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Cloud Technology for Service-Oriented Manufacturing

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Abstract. Cloud computing is changing the way industries and enterprises do their businesses in that dynamically scalable and virtualized resources are provided as services mostly over the Internet. Cloud Computing is also emerging as one of the major enablers for the manufacturing industry; it can transform the traditional manufacturing business model, help it align product innovation with business strategy, and create intelligent factory networks that encourage effective collaboration. Two types of Cloud Computing adoptions in the manufacturing sector have been suggested, manufacturing with direct adoption of Cloud Computing technologies and Cloud Manufacturing – the manufacturing version of Cloud Computing. Cloud computing has been implemented in some of key areas of manufacturing such as IT and pay-as-you-go business models. In Cloud Manufacturing, distributed resources are encapsulated into cloud services and managed in a centralized way. Clients can use cloud services according to their requirements. A cloud manufacturing platform has been proposed to provide users with a big range of flexible and sustainable manufacturing capabilities. Manufacturing capabilities and business opportunities are integrated and broadcasted in a larger resource pool, which can enhance the competiveness of the entire consortium.

Keywords. Cloud Computing, Cloud Manufacturing, Service-Oriented Business Model

Nomenclature

B2B	Business-to-business
BPM	Business Process Management
CAD	Computer-Aided Design
CAE	Computer-Aided Engineering
CAM	Computer-Aided Manufacturing
CNC	Computer Numerical Control
CRM	Customer Relationship Management
DAMA	Design Anywhere, Manufacture Anywhere
DARPA	Defense Advanced Research Projects Agency, USA
ERP	Enterprise Resource Planning
IaaS	Infrastructure as a Service
IT	Information Technology
MaaS	Manufacturing as a Service

MDSL	Manufacturing Description Service Language
MGrid	Manufacturing Grid
NIST	National Institute of Standards and Technology, USA
openCBM	open Computer-Based Manufacturing
OWL	Web Ontology Language
PaaS	Platform as a Service
RFID	Radio-Frequency IDentification
SaaS	Software as a Service
SHOE	Simple HTML Ontology Extension
SMC	Sustainable Manufacturing Cloud
STEP	Standard for Exchange of Product data
XaaS	everything is treated as a Service

1. Introduction

In the recent past, the manufacturing industry has undergone a major transformation enabled by information technology. Cloud Computing is one of such technologies. The main thrust of Cloud Computing is to provide on-demand computing services with high reliability, scalability and availability in a distributed environment. In Cloud Computing, everything is treated as a service (i.e. XaaS), e.g. SaaS (Software as a Service), PaaS (Platform as a Service) and IaaS (Infrastructure as a Service). These services define a layered system structure for Cloud Computing (Figure 1). At the Infrastructure layer, processing, storage, networks, and other fundamental computing resources are defined as standardized services over the network. Cloud providers' clients can deploy and run operating systems and software for their underlying infrastructures. The middle layer, i.e. PaaS provides abstractions and services for developing, testing, deploying, hosting, and maintaining applications in the integrated development environment. The application layer provides a complete application set of SaaS. The user interface layer at the top enables seamless interaction with all the underlying XaaS layers [1].

Sometimes, Cloud Computing is considered as a multidisciplinary research field as a result of evolution and convergence of several computing trends such as Internet delivery, "pay-as-you-go/use" utility computing, elasticity, virtualization, distributed computing, storage, content outsourcing, Web 2.0 and grid computing. In fact, Cloud Computing can be considered the business-oriented evolution of grid computing [2]. Implementing Cloud Computing means a paradigm shift of business and IT infrastructure, where computing power, data storage and services are outsourced to third-parties and made available as commodities to enterprises and customers.

There are valid reasons and perhaps requirement for manufacturing businesses to embrace Cloud Computing and to "borrow" the concept of Cloud Computing to give rise to "Cloud Manufacturing", i.e. the manufacturing version of Cloud Computing. Such a lateral thinking is considered logical and natural as manufacturing businesses in the new millennium become increasingly IT-reliant, globalised, distributed and agile-demanding.

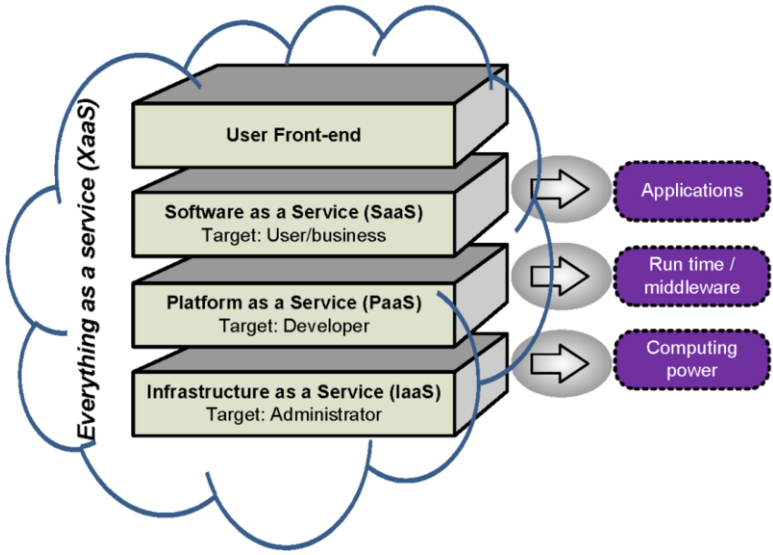

Figure 1. Cloud computing: everything is a service [3]

2. Cloud Computing in the Context of Manufacturing

The philosophy of "design anywhere, manufacture anywhere (DAMA)" has emerged in recent years [3-6]. DAMA also helps establish links between manufacturing resource planning, enterprise resource planning, engineering resource planning and customer relationship management. It is believed that Cloud Computing can play a critical role in the realization of DAMA. In general, there are two types of Cloud Computing adoptions in the manufacturing sector, manufacturing with direct adoption of some Cloud Computing technologies and Cloud Manufacturing – the manufacturing version of Cloud Computing.

2.1. Smart Manufacturing with Cloud Computing

Cloud computing is rapidly moving from early adopters to mainstream organizations. It has become one of the top priorities of many CIOs for strategic business considerations. Some manufacturing industry starts reaping the benefits of Cloud adoption today, moving into an era of smart manufacturing with the new agile, scalable and efficient business practices, replacing traditional manufacturing business models.

In terms of Cloud Computing adoption in the manufacturing sector, the key areas are around IT and new business models that the Cloud Computing can readily support the type of business models and operations such as pay-as-you-go, the convenience of scaling up and down per demand, and flexibility in deploying and customizing solutions. The adoption is typically centred on BPM applications such as HR, CRM, and ERP functions with Salesforce and Model Metrics being two of the popular PaaS providers. The cost benefit of adopting Clouds in a typical manufacturing enterprise can be multiple. The savings obtained from the elimination of some of the functions that were essential in traditional IT can be significant. With Cloud-based solutions, some application customizations and tweaks that the company needs at the process

level may be assisted by some of the smart Cloud Computing technologies. When it comes to supporting smart business processes, Cloud Computing can be effective in offering Business-to-business (B2B) solutions for commerce transactions between businesses, such as between a manufacturer and a wholesaler, or between a wholesaler and a retailer. Cloud-based solutions enable better-integrated and more efficient processes.

Collaboration at scale using Cloud technology is an emerging business trend. Adopting Cloud technologies, enterprise collaboration can happen at a much broader scale. Within the organization, demand planning and supply chain organization can be tied into a Cloud-based system, allowing different parts of the organization to take a peek into the opportunities that their sales teams are working on. In a more traditional environment, that would involve a few sit-down meetings, several face-to-face discussions, or phone conversations. The Cloud in this case provides a collaborative environment that can give people agility, more transparency, and empowerment through more effective collaborations.

Typically, there are some parts of the manufacturing firm that can quickly and easily adopt Cloud-based solutions, whereas other areas are better to remain traditional. Hence, what a Cloud-adopting manufacturing enterprise also requires is a smart mechanism to deal with integration.

2.2. Cloud Manufacturing

Moving from production-oriented manufacturing to service-oriented manufacturing and inspired by Cloud Computing, Cloud Manufacturing offers an attractive and natural solution. Like Cloud Computing, Cloud Manufacturing is also considered as a new multidisciplinary domain that encompasses technologies, e.g. networked manufacturing, manufacturing grid (MGrid), virtual manufacturing, agile manufacturing, Internet of things, and of course Cloud Computing. Cloud Manufacturing reflects both the concept of "integration of distributed resources" and the concept of "distribution of integrated resources". Mirroring NIST's definition of Cloud Computing, Cloud Manufacturing may be defined as "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 re¬leased with minimal management effort or service provider interaction."

In Cloud Manufacturing, distributed resources are encapsulated into Cloud services and are managed in a centralized way. Clients can use the 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. A Cloud Manufacturing service platform performs search, intelligent mapping, recommendation and execution of a service. Figure 2 illustrates a Cloud Manufacturing system framework, which consists of four layers, manufacturing resource layer, virtual service layer, global service layer and application layer.

2.2.1. Manufacturing Resource Layer

Manufacturing resources may take two forms, manufacturing physical resources and manufacturing capabilities. Manufacturing physical resources can exist in a hardware or software form. The former includes equipment, computers, servers, raw materials

and etc. The latter includes for example simulation software, analysis tools, "know-hows", data, standards, employees and etc. Manufacturing capabilities are intangible and dynamic recourses representing the capability of an organization undertaking a particular task with competence. These may include product design capability, simulation capability, experimentation, production capability, management capability and maintenance capability. The types of service delivery models that may exist at this layer are IaaSs and SaaSs.

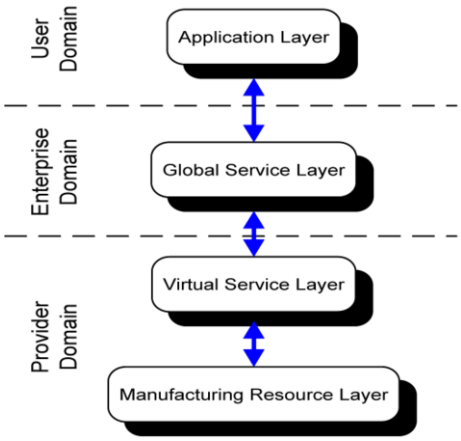

Figure 2. Layered architecture of a Cloud Manufacturing system

2.2.2. Manufacturing Resource Layer

The key functions of this layer are to (a) identify manufacturing resources, (b) virtualize them and (c) package them as Cloud Manufacturing services. Comparing with a typical Cloud Computing environment, it is more challenging to realise these functions for a Cloud Manufacturing application. Manufacturing resource virtualization refers to abstraction of logical resources from their underlying physical resources. Quality of virtualization determines the robustness of a Cloud infrastructure. The next step is to package the virtualized manufacturing resources to become Cloud Manufacturing services. To do this, resource description protocols and service description languages can be used. The latter may include different kinds of ontology languages, e.g. Simple HTML Ontology Extension (SHOE), DARPA Agent Markup Language (DAML) and Web Ontology Language (OWL).

2.2.3. Encapsulating Manufacturing Resources with Mapping

The process of virtualizing a manufacturing resource can also be viewed as an encapsulating process, which can be carried out using three different mapping methods, one-to-one, many-to-one and one-to-many. One-to-one mapping applies to manufacturing resources that can only provide a single function and can therefore directly be encapsulated into one service. The CAD and CAE data format exchange service is one of the common types of such resource. In a many-to-one mapping, multiple resources (each providing a specific function) may be combined to create a

more powerful or functional resource form. In Cloud Manufacturing, when multiple manufacturing resources are combined, more comprehensive manufacturing resource services called resource service composition can be provided to users to enable value-added services. The one-to-many mapping concerns with a single resource that appears to a client as multiple resources. The client interfaces with the virtualized resources as though he/she is the only consumer. In fact, the client is sharing the resource with other users. For example, ANSYS software can provide structure analysis, thermal analysis, magnetic analysis and computational fluid dynamics analysis. Therefore, ANSYS software can be encapsulated by many different services.

2.2.4. Enterprise Requirements – Global Service Layer

The Global Service Layer relies on a suite of Cloud deployment technologies (i.e. PaaS). Internet of things has advanced to a new level with RFID, intelligent sensors and nano-technology as supporting technologies. Interconnections between physical devices or products are made easier because of Internet of things. This said, a centralized and effective management regime needs to be in place to provide manufacturing enterprises with agile and dynamic Cloud services. Based on the nature of the provided Cloud resources and the user's specific requirements, two types of Cloud Manufacturing operation modes can take place at the Global Service Layer, complete service mode and partial service mode.

2.2.5. User Requirements – Application Layer

The Application Layer serves as an interface between the user and manufacturing Cloud resources. This layer provides client terminals and computer terminals. Some examples of interfaces are complex system modelling tools, generic simulation terminals and new product development utilities. The user can define and construct a manufacturing application through the virtualized resources. Such a manufacturing application often involves more comprehensive manufacturing resource services that provide users with a value-added service [7,8]. Similar to Cloud Computing, end-user consumption-based billing and metering in Cloud Manufacturing resembles the consumption measurement and allocation of costs of water, gas and electricity. The issue of user-centric privacy is a thorny one. The main concern is related to the storage of personal/enterprise sensitive data. This data includes not only product information but also information of some of the high-end manufacturing resources. A rigorous Service Level Agreements for Cloud Manufacturing is a must to win any end-user's trust and confidence over the services.

3. Research into the Concept of Cloud Manufacturing

Although the concept of Cloud Manufacturing is relatively new, virtual enterprise and distributed manufacturing concepts have been around for a while and some of the proposed systems and frameworks bear visible traces of Cloud Manufacturing or make contributions to a Cloud Manufacturing system. This section discusses some of these research outcomes.

Brecher, et al [9] recognised that applications in an information-intensive manufacturing environment can be organized in a service-oriented manner. They proposed a module-based, configurable platform for interoperable CAD-CAM-CNC planning. The approach is called open Computer-Based Manufacturing (openCBM) in support of co-operative process planning (Figure 3). STEP standard is utilized to preserve the results of manufacturing processes that are fed back to the process planning stage [10]. The openCBM platform is organized through a service-orient architecture providing the abstractions and tools to model the information and connect the models [20]. It is much like the Platform as a Service concept and resembles an Application Layer, where applications are not realised as monolithic programs, but as a set of services that are loosely connected to each other, guaranteeing the modularity and reusability of a system. The module providers as shown in the figure form the Manufacturing Virtual Service Layer and the module database forms a Global Service Layer.

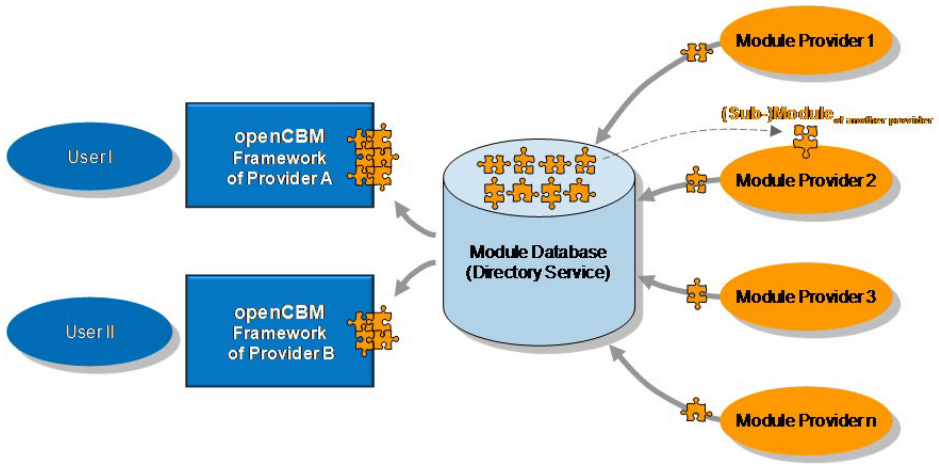

Figure 3. Module users and providers of the openCBM approach

More significantly, a Cloud-based manufacturing research project was launched in 2010, which was sponsored by the European Commission [11]. The goal of this project (named ManuCloud) is to provide users with the ability to utilize the manufacturing capabilities of configurable and virtualized production networks, supported by a set of SaaS applications. In the proposed system, customized production of technologically complex products is enabled by dynamically configuring a manufacturing supply chain [12-14]. It is considered that the development of a front-end system with a next level integration to a Cloud-based manufacturing infrastructure is able to better support the specification and on-demand manufacture of customized products. Based on the conceptual architecture, two main types of users who interact with the front-end system are identified: manufacturing service consumer (e.g. a product designer) and manufacturing service provider (e.g. a lighting product manufacturer). Compared with service consumer, more interactions are required between service provider and the manufacturing Cloud. Nevertheless, there is still a lack of methods to support the activity provider. In this Research work, Manufacturing-as-a-Service (MaaS) was proposed to achieve configurable and customized manufacturing (Figure 4) [14].

Manufacturing Description Service Language (MDSL) was developed to model and represent different types of product characteristics, for example, shape, size, mechanical, electrical and etc. However, it is envisaged that this language may have difficulties in integrating with exiting CAD models because of the different data syntax.

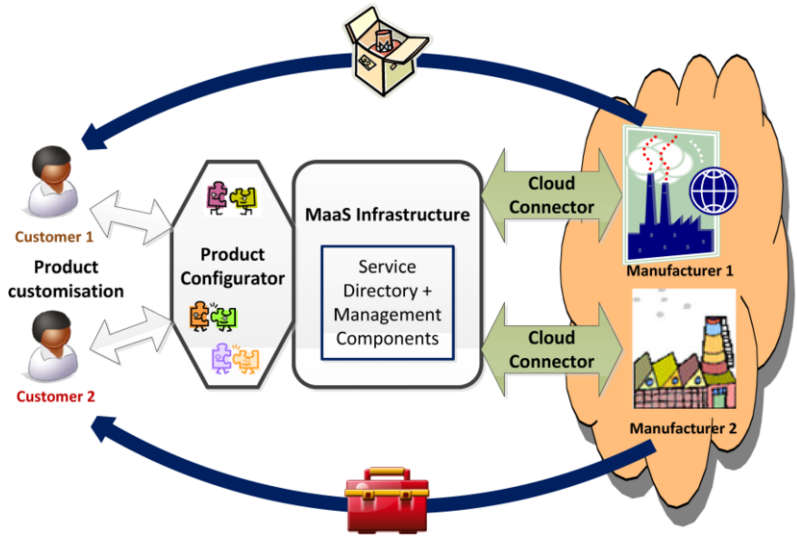

Figure 4. Processing of Manufacturing Service Descriptions in the MaaS Environment

A Sustainable Manufacturing Cloud (SMC) has been is proposed (Fig. 5). This platform aims to provide a solution for rapid development of customized products, with the intention of minimizing costs of consumers and maximizing profits of service providers, as well as taking environmental issues into account. Consumers only need to submit their service requests, and the platform takes care of the remaining procedures, such as cost estimation, time estimation, service selection optimization, sustainability evaluation, and other aspects related to manufacturing service. Once the solution is composited, it will be delivered to demanders automatically.

The platform consists of four layers:

- Resource Layer - enveloping the resources compulsory for the platform, including manufacturing resources and customer demands and their virtual mapping information;
- Infrastructure Layer - the hardware environment of the platform, comprising of cloud servers, cloud database, Internet/ Intranet.
- Global Service Layer- coalescing all task processing procedures into an integrated intelligent package, including order processing, resource retrieval and matching, manufacturing resources monitoring, service quality evaluation and data security protector.
- Application Layer- an interface between users, i.e. service demanders and service providers, and the platform. The interface to service demanders offers a toolkit for product design optimization and service provider selection. The interface to service providers can be used to aid in manufacturing simulation and manufacturing process optimization.

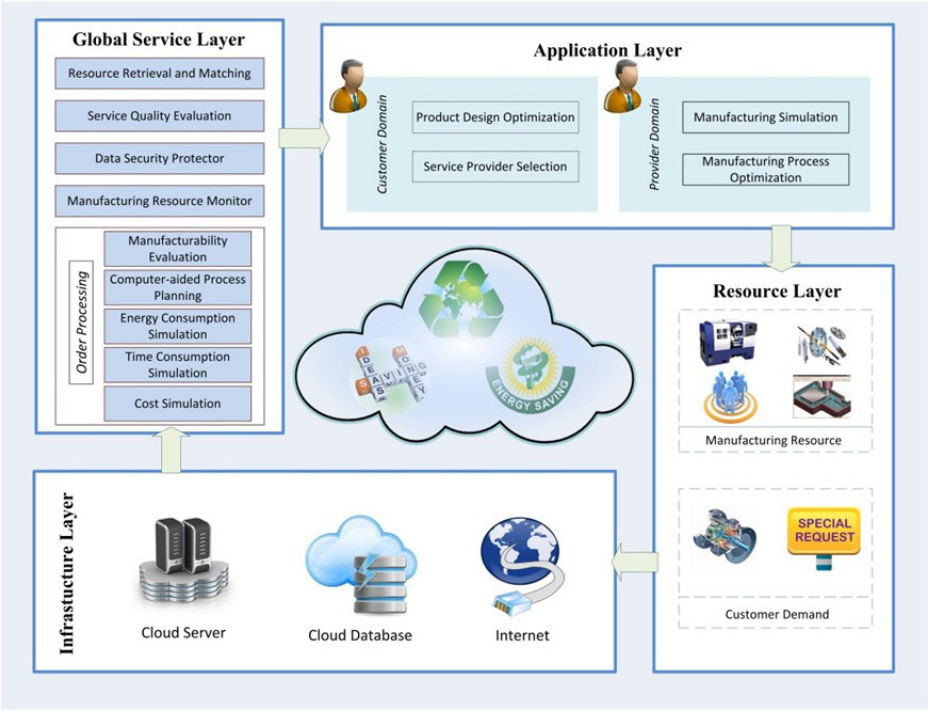

Figure 5 A Sustainable Manufacturing Cloud- solution for rapid development of customized products

Intelligence, user experience, and resource sharing are enhanced in this platform by providing a one-stop service, from product design to product delivery. Having the capabilities common to Cloud Manufacturing systems, this platform is seen as an ideal and mature scenario when implementing Cloud Manufacturing. With this platform, customized products fabrication, environment protection and energy saving can be achieved.

Some substantial impacts on industry may emerge with the proposed platform. Traditional industry companies can be classified into three categories, that is, companies only engaged in product design, companies only engaged in fabrication, and companies engaged in both. By implementing this platform, the boundary between these companies would be more explicit, as the division of work throughout the life cycle of product development becomes more distinct as enabled by Cloud Manufacturing. In the long run, companies that used to carry out both design and fabrication would evolve into ones that either undertake design or fabrication according to their expertise. An industry network consisting of heterogeneous nodes, being either design agencies or fabrication workshops, facilitates products customization and user experience improvement from the customer side, and service upgrade and product innovation from the service provider side.

4. Research into the Concept of Cloud Manufacturing

Cloud Computing is emerging as one of the major enablers for the manufacturing industry, transforming its business models, helping it align product innovation with business strategy, and creating intelligent factory networks that encourage effective collaboration. This pay-by-use scenario will revolutionize manufacturing in the same way that the Internet did to our everyday and business lives. Manufacturing shops are starting to take advantage of cloud computing because it simply makes good economic sense. Two types of Cloud Computing adoptions in the manufacturing sector are suggested, manufacturing with direct adoption of Cloud Computing technologies and Cloud Manufacturing – the manufacturing version of Cloud Computing.

In terms of direct adoption of cloud computing in the manufacturing sector, the key areas are around IT and new business models, e.g. pay-as-you-go, production scaling up and down per demand, and flexibility in deploying and customizing solutions. The HR, CRM, and ERP functions may benefit from using some emerging PaaS. Cloud Computing can be effective in offering Business-to-business solutions for commerce transactions between businesses, such as between a manufacturer and a wholesaler, or between a wholesaler and a retailer.

Moving from production-oriented manufacturing to service-oriented manufacturing, Cloud Manufacturing can offer an attractive and natural solution. In 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. The Cloud Manufacturing service platform performs search, mapping, recommendation and execution of a service. Two main types of manufacturing resources can be considered at the manufacturing resource layer, manufacturing physical resources and manufacturing capabilities.

A Cloud Manufacturing platform is proposed. This platform is designed to facilitate the rapid development of customized products. It is envisioned as the future business model and implementation strategy for Cloud Manufacturing. Customized and original requirements can be easily realized, compared with traditional manufacturing practices. The proposed platform offers new opportunities, especially for SMEs. With an industry network consisting of heterogeneous nodes, being either design agencies or fabrication workshops, product innovation and customization can be achieved with minimum investment and effort.

It can be anticipated that Cloud Manufacturing will provide effective solutions to the manufacturing industry that is becoming increasingly globalised and distributed. Cloud Manufacturing means a new way of conducting manufacturing businesses, that is everything is perceived as a service, be it a service you request or a service you provide.

References

[1] Pallis G. Cloud computing: the new frontier of internet computing. IEEE Internet Computing 2010:14:5: 5562494:70-73.

[2] Foster I, Zhao Y, Raicu I, Lu S. Cloud comput¬ing cloud computing and Grid computing 360 degree compared. In: Grid Computing Environments Work¬shop (2008)

[3] X. Xu. "From cloud computing to cloud manufacturing". Robotics and Computer-Integrated Manufacturing. Vol. 28 No. 1 (2012) pp 75–86
[4] Heinrichs W. Do it anywhere. IEE Electronics Systems and Software 2005:3:4:30-33.
[5] Venkatesh S, Odendahl D, Xu X, Michaloski J, Proctor F, Kramer, T. Validating Portability of STEP-NC Tool Center Programming. 2005 ASME International Design Engineering Technical Conferences & Computers and Information In Engineering Conference, Hyatt Regency, Long Beach, California September 24-28, 2005. IDETC/CIE 2005, DETC2005-84870, CIE-3-1. 3:A:285-290
[6] Manenti P. Building the global cars of the future. Managing Automation. 2011:26:1:8-14.
[7] Zhang L, Luo Y-L, Tao F, Ren L, Guo H. Key technologies for the construction of manufacturing cloud. Computer Integrated Manufacturing Systems, CIMS 2010:16:11:2510-2520.
[8] Guo H, Zhang L, Tao F, Ren L, Luo YL. Research on the Measurement Method of Flexibility of Resource Service Composition in Cloud Manufacturing. Proc. of Int. Conf. on Manufacturing Engineering and Automation (ICMEA 2010), Guangzhou, China, Dec. 10-12 2010
[9] Brecher C, Lohse W, Vitr, M. Module-based Platform for Seamless Interoperable CAD-CAM-CNC Planning. In: XU, X. W., NEE, A. Y. C. (eds.) Advanced Design and Manufacturing Based on STEP. London: Springer. 2009
[10] Brecher C, Vitr M, Wolf J. Closed-loop CAPP/CAM/CNC process chain based on STEP and STEP-NC inspection tasks. International Journal of Computer Integrated Manufacturing. 2006:19:570-580
[11] W. Terkaj, G. Pedrielli, M. Sacco, Virtual Factory Data Model, in: Proceedings of the Second International Workshop on Searching and Integrating New Web Data Sources (VLDS 2012), Istanbul, Turkey, 2012.
[12] A.L.K. Yip, A.P. Jagadeesan, J.R. Corney, Y. Qin, U. Rauschecker, I. Fraunhofer, A Front-End System to Support Cloud-Based Manfuacturing of Cutstomized Products, in: Proceedings of the 9th International Conference on Manufacturing Research ICMR 2011, 2011.
[13] O.E. Ruiz, S. Arroyave, J. Cardona, EGCL: An Extended G-Code Language with Flow Control, Functions and Mnemonic Variables, World Academy of Science, Engineering and Technology, 67 (2012) 455-462.
[14] Abdul-Ghafour, S., Ghodous, P., Shariat, B. Integration of product models by ontology development. Proceedings of the 2012 IEEE 13th International Conference on Information Reuse and Integration, IRI 2012, art. no. 6303057, pp. 548-555.