A NEW PARADIGM OF MANUFACTURING MANAGEMENT:
CLOUD MANUFACTURING

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Abstract

The global economic constantly changing and the advent of new technologies imply the demand of changing in the business pattern of manufacturing industry. Nowadays, most manufacturing companies have realized the importance of collaboration between dispersed factories, different suppliers and distributed stakeholders, in a quick, real-time and effective manner. Cloud computing is an evolution of the Internet. But it does not only change the technology, also enables collaborative innovation. Cloud manufacturing is a new form of networked manufacturing. It provides common and standard manufacturing services by cloud logic and principle. In this paper, a new concept is proposed based on the fundamental theory and key technologies of cloud manufacturing. It is Cloud Future Factory, which is designed to a real case company to manage its matrix-type organizational structure. Its production lines and business departments are distributed. Therefore, it’s very necessary to introduce an effective and dynamic information integration platform. This research paper offers an application of cloud manufacturing and leads to a new thinking of using cloud manufacturing concept in different formations.

Keywords: Cloud manufacturing, Cloud computing, Networked manufacturing, Case study.
INTRODUCTION

The current manufacturing environment is highly competitive and uncertain. The mounting demand for new products has brought more production activities worldwide in recent years. More and more opportunities are bringing to us with sharing knowledge and expertise in a collective manner according to the globalization tendency. People and other resource from all across the globe need to connect instantaneously.

The advent of the internet has led to the development of collaboration networks that have resulted in a power-shift from the once mighty hierarchical business models (Wu et al., 2013). Especially in manufacturing industry, companies have to be flexible and reconfigurable so that their business structures or products can be adaptive in a dynamic environment.

Cloud computing is becoming an attractive element of companies’ competitive strategy. It is emerging as one of the major enablers for the manufacturing industry. Xu (2011) emphasized that cloud computing is considered as a multidisciplinary research field. However, little work has been reported on investigating the potential of cloud computing in the field of product design and manufacturing (Wu et al., 2012). As discussed by Xu (2011), the cloud computing adoptions in manufacturing industry can be mainly classified into two types: smart manufacturing and cloud manufacturing. Smart manufacturing means manufacturing with direct adoption of cloud computing technologies and enable better-integrated and more efficient processes. Cloud manufacturing means the manufacturing version of cloud computing, which very similar to networked manufacturing concept. Regardless which cloud adoption is used in the company, the concept of cloud transforms the traditional manufacturing business model, help it to align product innovation with business strategy, and create intelligent factory networks that encourage effective collaboration (Xu, 2011).

Columbus (2013) posted an article in Forbes and discussed about using cloud computing to revolutionize manufacturing based on his visits with manufacturers. He pointed out 10 ways to utilize cloud computing such as implementing cloud-based business tools to mobility support the analysis and reporting, also deliver real-time order status and forecasts, and create multiple access entry points. These business tools can support different business purposes customer management, marketing management, product management, vendor management, etc. However, there was a main central theme draw out attentions: collaboration. Using cloud-based platform can ensure collaboration in any phase of manufacturing and product management, which is strategy that many manufactures are pursing today. Zhou et al. (2011) emphasis enterprise has become a node in global inter-enterprise collaborative manufacturing network.

In this research paper, we introduce main prior research in cloud manufacturing and its associated characteristics. Since there are several definitions of around novel concept, it’s very vita to review these definitions and propose a comprehensive definition embracing the competitive foundations of cloud and the key concepts of cloud manufacturing. Accordingly, our goal in this paper is to answer the following questions:

- What is cloud manufacturing?
- What new opportunities are derived from cloud manufacturing?

Moreover, this paper attempts to address some of the basic requirements for achieving cloud manufacturing in a real case company. Many manufacturing companies are already using a form of cloud computing in their existing network infrastructure and providing services to employees and assets within their enterprise. In this paper, we will present how the case company embraces a private cloud into its value chain, increases flexibility of its supply chain and centrally manages its dispersed factories via this new paradigm, namely Cloud Future Factory, herewith, to improve the ability to react faster on market needs and individual customer requirements.
2 RESEARCH OVERVIEW

2.1 Related concepts

In the manufacturing industry, many advanced business models and technologies have been developed to address different manufacturing challenges and to improve the manufacturing quality. Related concepts and definitions are listed in Table 1. These models are proposed and used widely, and they are capable of satisfying current manufacturing requirements on different aspects. According to the differences of these concepts’ attributes and orientations, they can be classified into two different aspects: structure oriented and technology oriented. Structure oriented concepts mainly focus on the structure of business formation. On the other hands, technology oriented concepts primarily emphasize the importance of technology involvement.

<table>
<thead>
<tr>
<th>Concept</th>
<th>Main attributes</th>
<th>Citation</th>
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<tr>
<td><strong>Structure-oriented</strong></td>
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<tr>
<td>Agile Manufacturing</td>
<td>emphasizes cooperative enterprises to adapt and respond quickly to rapidly changing markets driven by customer-based valuing of products and services</td>
<td>Yusuf et al. 1999</td>
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<tr>
<td>Networked manufacturing</td>
<td>includes the integration of distributed resources</td>
<td>D’Amours et al. 1999</td>
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<tr>
<td>Virtual manufacturing</td>
<td>integrates manufacturing resources and activities distributed in computer networks</td>
<td>Iwata et al. 1997</td>
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<td><strong>Technology-oriented</strong></td>
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<td>Digital manufacturing</td>
<td>incorporates technologies for the virtual representation of a physical manufacturing resources, such as of factories, buildings, machine systems equipment, labour staff and their skills, as well as for the closer integration of product and process development through modelling and simulation</td>
<td>Chryssolouris et al. 2009</td>
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<tr>
<td>Computer-integrated manufacturing</td>
<td>uses computers and integrate with Computer Aided Design and also other business operations and database, to control the entire production process and allows that the processes exchange information with each other and they are able to initiate actions</td>
<td>Alavudeen &amp; Venkateshwaran 2008</td>
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<tr>
<td>Manufacturing Gird</td>
<td>uses for sharing and integrating resources in manufacturing processes and for the cooperating operation and management of the enterprises based on the grid and relative advanced computer and information technologies</td>
<td>Fan et al. 2004</td>
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Table 1. Related concepts and definitions.

However, current manufacturing models are lacking in the centralized operation management, which includes management of the services, choice of operation modes and embedded access of manufacturing equipment and resources (Xu, 2011). It’s not suitable for dealing with the strategic, long-term barriers to efficient manufacturing process across enterprises internal and external boundaries over highly complex and dynamic networked environment. Moreover, the integration of manufacturing IT systems to the overall supply chain management infrastructure is missing (Rauschecker & Stohr, 2012). In other words, the coordination among the parties in the distributed network has been little and less effective in the reality.

In order to achieve seamless, stable and high quality transaction of manufacturing resource services, a new manufacturing business model should be proposed. According to Xu (2011), cloud manufacturing is considered as a new multidisciplinary domain that encompasses these concepts. Cloud manufacturing has become a new mode of networked manufacturing (Xu, 2011; Tao et al., 2011; Li et al., 2012). In contrast to the conventional networked manufacturing approach, the cloud manufacturing promises elasticity, flexibility and adaptability through the on-demand provisioning of manufacturing resources (Zhou et al. 2011).
Figure 1 illustrates the scope of cloud manufacturing and its relation with existing concepts. Cloud manufacturing reflects existing concepts, but also extends current knowledge with both the dimension of level of integration with other partners and the degree of ICT involved. As highlighted by D’Amours et al. (1999), the networking strategies are classified by different levels of shared information, such as on price and capacity. Therefore, in this scope scheme, the horizontal axis represents the level of ICT involved and the vertical axis.

**Figure 1. Scope of Cloud Manufacturing**

### 2.2 Cloud computing concept and application in manufacturing

Cloud computing is treated as the evolution of the Internet. The concept of cloud is a combination of different technologies and resources, such as computing, networking, storage, and management solutions, etc. Cloud enables ubiquitous, convenient and on-demand network access. However, cloud is not only an evolution of technology, but also an evolution of business model.

Xu (2011) identifies two types of cloud computing adoptions in the manufacturing sector. The first type is the manufacturing with direct adoption of cloud computing technologies. The second type is cloud manufacturing, which means the manufacturing version of cloud computing. He provides a definition of cloud manufacturing: distributed resources are encapsulated into cloud services and managed in a centralized way. Clients can use cloud services according to their requirements. Cloud users can request services ranging from product design, manufacturing, testing, management, and all other stages of a product life cycle.

Mezgár (2011) asserts cloud computing is an important technology for networked enterprises as it offering high level collaboration possibilities. It enables a new generation of IT, and also manufacturing services. It makes the services be available based on every demand. Cloud computing can realize dynamic resource sharing and on-demand resource provisioning by leveraging virtualization technologies at multiple levels (hardware, platform & application) (Zhou et al. 2011).

### 2.3 Comparison of cloud manufacturing definitions

Cloud manufacturing concept owes a lot previous paradigms of manufacturing models. It is a hybrid construct of advanced technologies and any previous method of manufacturing, which provides a sharing and collaborative manufacturing environment. The advanced technologies can be cloud computing, the internet of things, semantic web, and information system integration, etc (Luo et al. 2011). The concept is at the moment a vision and currently being refined to further its understanding.
The first serious discussions and analyses of cloud manufacturing emerged in 2010 with a research project funded by the National Natural Science Foundation of China. Li, Zhang and Chai (2010) proposed the definition of intelligent cloud manufacturing as: “a service-oriented, knowledge-based smart manufacturing system with high efficiency and low energy consumption”. Xu (2011) also developed a definition of cloud manufacturing by mirroring NIST’s cloud computing definition: “a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable manufacturing resources (e.g., manufacturing software tools, manufacturing equipment, and manufacturing capabilities) that can be rapidly provisioned and released with minimal management effort or service provider interaction.”

Wu and Yang (2010) addressed the concept of cloud manufacturing. The authors summarized: “Cloud manufacturing is an integrated supporting environment both for the share and integration of resources in enterprise. It provides virtual manufacturing resources pools, which shields the heterogeneity and the regional distribution of resources by the way of virtualization. Cloud manufacturing provides a cooperative work environment for manufacturing enterprises and individuals and enables the cooperation of enterprise”.

Wu et al. (2012) state that cloud manufacturing also refers to a product realization model that enables collective open innovation and rapid product development with minimum costs through a social networking and negotiation platform between service providers and consumers. It is a type of parallel and distributed system consisting of a collection of inter-connected physical and virtualized service pools of design and manufacturing resources (e.g., parts, assemblies, CAD/CAM tools) as well as intelligent search capabilities for design and manufacturing solutions (Wu et al., 2012).

Cloud manufacturing provides the whole manufacturing lifecycle with secure, reliable, high quality, and on-demand services at low prices through networked system (Ai et al. 2013). The manufacturing lifecycle includes pre-manufacturing (argumentation, design, production and sales), manufacturing (product usage, management and maintenance), and post-manufacturing (dismantling, scrap and recycling) (Li, Zhang and Chai, 2010).

Zhou et al. (2011) labeled cloud manufacturing paradigm with five parts: resource cloud, manufacturing cloud, business cloud, infrastructure & public platform for cloud manufacturing and cloud users. This definition is very significant, because it reveal the essential potentiality offered by cloud manufacturing.

### 2.4 Characteristics of Cloud Manufacturing

Although each of the cloud manufacturing definitions has its own emphasis, apparently five common characteristics are existed, namely: intelligent, distributed manufacturing, networked, resource sharing and cooperative work. Li, Zhang and Chai (2010) highlight the keys of cloud manufacturing are service-oriented, knowledge-based and energy efficient. Since cloud manufacturing is built up based on cloud computing concept, it follows the principle of X as a service. Therefore, it can be also named as manufacturing as a service (Wu and Yang, 2010).

NIST’s definition of Cloud computing (Mell & Grance 2009) states that the essential characteristics are: on-demand self-service, broad network access, resource pooling, rapid elasticity, measured service. These features are also detectable in cloud manufacturing. Wu et al. (2012) defined the essential characteristics of cloud manufacturing based on this formation:

- **On-demand self-service:** Manufactures which join in this cloud manufacturing platform can both release manufacturing resources and services, and also access a shared collection of on-demand manufacturing resources and services to form a networked manufacturing model, which is a temporary and reconfigurable production line according to their requirements (Wu et al., 2012; Wu et al., 2013; Tai et al., 2012).

- **Broad network access:** In order to ensure that various stakeholders (e.g., customers, designers, managers) can interact with each other and actively participate throughout the entire production process and achieve value co-creation, cloud manufacturing can provide users access to the
resources and services through heterogeneous tools, e.g., mobile phones, tablets, laptops, and workstations (Wu et al., 2012).

- Resource pooling: All the manufacturing resources and services are virtualized and made available to users through cloud manufacturing platform. Cloud manufacturing services is formed by identifying, virtualization and packaging process (Xu 2011; Wu et al. 2012). Cloud manufacturing enables convenient and on demand network access to such a shared pool of configurable manufacturing resources.

- Rapid elasticity: This cloud manufacturing platform allows users to quickly scale up and down to respond quickly to changing requirements. It helps to better handle dynamic capacity planning under emergency situations incurred by unpredictable customer needs and reliability issues. For example, the cloud system allows the cloud service consumers to quickly search for and fully utilize resources, such as idle and/or redundant machines and hard tools, in another organization to scale up their manufacturing capacity (Wu et al., 2012).

- Measured service: For manufacturers, there are too many services and resources in the business environment, only on-demand optimized resource are provisioned to their particular business processes. Therefore, the services and resources are monitored, controlled and reported to ensure the quality of cloud manufacturing services and resources (Tao et al., 2011).

3 CLOUD FUTURE FACTORY PROPOSAL

3.1 Concept and Objectives

In this research paper, a new cloud manufacturing model is proposed based on review previous research. The approach in this work is named as Cloud Future Factory (CFF). This CFF concept is designed for a real case company from Finland, for the confidential reason, we use Company PP as anonymous.

Company PP is a leading provider in machines and systems for sheet metal working. Its solutions include laser processing, punching, shearing, bending, automation, and so on. Currently, this company employs around 1,500 people and operates in over 70 countries. Company PP’s manufacturing facilities are divided into 4 groups: 2D & 3D Laser (Product Unit 1), Punching, Combi & Systems (Product Unit 2), Bending (Product Unit 3) and Laserdyne (Product Unit 4), respectively dispersed in Italy, Finland, USA and China, from which they deliver machines and systems all over the world. Company PP targets to provide customers with the most comprehensive range of high performance, profitable and sustainable machines, and relevant services, and also to have a business model focused on actual customer's needs. In order to achieve this goal, company PP is adopting with matrix organization structure as shown in Figure 2. Different Region Units are responsible for sales, installation, training and service of all company PP’s products for certain areas.

![Matrix organization structure with 4 Product Units (PU) and 4 Region Units (RU).](image)

Although this matrix organization structure provides many advantages to company PP, one obvious feature is the internal complexity in information exchange. Region Units are responsible for collecting
customer requirement, and providing the customized design and prototype of the machines then sending to specified Product Units accordingly. For instance, if customer needs machines for the processing of three-dimensional parts, the working order will send to PU1. The transferring of information and production plan phase needs significant amount of time.

Due to this unique property of organization structure, company PP needs an efficient way to manage its network of supply, manufacturing, sales and also various services, etc.

The aim of CFF is to effectively organize all kinds of manufacturing resources and manufacturing capabilities separated in different Product Units all over the world, and virtually manage these resources and capability by different Region Units and also centralized in this CFF. Therefore, the project described here will set up and customize the cloud manufacturing infrastructure into company PP.

Figure 3 illustrates the abstract framework of Cloud Future Factory. Two main directions state the matrix-type relationships among Product Units and Region Units. All the Product Units publish their product manufacturing resources and capabilities in to the cloud, in the meanwhile, all Region Units are able to publish sales, customer orders, etc in to the cloud with customized design. By using this CFF concept, it is able to centrally manage the production and manufacturing.

It covers the whole machines and software manufacturing process. Strictly speaking, it refers to the product lifecycle management, from pre-manufacturing, manufacturing to post-manufacturing. All the activities in this CFF are to achieve the core business value. The core business value is the business objectives of this case company:

- Reducing cost of manufacturing: manufacturing line optimization;
- Improving elasticity of system: dynamic production planning;
- Expanding scope of services: more partners, namely suppliers and customers, involved in this manufacturing process.

![Figure 3. Abstract framework of Cloud Future Factory.](image)

This CFF includes the areas covering products life cycle management, modelling, design and optimization, and also inter-organizational relation management in cloud computing. In this particular research, company PP is addressed to encourage international cooperation under the cloud manufacturing model.
3.2 Cloud Future Factory System Platform Architecture

To demonstrate the tool of CFF, a Cloud Future Factory System Platform (CFFSP) is under developing. CFFSP is designed as an Information and Communication technology (ICT) tool. It can be used as a concrete tool of manufacturing management system to fulfil the concept of cloud manufacturing in reality, and to realize the integration within manufacturing processes in an increasingly globalized industrial context. Factories involved can share and circulate their manufacturing resources and capabilities while they can also request various manufacturing services on-demand for the whole lifecycle of manufacturing.

Figure 4 shows a function view of CFFSP. The proposed architecture of the CFFSP is a hierarchical structure. It consists of the following three layers: CFFSP business management layer, Technology support layer and Manufacturing layer.

- CFFSP business management layer: provides the business process definitions which oriented to the business requirements of the CFFSP consumers (Region Units). All manufacturing applications are provided to users depending on various requirements.
- Technology support layer: is similar as Infrastructure as a service (IaaS) layer, which establishes a basic operation support environment.
- Manufacturing layer: provides the manufacturing resources and capabilities involved in the whole manufacturing lifecycle. It enables CFFSP services provider (Product Units) to unload their services. Each of the resources and capabilities is encapsulated as a service, and then it can be requested on demand by CFFSP.

Most manufacturing companies use various systems to determine product manufacturing and the production planning process. CFFSP is used herein to translate all the products orders into production plan. The CFFSP is a cloud based system for distributed (multi-site) production planning and control system. The key features of the system include:

- Production scheduling is done continuously, not daily etc.
- Alternative possibilities are processed beforehand
- Actual processing times are fed to production plan and control system real-time
- Machine or work phase specific error data could be input directly to production plan and control system
- Alternative schedules are adjusted based on feedback and situations
- Possible integration to wider supply chain

CFFSP can support a dynamic manufacturing process with a closed-loop pre-emptive production planning and control. The objectives are to develop a concept of real-time multi-level optimization production scheduling system and test it at sheet metal processing line.
Service composition and optimal selection is one of the key issues for implementing a cloud manufacturing system (Xiang et al., 2013).

The virtual-logical system simulates manufacturing activities that mainly deal with information such as design, planning, management, and so on. The virtual-physical system models physical entities on the factory floor such as machines, materials, and workers within computers, and it simulates physical interactions between these entities based on the models. The virtual-physical system is the key to realizing a virtual manufacturing system because it should mainly ensure the informational equivalence with the real manufacturing system.

4 FUTURE WORK

In order to continue the work described and to achieve further results, this project will be extended to include more partnerships, business and research activities. It is very crucial to combine various manufacturing services from different providers. It will support the product innovation and production process innovation. Furthermore, this cloud manufacturing will play a major role in floor shop management as well.

Future work will concern more about the technologies needed to support the cloud manufacturing. Cloud computing technologies can be used to realize the integration between different business applications and enable the collaborations. However, the security issues about this cloud manufacturing infrastructure should be considered as well.

5 CONCLUSION

Cloud computing is not a new concept any more, and it is already embodied in practices from many aspects. Many manufacturing companies are using cloud concept to their business model, namely, cloud manufacturing. Such concept may not be radically different from existing manufacturing paradigms, such as networked manufacturing, but it brings new way to think the agility.

This Cloud Future Factory represents an example of cloud manufacturing. It was proposed to manage all dispersed factories in a case company, which is a matrix-type organizational structure. This paper attempts to offer a system platform that not only coordinates the production of complex customized components across many physical locations but also allows the limitations and capabilities of the supply chain to be explicitly available during the product design process.

The purpose of CFFSP is to construct a flexibly and effectively management platform and provide users a concrete ICT tool. This approach of CFFSP, however, demands more technology design and concerns. The major work undertaken to date includes:

- A comprehensive literature review which highlights the possibilities and potentials can be achieved by CFF.
- A technology review needed to be conducted to find out a set of cloud technologies used in implementing such platform.

References
