Cloud manufacturing: vision and state-of-the-art

Pavel Vitliemov

Cloud manufacturing: vision and state-of-the-art: *Cloud manufacturing, a service oriented, customer centric, demand driven manufacturing model is explored in both its possible future and current states. A vision for the field is documented and the current state of technology is presented from academic viewpoints. The state of research in fields critical to enablement of cloud manufacturing, including automation, industrial control systems, service composition, flexibility, and proposed implementation models and architectures are presented.*

Key words: *Cloud manufacturing, vision, state-of-the-art, distributed systems.*

1. INTRODUCTION

The force of globalization has served to instantaneously connect peoples from all across the globe, bringing with it game-changing opportunities to share knowledge and expertise to benefit in a collective manner (sometimes called share-to-gain). Friedman [2] explains that the latest globalization phase, which he coins Globalization 3.0, began around the year 2000 and was enabled by the expansion of the internet on a global basis during the dotcom boom. According to Friedman, Globalization 3.0 is defined by individuals and small groups from across the globe collaborating in areas once dominated by less-connected western economies.

Many engineering paradigms have evolved as result of Globalization 3.0, some of which are mentioned by Tapscott and Williams (mass collaboration and self-organization, for example). Of the many paradigm shifts still in their infancy, cloud manufacturing (CM) will be the focus of this paper [9,12]. CM, as will be defined shortly, benefits from the share-to-gain philosophy as a wide number of manufacturing resources and expertise are shared to provide consumers with enhanced experiences. CM follows naturally from the introduction and success of cloud computing, for which the National Institute of Standards and Technology (NIST) offers the following definition [5]:

“Cloud computing is a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction.”

Building on NIST’s definition of cloud computing, many authors have proposed definitions of CM. The term, cloud manufacturing, was first used by Li et al. [6] in 2010. Xu discerns between two forms of cloud manufacturing: the introduction of cloud-computing technologies into the manufacturing environment and cloud manufacturing. The latter is a replication of the cloud-computing environment using physical manufacturing resources in lieu of computing resources – this idea will be the focus of this paper. Using the work of the NIST [5] and Smith [11] as a foundation, the following definition of CM is offered:

“Cloud Manufacturing (CM) 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.” [13]

This paper will focus on developing a strategic vision for the CM environment, documenting the current state of academic research and industry implementation, and then making recommendations for future research.

2. CURRENT STATE

CM will require interaction between three groups: the users (consumers), application providers, and physical resource providers. The needs of users will be matched with the capabilities of resource providers through the application layer. This three-group model represents the simple supply-demand market that will motivate the existence of CM. The provider–consumer model is shown in Fig. 1.

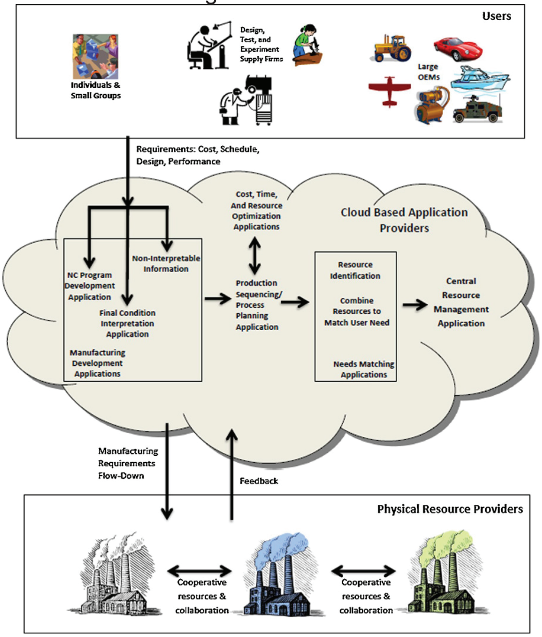

Fig. 1 Vision for Cloud Manufacturing [14]

Users are the consumers in CM; these individuals or groups have the need to manufacture something, but do not possess the capabilities to do so, or they possess the capabilities but stand to gain a competitive advantage by utilizing CM. Users can range anywhere from individuals to large OEMs – any group that can generate engineering requirements to be used in a manufacturing setting can participate in CM partnerships. These engineering requirements, which describe the desired object and its final conditions, are provided to the cloud based application layer for interpretation.

The cloud based application layer is responsible for managing all aspects of the CM environment and interprets user requirements into data required for production of the desired objects. Furthermore, production planning and sequencing can be carried out through automated applications that determine the numerous production paths that could lead to the desired object. Finally, the application layer is responsible for locating the required resources, pending them to the engineering job, and managing resources in the event of a service interruption. The application layer will be managed and controlled by application providers, who offer their services as an intermediary between users and resource providers for a portion of the product profit.

Physical resource providers (PRPs) own and operate manufacturing equipment, including but not limited to machining technologies, finishing technologies, inspection technologies, packaging technologies, and testing resources. In addition to owning physical resources, PRPs have the know-how and experience to utilize these machines effectively and efficiently. These PRPs are not limited by geographic location; rather, PRPs join the CM network based upon their expertise alone. Ideally as a whole, the PRP network would represent every type of manufacturing capability available in the marketplace, offering users instantaneous access to manufacturing capabilities provided through the cloud as a service. The input to the PRP group is the manufacturing data created by the cloud based applications, and the output is a finalized product in conformance with user requirements.

The ManuCloud Project, funded under the European Commission's Seventh Framework Program for Research (FP7), is perhaps the research project most relevant to CM today [7]. According to Meier et al. [4], the ManuCloud project is meant to enable creation of integrated manufacturing networks spanning multiple enterprises which are facilitated by service oriented information technologies. According to the authors, "[The ManuCloud architecture] provides users with the ability to utilize the manufacturing capabilities of configurable, virtualized production networks, based on cloud-enabled, federated factories, supported by a set of software-as-a-service applications". This architecture is reproduced in Fig. 2. The ManuCloud project architecture is very similar to the strategic vision of CM as presented in this report, and represents a major advancement toward the realization of CM.

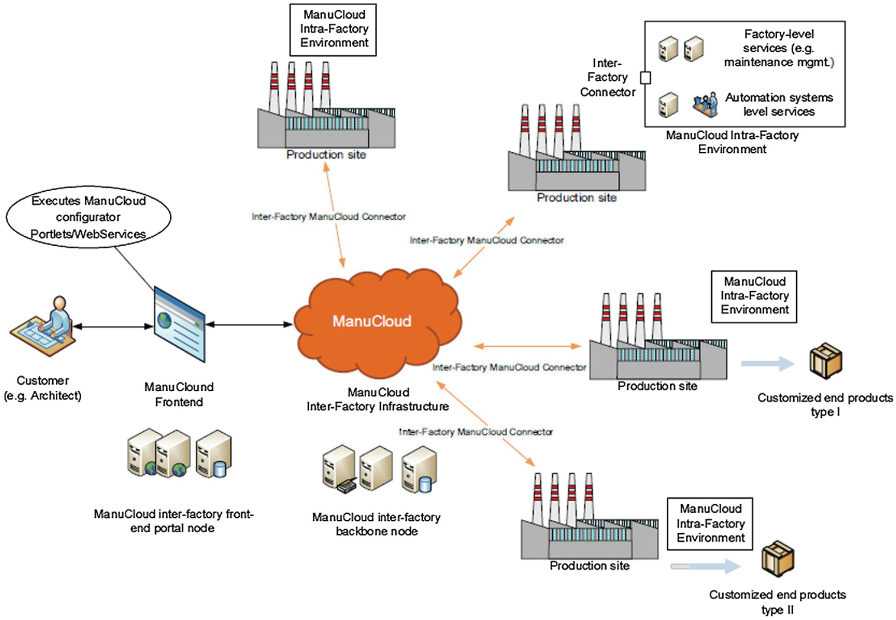

Fig. 2 ManuCloud architecture, from [5]

Xu [12] presents that the implementation of cloud computing in manufacturing can take two (2) forms. The first form is that which is discussed in the strategic vision section – that is, the mimicking of the cloud computing environment in manufacturing. The second form deals simply with the incorporation of cloud computing technologies into the manufacturing industry.

Katzel [3] presents that the manufacturing sector in defined by computing needs which vary significantly with the product lifecycle phase. Cloud-computing, as stated by Katzel, can be thought of as a utility service which can be accessed on-demand without owning the enabling technologies. According to Katzel, cloud-computing can aid manufacturing and engineering by providing data storage, software services, and computational power.

Edstrom [1] presents that typical server usage lingers at roughly 8–15% of total capacity. The need to oversize computing resources based upon peak usage rates, in addition to the cost of maintaining these technologies, makes a usage based pay on-demand system truly beneficial and cost effective.

Schultz [10] presents that despite its clear benefits, data storage in the cloud has been slow to gain popularity because of concerns over data security, meeting regulatory compliance requirements, and cloud performance.

Architectures, models, and frameworks for implementation of CM have been presented by numerous authors. These proposed structures vary in their complexity, maturity, and level of demonstrated potential, yet many have similar characteristics. Development of feasible implementation structures should be a key area of interest for academia and industry alike as they will help demonstrate the possible capabilities of a CM environment [8].

Xu [12] proposes a four (4) layer CM framework consisting of a manufacturing resource layer, a virtual service layer, a global service layer, and an application layer (see fig. 4). According to Xu, the Manufacturing Resource Layer contains the physical manufacturing resources and capabilities of the shop floor, which are ultimately provided to the customer in Software-as-a-service (Saas) and Infrastructure-as-a-service (Iaas) delivery models. The Virtual Service Layer identifies, virtualizes, and packages the resources as CM services, which are then managed using the Global Service Layer (GSL).

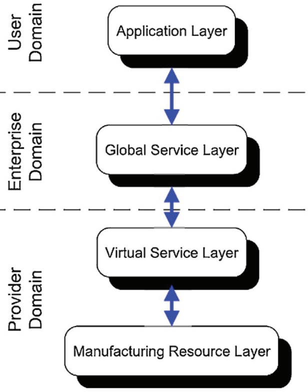

Fig. 3 CM layered framework from [12]

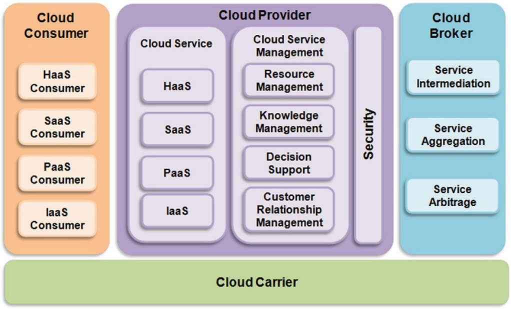

Fig. 4 CBDM model, from [15]

Wu et al. [15] propose a Cloud Based Design and Manufacture (CBDM) model composed of a cloud consumer, cloud provider, cloud broker, and cloud carriers. The cloud consumers serve the obvious role of utilizing the cloud's services, while the providers have the equally obvious role of providing services in the cloud. The cloud broker is an intermediate party between the consumers and providers, and manages the use, performance, and delivery of services. Finally, the cloud carriers enable the exchange of services between providers and consumers through the provisioning of transport networks (see fig. 4). As can be seen in fig. 4, Wu et al. specify that there are four cloud service types, including Hardware-as-a-service (Haas), Software-as-a-service (Saas), Platform-as-a-service (Paas), and Infrastructure-as-a-service (Iaas).

3. POTENTIAL IMPACT

The possible impact of CM on three key sectors including engineering design, manufacturing, as well as marketing and service are formulated [14].

Engineering design: In the short term, the benefits of CM on engineering design are ubiquitous access to design information, improved efficiency, and affordable computing resources. In the long term, the impact area is collaborative design which is to support engineering design in geographically dispersed environments.

Manufacturing: In the short term, the benefits of CM on manufacturing are improved resource sharing, rapid prototyping, and reduced cost. In the long term, the impact area is distributed manufacturing.

Marketing and service: In the short term, the benefits of CM on marketing and service are reduced time-to-market, improved service, and enhanced user experience. In the long term, the impact area is customer co-creation.

In order for manufacturing enterprises to create value through collaboration, there is an increasing need to establish a new form of information, knowledge and resource sharing mechanism that emphasizes the generation and realization of various product stakeholders' value. CM has the potential to create new marketing channels for information and resource sharing which will transform the traditional product realization process into a value co-creation process. Specifically, the co-creation process enhanced by CM can engage customers, designers, manufacturing engineers, and production managers to communicate with each other through social media such as Facebook, Twitter, Blogs, and online forums.

As cloud manufacturing (CM) has been recognized as a promising paradigm for the next generation manufacturing systems, many research studies on CM have been conducted. This review aims to highlight the motivations and drivers of CM, propose a strategic vision, present current status of CM, and point out some of the key future directions.

REFERENCES

[1] Edstrom D. Cloud computing in manufacturing. Production Machining 2010;10:28–31.

[2] Friedman TL. It's a flat world, after all; 2005. Web Link: http://www.nytimes.com/2005/04/03/magazine/03DOMINANCE.html

[3] Katzel J. Power of the cloud. Control Engineering 2011;58:16–21.

[4] Meier M, Seidelmann J, Mezgár I. ManuCloud: the next-generation manufacturing as a service environment. European Research Consortium for Informatics and Mathematics News 2010;83:33–4.

[5] Mell, P., Grance, T., 2011. The NIST definition of cloud computing, National Institute of Standards and Technology, U.S. Department of Commerce. Web Link: http://csrc.nist.gov/publications/nistpubs/800-145/SP800-145.pdf

[6] Li BH, Zhang L, Wang SL, Tao F, Cao JW, Jiang XD, et al. Cloud manufacturing: a new service-oriented networked manufacturing model. Computer Integrated Manufacturing Systems 2010;16(1):1–7.

[7] Project Overview: ManuCloud Fact Sheet, ManuCloud; 2012. http://www.manucloud-project.eu/index.php?id=185 [accessed 07.07.15].

[8] Putnik G. Advanced manufacturing systems and enterprises: Cloud and ubiquitous manufacturing and an architecture. Journal of Applied Engineering Science 2012;10(3):127–34.

[9] Schaefer D. AC 2012–3017: Distributed collaborative design and manufacture in the cloud-motivation, infrastructure, and education.

[10] Schultz B. Cloud Storage a STEEP CLIMB. Computerworld 2011;45(6).

[11] Smith J. Harnessing the power of cloud computing for M2M; 2009. Web Link: http://www.numerex.com/files/wp/m2mCloudComputing.pdf

[12] Xu X. From cloud computing to cloud manufacturing. Robotics and Computer Integrated Manufacturing Systems 2011, http://dx.doi.org/10.1016/j.rcim.2011.07.002.

[13] Wu D, Greer MJ, Rosen DW, Schaefer D. Cloud manufacturing: drivers, current status, and future trends. In: Proceedings of the ASME 2013 international manufacturing

science and engineering conference (MSEC13), Paper Number: MSEC2013-1106, Madison, Wisconsin, US. 2013.

[14] Wu D, Greer MJ, Rosen DW, Schaefer D.. Cloud manufacturing: Strategic vision and state-of-the-art, Journal of manufacturing systems, 2013.

[15] Wu D, Thames JL, Rosen DW, Shaefer D. Towards a cloud-based design and manufacturing paradigm: looking backward, looking forward; 2012. IDETC/CIE, 1–14.

Author data:

Pavel Vitliemov, Assoc. Prof. PhD., Department of Management and Business Development, University of Ruse” Angel Kanchev”, tel.: 082-888 495, e-mail: pvv@manuf.uni-ruse.bg

Докладът е рецензиран.