that the system is flexible enough to provide load sharing across interchangeable resources. Finally, the last characteristic of CM is related to the possible business models. Indeed, business innovation could come also from the adoption of a share-to-gain philosophy. In particular, one of the key challenges is to decide how the value of the final products should be divided across contributors. In fact, with an extremely dynamic cloud of resource providers, there is not a clear and stable representation of how value is added, which is given by value chain structure. Instead, new business models would be needed to deal with new issues, such as the role of app providers and the ownership of intellectual property.
According to Wu (Wu et al., 2014), CM is definitely a new paradigm that could revolutionize manufacturing, even though it is the result of an evolution and adoption of existing technologies. Nevertheless, from the contributions found in literature, it is clear that a CM system is still hardly applicable into reality because of the many technical and business conditions.

3. Research methodology

Even though Cloud Manufacturing is extremely interesting, the topic is still in its infancy and it was not possible to find both in the literature and into reality some clear and complete examples of such manufacturing paradigm. Many authors are working on the technological issues of CM (e.g. resource virtualization, service decomposition, task allocation), others on the new business models that could be born with the advent of CM, but still it’s difficult to understand “when” and especially “where” CM could be introduced. Thus two main research questions have been identified:

- What types of industries are suitable to adopt CM?
- What are the characteristics of a company that allow or discourage the application of the CM paradigm?

Through both a deductive and inductive approach, we build up a model to address this concern (fig. 2). The model considers both technical and business features that, according to authors and experts, are connected with the applicability of this paradigm; the model is then translated into a questionnaire (described in the following section of this paper) that allows to address a single company, and to understand how much it may be close or far from a possible application of CM. The deductive approach here stems from the fact that the model has been developed starting from the literature and the theoretical pillars acknowledged, but also an inductive approach is used, because different companies were interviewed which allowed to revise and adjust the model and the related questionnaire.

The first phase of validation of the model is carried out through a first application of the model to 7 companies belonging to 6 different industries. Then, the following validation phase considered the calibration of the model; it has been made together with experts of CM (prof. X. Xu, prof. X. Wang and the IIMS research Group in Oakland, New Zealand).

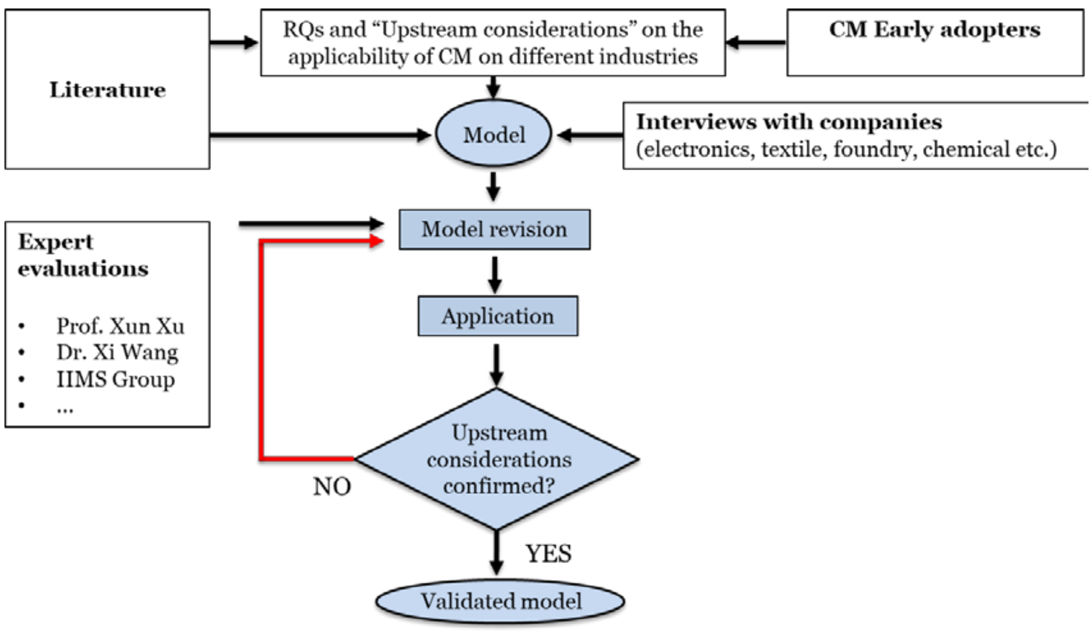

Fig. 2 – *Research methodology*

4. Model – Questionnaire

The model is composed by a questionnaire that can be easily filled out by a company: each question give rise to a score, and the higher the total score obtained, the more the enterprise is suitable for the application of CM. Each question investigates a particular feature of a manufacturing system: for each question, just one answer can be given among 2 or 3 possible alternatives, each answer scoring -1 / 0 / +1 depending on the alternative chosen. Negative alternatives (scoring -1) are those ones that make difficult the application of CM while positive answers (scoring +1) are those ones that show affinity with CM.

Since two main types of barriers appear in the application of Cloud Manufacturing, the questionnaire is divided into two section: the first one is related to the Technical issues and the second one is related to Business taken into consideration. In fact, the applicability of CM is not only a matter of technical issues; CM aims to create specific benefits (efficiency, flexibility, reduced lead times etc.) that are not necessarily valid for all the industries or specific businesses (fig. 3).

4.1 Technical level

In this section the objective is to understand if products and processes of an enterprise could be formalized, converted and inserted in a CM architecture in compliance with the previously described characteristics of such a manufacturing environment. Therefore here questions are considered about the product and services sold by the enterprises; at the technical level, questions belong to five main areas of interest, from the customer's RFQ (Request For Quotation) to the delivery of the product:

- RFQ analysis
- Resource identification and virtualization
- Services composition
- Service-task matching
- Task scheduling

4.2 Business level

The objective of this section of the questionnaire is to study the particular business of an enterprise in order to evaluate if CM could effectively bring the benefits it is designed for. It considers some characteristics of the business as follow:

- Plant / Production (saturation of the resources, cost of equipment, setup costs)
- Logistics (costs, coordination complexity)
- Workforce (skills, flexibility)
- Suppliers (flexibility, availability)
- Customers (importance of the relation with the customers)
- Data sensitivity (intellectual property issues)

	Score			Factor of Importance			
				Single	Group		Any
Technical level	-1	0	+1		SPO	Dual	
I aspect							
II aspect							
III aspect							
...				...			
Business level							
I aspect							
II aspect							
III aspect							

Fig. 3 – *Representation of the model: matrix where rows are questions and columns (scores) are the answers. To each question is assigned a weight (Factor of importance) that may vary depending on the cloud environment taken into consideration.*

For each question is assigned a weight, called Factor of Importance, to highlight the different importance of each question and, more in detail, this weight can vary for each question depending on the kind of cloud environments. The cloud environment refers to the provider side of the service virtualized. Three different kinds of provider are possible: Single Company, Group of Companies and Any Company (fig. 4).

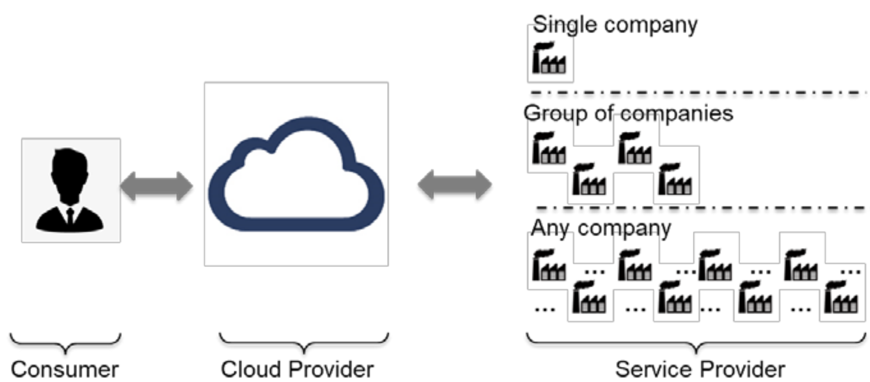

Fig. 4 – *Different kinds of cloud environment*

Thus, inside the main column "Factor of Importance", we assigned specific weights for each question depending on the type of environment.
Moreover, in the "Group of Companies" sub-column, it is important to distinct the "Service Provider Only" (SPO) company case and the "Dual-role" case: in the first case, companies just sell services through the cloud, while in the second case they are both consumer and provider of the service, hence they could not able to provide the service for some reason (e.g. full capacity utilization in a certain period).

The Factors of Importance range from 1 to 5; the highest value indicates the higher importance of that aspect for the related kind of environment.
Of course, in order to obtain a conclusive result through the application of the model, for each row it is necessary to multiply the score obtained by the respective Factor of Importance, and then to sum each row's result, for each kind of environment.
The higher is the final value, the higher is the probability to see CM applied in that company in such a cloud environment.

5. Results

The model was finally applied to companies belonging to different industries: two companies from the electronics industry (PCBA manufacturers), and one coming from the metal industry, a heavy foundry.

5.1 PCBA manufacturers

PCBAs (Printed Circuit Board Assembly) are relatively simple products. The type of the products and processes are very standard and this makes possible to have a formalized process. Indeed, the RFQ process can be definitely formalized because customers usually request products through a .gbr "Gerber file" (an international standard) and a .pdf with the BoM (Bill of Materials). The machines involved in such a manufacturing system are basically the same for every type of PCBAs production (e.g. pick-and-place, thermal processes). These manufacturing systems seems suitable for CM because they allow a rapid scalability through resources sharing. The simplicity of these products and the machineries involved (combined with the international standard that each company in this sector has to provide) could enable the transition to the CM paradigm. Moreover, concerning the business level, this type of business involves machineries that are seldom fully saturated: these companies do not have a plant that works 24/7 and CM could bring great benefits to enterprises of this sector increasing the machines' saturation levels.

These considerations are valid for both companies evaluated. The second company interviewed got a final result lower than the first, so it looks less suitable for the application of CM. The reason is that the second one offers more assembly services than the first and this induces some complications in the formalization processes, especially about the feasibility check, i.e. the matching between tasks and services. For this reason, we decided to analyze the second company from two points of view: as "PCBA only" manufacturer and then as "all range" product manufacturer. As expected, making this distinction the model obtained different results for these two different scenarios, both suitable to CM application, but higher if the production is limited to PCBA.

5.2 Iron and steel foundry

At the technical level, RFQ process is quite difficult to be automatized, because it needs an engineering phase (feasibility study) more or less important depending on the complexity of the product requested. Very skilled personnel has to study the drawings received and very often suggests modifications in order to meet the main characteristics of the product (e.g. shapes and geometries). The RFQ process lasts days or weeks depending on the complexity of the products and communications with customers are currently made by email/phone calls. Other technical issues are present in this type of industry, for example:

- Virtualization of different resources and heterogeneous capabilities within the company (e.g. skills of the employees);
- The scheduling process is driven by a team of experts.

Considering the business level, it appears that Iron and steel foundries generally work 24h, seven days a week with a high saturation of the furnaces. Moreover, they are used to work with big volumes of products because of the very high setup costs: also, before starting the production two or three prototypes are usually produced in order to check shapes, geometries and quality standards to achieve.

6. Conclusions and future research

The model has been applied to two different industries, confirming what we could expect: PCBA manufacturers could be more ready for CM rather than the foundry. The standardized processes and product of PCBA manufacturers, together with the need to increase the saturation level of the machineries makes this business particularly suitable for the application of CM. Nevertheless some technical issues are still open (e.g. task-resource matching, task allocation) for this business: among these, one interesting question to address could be "Which developments in logics and/or planning algorithms will be necessary to accomplish this new manufacturing paradigm?".

The model presented in this paper takes into account just the provider side of CM, differentiating from the three type of environment explained in the previous section (Single company, Group of company and Any company). A second research direction could be to expand the model by the consumer side differentiating between Private cloud, Community cloud and Public cloud (and eventually Hybrid cloud), following the definitions given by Lu (Lu, Y., et al. 2014).

Third, the authors think that starting from the present model it should be valuable to understand the potential impact of CM on different industries. Thus, after having answered to the research question presented in this paper: "what types of companies are suitable to adopt CM?", a new question could be: "Which type of companies could benefit most from the application of CM?".

Bibliography

Li, B.-H., Zhang, L., Wang, S.-L., (...), Song, X., Chai, X.-D. (2010). Cloud manufacturing: A new service-oriented networked manufacturing model. *Jisuanji Jicheng Zhizao Xitong/Computer Integrated Manufacturing Systems*, 16(1), 1-7+16.

Xu, X. (2011). From cloud computing to cloud manufacturing. *Robotics and Computer Integrated Manufacturing*, 28(1), 75-86.

Wu, D., Rosen, D.W., Wang, L., Schaefer, D. (2014). Cloud-based manufacturing: Old wine in new bottles? *Procedia CIRP* 17, 94-99.

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

Adamson G., Wang L., Holm M., Moore P. (2015). Cloud manufacturing – a critical review of recent development and future trends, *International Journal of computer integrated Manufacturing*, 347-380.

Liu, Y., Xu, X. (2017). Industry 4.0 and cloud manufacturing: A comparative analysis. *Journal of Manufacturing Science and Engineering, Transactions of the ASME*, 139(3), 034701.

Helo, P., Suorsa, M., Hao, Y., Anussornnitisarn, P. (2014). Toward a cloud-based Manufacturing execution system for distributed manufacturing. *Computers in Industry*, 65(4), 646-656.

Lu, Y., Xu, X., Xu, J. (2014). Development of a Hybrid Manufacturing Cloud. *Journal of Manufacturing Systems*, 551-566.

Wu, D., Greer, M.J., Rosen, D.W., Schaefer, D., (2013). Cloud manufacturing: drivers, current status, and future trends. *Proceedings of the ASME 2013 international manufacturing science and engineering conference (MSEC13)*, 1016.

Esposito, C., Castiglione, A., Martini, B. and Choo, K. K. R. (2016). Cloud Manufacturing: Security, Privacy, and Forensic Concerns. *IEEE Cloud Comput.*, vol. 3, no. 4, pp. 16–22.

Notes