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A REVIEW OF CLOUD MANUFACTURING: ISSUES AND OPPORTUNITIES

M.N. Abd Rahman[1], B. Medjahed[2], E. Orady[3], M.R. Muhamad[4], R. Abdullah[5]
and A.S.M. Jaya[6]

[1,4]Fakulti Kejuruteraan Pembuatan, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, Melaka, Malaysia.
[2]Department of Computer and Information Science, University of Michigan – Dearborn, USA.
[3]Industrial and Manufacturing Systems Engineering Department, University of Michigan – Dearborn, USA.
[5]Fakulti Teknologi Kejuruteraan, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, Melaka, Malaysia.
[6]Fakulti Teknologi Maklumat & Komunikasi, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, Melaka, Malaysia.

Corresponding Author's Email: [1]mdnizam@utem.edu.my

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ABSTRACT: Cloud Manufacturing (CM) is the latest manufacturing paradigm that enables manufacturing to be looked upon as a service industry. The aim is to offer manufacturing as a service so that an individual or organization is willing to manufacture products and utilize this service without having to make capital investment. However, industry adoption of CM paradigm is still limited. This paper compared the current adoption of CM by the industry with the ideal CM environment. The gaps between the two were identified and related research topics were reviewed. This paper also outlined research areas to be pursued to facilitate CM adoption by the manufacturing industry. This will also improve manufacturing resource utilization efficiencies not only within an organization but globally. At the end, the cost benefits will be passed down to end customer.

KEYWORDS: *Cloud Manufacturing; Industry 4.0; Manufacturing Paradigms; Cloud Computing; Evolution of Manufacturing System*

1.0 INTRODUCTION

Recent development in the area of manufacturing model focuses on two significant concepts namely Industry 4.0 and Cloud Manufacturing (CM). Industry 4.0 scopes consist of both vertical and horizontal integration of manufacturing activities whereas CM focuses on the integration of various components to enable "manufacturing-as-a-service" activities in the cloud. Even though their focus areas are different, their goal is the same, meeting individualized requirements specified by customers through adopting Internet of Everything approaches [1]. This paper focused on initiatives on CM only.

CM has been coined based on the term widely used in IT: cloud computing. In cloud computing, IT resources reside in the "cloud" and companies or individual pay to use those resources without having to invest in the hardware and human resources to maintain it [2]. In CM environments, the manufacturing facilities and support systems reside in the "cloud". The basis of CM is to offer production system services to those who want to manufacture their products [3-4].

The first literature on manufacturing as a service was traced back to the 1990s in the dot-com era. Those literatures reflect the vision on the influence of the Internet on future manufacturing paradigm. Some of the earlier discussion topics are the change of focus in manufacturing operation from mechanical-centric to IT-centric to enable mass customization, the possibility of connecting design and manufacturing services through IT capabilities [4], and the implementation of manufacturing services and creation of integrated products and processes over the Internet [5].

In year 2000s, advancement and expansion in internet capabilities initiated the latest globalization phase, referred to as Globalization 3.0, defined by collaboration of individual and small groups across the world [6]. Taking advantage of the communication barrier removal around the globe,the current manufacturing system needs the agility and flexibility to address shorter than ever product life cycle to be garnered without capital spending but rather by outsourcing manufacturing operation services offered by companies around the globe. And this is the basis of the CM paradigm. Unfortunately, current CM adoption by industry is still in its infancy. Even though there are numerous publications on CM, there is lack of study comparing the extent of industrial adoption of CM with what the ideal CM environment should be. This paper considered the gaps between what was being practiced in the industry and the ideal CM environment. Gaps between the two were identified and a review on the published work on the areas related to the identified gaps was carried out. Finally, future research areas were recommended.

2. 0 CLOUD MANUFACTURING ARCHITECTURE

CM involves interactions between three entities (Figure 1): users (consumers), application providers, and physical resource providers (PRP). Users' needs are matched with the PRP's resources through the application layer. Matching between users' demands and the production system owned by PRPs through the application layer minimizes manufacturing cost and optimizes the utilization of PRP resources [7-8]. The cost benefits are passed down to the end users of the product [9].

Users/OEMs - Users/OEMs are the consumers in CM network. They can be individuals or organizations that want to manufacture a product without investing in manufacturing capabilities. A consumer can also possibly an organization that already has manufacturing capability but can gain competitive advantage, such as lower cost, by participating in CM. Consumers have to generate product engineering requirements which describe the desired object and its final conditions. Expected cost and schedule also need to be specified.

Application Providers - Based on the information specified by consumers, the application providers have to perform three main tasks: (i) interpret product engineering requirements into data requirement for the production of the product; (ii) determine the Production planning and sequencing to produce the product; and (iii) match and locate the required resources among the PRPs to produce the product. This application layer is managed and controlled by application providers who act as mediators between users and PRPs for a portion of the product profit.

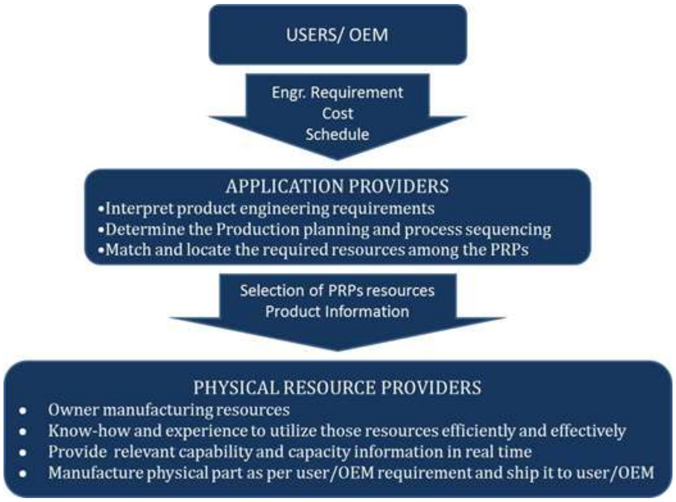

Figure 1: Interactions among CM players

Physical Resource Providers (PRPs) - PRPs can be located anywhere around the world with no geographical limitation. PRPs own physical manufacturing resources include manufacturing equipment, human resources, inspection equipment, and related software. PRPs must also have to know-how and experience to utilize those resources efficiently and effectively. PRPs provide relevant real time information of their capabilities and capacity availability to the application providers so that a matching process between customer requirement and PRPs capability and capacity can be done in real time. Ideally, PRPs should represent all types of manufacturing capabilities available so that all manufacturing capabilities can be offered through the cloud as a service. However, the CM can also be dedicated to a specific product family or product technologies. Consumer and PRPs can then choose the appropriate CM to participate. The output of PRPs group is the final product that meets customer requirement.

The flows of information, money, and materials within a typical CM platform are depicted in Figure 2. If compared with typical manufacturing environments, the flows of information, money and materials are occuring in a cascading manner from user/OEM to first tier manufacturer, to second tier manufacturer, to third tier manufacturer and so on. In the CM environment, this cascading flows are eliminated which result in flexibility for CM service providers to utilize resources available in the CM platform to meet users/OEM requirement in the most efficient manner possible.

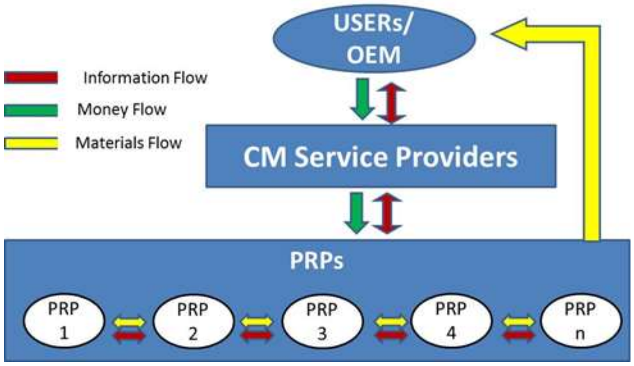

Figure 2: Flow of information, money and material in CMs

3.0 CLOUD MANUFACTURING: INDUSTRIAL IMPLEMENTATION VERSUS IDEAL CHARACTERISTICS

Wu et al. [8] defined eight requirements for ideal CM environments. These requirements can be used as a reference in defining an ideal infrastructure for CM implementations:

- R1: The three main CM players (users, application providers, and PRPs) should be connected through social media-based services to facilitate communication and data/knowledge sharing.
- R2: There should be cloud-based data sharing capability for CM players to access and share manufacturing related data.
- R3: Framework of open-source programing should be developed to process, manage and analyze data stored in the cloud.
- R4: CM should provide a multi-tenancy environment where a single software can serve the players in the CM environment.
- R5: CM should allow to remotely collect, store, and monitor real-time PRPs' manufacturing data and remotely control these manufacturing resources.
- R6: CM should implement "everything as a service" oriented architecture model in manufacturing applications for users.
- R7: CM should assist users to find suitable manufacturing resources in the cloud, CM should provide an intelligent search engine.
- R8: CM should have the capability to provide instant quotation online upon user's specification.

Based on the defined characteristics, comparison can be made between current CM practice in industry and what the ideal CM environment should be. This comparison will give some indications on where the research on CM should be focused on to facilitate a wider CM adoption.

3.1 Gaps in Current CM Adoption in Industry

Research focusing on CM development is still at its early stage. Even though CM, theoretically, benefits its participants (users, PRPs, and application providers), its adoption in the manufacturing sector is still limited. Currently, one example of CM implementation for traditional manufacturers is MFG.com, which connects consumers with over 200,000 manufacturers in 50 states within the US [9-10]. Based on users' requirements (drawing, delivery date, specification), MFG.com matches those requirements to potential suppliers' capabilities, expertise, and instantaneous production capacity for the quotation. MFG.com provides activities from creating the request for quote to the shipment of the final product.

Comparing what has been established in the current CM implementation in the industry based on MFG.com initiatives and the ideal CM environment stated earlier, there are still significant gaps between the current practice and ideal CM environment. Some of those gaps are:

- Inter-factory (PRPs) integration within the CM (requirement R1). Based on MFG.com practices, individual PRP's are to submit quotation for part fabrication using resources from one particular PRP. Further benefits can be realized if process integration between PRPs is possible.
- Instantaneous quotation of requested services (requirement R8). The quotation for part fabrication is not instantaneously done by service providers. It is performed by individual PRPs who is interested in bidding for a job. In order to address this gap, standard input parameters have to be established for both users and PRPs and standardized cost algorithm needs to be developed by CM service providers.
- Implementation of "everything as a service" is lacking (requirements R4 and R6). The focus of CM is to offer manufacturing as a service to the users. These services should not be limited to the fabrication of the requested parts. They should also include other resources to enable the manufacturing activities such as multi-tenancy CAD/CAE software that can be offered to CM participants as a service.
- Real time monitoring and control of PRP resources (requirement R5). One of the characteristics of ideal CM environments is the ability of service providers to monitor real time data of PRP resource performance and capacity so that their utilization can be optimized. Current practice is for the CM service provider to use machine availability given by the PRP (not real time) to identify the potential PRP to be assigned a particular job. To enable this capability, the PRP resource utilization and performance must be able to be tracked in real time by means of Internet of Things (IoT) through proper sensors [11]. Those data then have to be linked to the service providers to be analyzed.

Based on the gaps identified between ideal CM versus the current CM practice in industry, the subsequent section discussed the current research activity pertinent to those topics. This will enable the identification of research area to facilitate industry of an ideal CM adoption.

3.2 Current State of Cloud Manufacturing Research

This section discusses the research work carried out on the topics defined as the possible enablers for ideal CM adoption by manufacturing industry. Table 1 analyzes the major existing CM approaches found in published literature with respect to the aforementioned requirements.

Table 1: CM approaches vs CM requirements

Ideal CM environment requirements	Literatures
R1	[9-17]
R2	[9, 18-23]
R3	[9, 18, 24-26]
R4	[11]
R5	[28-36]
R6	[11, 37]
R7	[8, 10, 38-47]
R8	[16]

3.2.1 Inter-factory (PRPs) integration within the CM

Seamless integration between PRPs is the key in ensuring the efficiency of a particular CM platform. Wang and Xu [27] proposed Interoperable Cloud-based Manufacturing System (ICMS). ICMS provides a cloud-based environment for integrating existing and future manufacturing resources (software tools and physical manufacturing devices) by packaging them using the Virtual Function Block mechanism and standardized description according to user's specification. In addressing possible needs for PRP to have the capability to create different cloud modes for different users grouping, Lu et al. [13] defined a hybrid manufacturing cloud (HMC) system. This system enables PRPs to create different cloud modes (private cloud, community cloud, and public cloud) to be used in a particular CM platform. HMC allows PRPs to define their own resource sharing rules for the different cloud modes. It gives PRPs ability to have control over their resources, improve trust in the system with an ability to protect access to resources.

Multi-granularity resource virtualization and sharing strategies are discussed to bridge the gap between complex manufacturing tasks and available resources [14]. The proposed approach considered the effect of stepwise decompositions of a manufacturing task using workflow. Correlations between resources estimated using multi-granularity resource aggregation functions and resource clustering algorithms are presented to integrate the physical resources into virtualized resources which provide a solid foundation for resource discovery and selection. Wei and Liu [15] analyzed the usage of Ant Colony Optimization algorithm to match tasks with resources in CM using factors such as selection of time, cost, quality of services, and workload of equipment. An optimum solution is suggested and evaluated based on case studies.

CM service providers carry the allocation of resources based on users requirements autonomously. This matching activity needs to be executed so that resource optimization is achieved and it has to be done in almost “real time” situation to enable real-time quotation. Hence, the time required in performing the simulation for resource or task allocation needs to be estimated. Chen and Wang [16] defined a methodology to estimate the time taken for this simulation. The methodology classifies tasks using k-means before their simulation times are estimated. For each task category, an Artificial Neural Network (ANN) is constructed to estimate the required task time in the category. However, to reduce the impact of ANN over-fitting, the required time for each simulation task is estimated using the ANNs of all categories. The estimated times are then weighted and summed. While this approach addresses the automation and control requirements, it does not cope with the inter-factory style Industrial Control System (ICS) that requires high speed, high reliability, and long-distance range. Typical communication systems used in the intra-factory environment such as Distributed Control Systems (DSC) are usually more reliable and allow faster transmittal of data than Supervisory Control and Data Acquisition (SCADA). However, they are not well suited for long distance communications [17].

3.2.2 Instantaneous Quotation of Requested Services

One of the critical steps to enable autonomous and instantaneous quotations is to develop product cost models specific for CM environments. However, there is dearth of research on this topic [9]. One study related to this topic is reported [16]. The study provided important insights into the economics of Cloud-Based Design and Manufacturing (CBDM) based on the case studies of products manufactured using 3D printers. Aside from this approach, little or no research has been done on CM cost model. Standards need to be established with respect to input information required from users and PRPs.

3.2.3 Implementation of Everything as a Service

The aim of CM is to offer manufacturing services and optimize the usage of other resources such as design and engineering software through the cloud. Offering of a broad range of computer-aided technologies (CAx) such as computer -aided design (CAD), computer-aided engineering (CAE), computer-aided manufacturing (CAM) has been pursued by organization such as UberCloud [45]. UberCloud brings industry partners, computing resource providers, software providers, high performance computing (HPC) and cloud computing experts together to integrate HPC and cloud computing with CAx vendors such as Autodesk and ANSYS [34]. This act provides affordable access especially to small and medium manufacturers (SMMs), to advanced data analytics, modeling and simulation tools in product design and manufacturing.

3.2.4 Real-time Monitoring and Control of PRP Resources

In today’s dynamic business environment, there are various uncertainties that can disrupt manufacturing activities. Such disruption will render original schedules to become obsolete. To react to such events in a timely manner, it is necessary to execute real time resource rescheduling adjustments. This can only be done if the real-time resource status information across the CM is available. Yang et al. [35] proposed dynamic service selection that utilizes IoT's real-time sensing ability and big data knowledge extraction capabilities to improve service selection. IoT enables real-time capture of disturbances and resources status. Big data technologies are employed to extract knowledge about service qualities and market demands. Wang [36] introduced a tiered system architecture and introduces IEC 61499 function blocks for prototype implementation. By connecting to a Wise-ShopFloor framework, it enables real-time machine availability and execution status monitoring during metal-cutting operations both locally and remotely. The closed-loop information flow makes process planning and monitoring possible.

4.0 RESEARCH DIRECTION

Based on analysis between the CM implementation in the industry and the ideal CM structure, there are few areas of concerns that need to be addressed in closing the gaps between the two that has not been addressed by researchers in this field.

- **Standardization on PRPs and user input variables to develop universal manufacturing cost modeling for various manufacturing processes.**
  In order to be able to provide real - time quotation in response to user requests, development of universal cost modeling for various manufacturing process is required. This model should be applicable for all PRPs and specific common variables have to be defined so that specific values of the variables can be specified by the users and PRPs as the inputs to the costing model.

- **Definition of cost models for "everything as a service" in CM.**
  Based on the review, capabilities to offer such service for CAx in cloud environments is available [11]. What is missing is the cost structure based on user requirements and input variables; for examples, the user has physical prototype without CAD drawing and no expertise in using the CAD system, or would like to perform CAE (Computer Aided Engineering) analysis on the prototype.

- **Integration of real-time monitoring, control data, resource allocation algorithms, and sharing strategies.**
  Most current research analyze this area separately, real-time monitoring [26-27] and allocation algorithm and sharing strategy [8, 10, 35-36]. Integration of the two is essential so that "real time" resource allocation can be performed. The integration of "real-time" data monitoring into resource allocation exercise will significantly improve the agility of the system to respond to any changes in the platform such as demand, machine break down, and material availability.

- **Integration of all supply chain components in the CM.**
  Most research in CM analyze the integration of users, PRPs and service provider [9, 12, 16]. The integration of other supply chain components, such as logistic and materials, in the CM environments is also imperative in meeting user requirements. Those components are also dynamic in nature and need to be adjusted accordingly in real-time during resource allocation exercise.

- **Information security concern.**
  In CM environment, huge amount of data from user/OEM and PRPs are shared with the service provider. This information can be quite sensitive that represent competitive advantage of the specific organization. For the CM players to be willing to share this information, CM service provider must ensure that the information in security system and policy are in place to ensure data can be shared and protected at the same time. This aspect of CM has not been well documented yet [48].

5.0 CONCLUSIONS

CM has been recognized as an emerging manufacturing paradigm that can provide cost and flexibility advantages. This review compares current CM practices with those of the ideal CM environments. Gaps between the two are highlighted and current states of CM research pertinent to the gaps are reviewed. Finally, future research directions to address the gaps that have not been holistically studied are discussed.

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