Cloud-based Manufacturing Ecosystem – application development

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Abstract

Cloud computing enables offering of manufacturing services over the Internet. Manufacturing related transactions such as product data, order data, production planning and status updates can exchange in the network. Close to real-time information provided by manufacturing portals can create manufacturing ecosystems, where machine owners, product designers and customers may collaborate and compete. This paper reviews potential models for cloud based manufacturing ecosystems and presents possible implications for practice. A prototype model of CloudEcosystem is presented.

Keywords
Manufacturing ecosystems, virtual enterprise, supply chain management, cloud manufacturing.

1. Introduction

The advances in cloud technology enable new models of collaboration and competition in the field of manufacturing and supply chains (Ren et al 2015; Wu 2013). Manufacturing oriented portals are being introduced for exchange of production related data and transactional information related to managing the supply chains (Hao et al 2013). Developments in Industry 4.0, Internet of Things (IoT) and Internet Plus have connected the manufacturing machinery to the cloud and many companies are currently testing business potential of portals (Huang 2013). The objective is very often to achieve responsiveness, robustness and resilience for the global manufacturing (Kristianto, et al 2015).

The concept of manufacturing ecosystems relates to networked value chains, holonic enterprises, virtual enterprises (Gunasekaran & Ngai 2004), distributed manufacturing (Fujii et al 2000) and in some extent to non-hierarchical networks (Shamsuzzoha et al. 2016). The ecosystem offers a niche for each agent to operate, form collaboration and compete (Gawer & Cusumano 2014). Apple AppStore is a well-known and often mentioned reference of a business ecosystem where a large central operator offers to smaller agents, i.e. software developers, an access to the market and simultaneously to the mobile phone end-users by using a profit sharing scheme and a process for financial transactions. In the context of manufacturing, similar aims have been presented by web portals Ponoko and 3D-Hubs.These portals can be described as manufacturing ecosystem.

This paper analyses some possibilities of cloud-based manufacturing systems by reviewing the possible practices. Based on analysis part, implications for portal design are presented. Finally, the conclusions and further research is considered.

2. Recent developments

Cloud manufacturing and manufacturing ecosystems are the two central concepts needed for developing production toward on-line real-time systems. Cloud computing and cloud based services are the enablers for conducting operations within the manufacturing ecosystem.

2.1 Cloud manufacturing

The concept of cloud manufacturing refers to use of cloud computing technologies in context of manufacturing (Xu 2012). Sub-technologies such as virtualization, service-oriented architectures (SOA), advanced computing and Internet connectivity can distinguish control logic from actual operations and execution side (Zhang et al 2014). This creates a potential driver for distributed global manufacturing.

Virtualization of objects related to manufacturing enables processing machines and components in virtual space offline and once prepared released to real-space (Verdouw et al 2015). Product design related interactions between the designers and manufacturers have been studied (Wei et al. 2013) and some authors such as Wu et al (2014) suggest that cloud-based design and manufacturing will present a new paradigm. Distributed software architectures based on open interfaces such as SOA can enable the use of distributed computing resources (Tao et al 2011).

The concept Manufacturing as a service (MaaS) is about introducing manufacturing related services which can be offered in a cloud to complete a task. Examples of applications presented in recent related studies include:

- Selling machine capacity (e.g. 3D printer) online (Wu 2015).
- Providing visibility for supply chain collaboration (Manthou et al 2004; Luo et al 2011)
- Production planning and scheduling as a service (Helo & Hao 2017)
- Manufacturing execution system serving multiple factories (Helo et al 2014)
- Collaborative delivery of customized products (Shamsuzzoha et al 2015).
- Collaborative smart process monitoring (Shamsuzzoha et al 2016)

2.1 Manufacturing ecosystems

Economy and biology have many common features. Rothschild (1990) introduced a concept of bionomics and described economy with transactions between agents as a business ecosystem. Authors such as Basole et al (2015) have studied such dynamics by analyzing which companies operate with each other and what kind of network is the result of dynamic behavior.

Digitalization has brought new aspect on business ecosystems as network formation, transactions and deformations can occur in the cloud. This can be referred as digital business ecosystems (Nachira et al 2007). The cases of Apple AppStore and Google Play stores are famous examples combining the development forces from the market with mobile phone users. Enabling a trusted access and transaction mechanisms from both sides has driven the service innovation (Eaton et al 2011).

Manufacturing ecosystems can be considered as a subset of digital business ecosystems. Similar kinds of structures of control and generativity probably take place as in other digital ecosystems. Some well-known implementations are based mainly on additive manufacturing and 3D printers, but interest is growing to other areas as well:

- 3D Hubs – A privately held company offering more than 6000 3D printers around the world
- Thingiverse – A website for sharing user-created designs for printing, milling and laser cutting
- Ponoko – an online manufacturing service for small scale production
- Autodesk Forge – cloud based software platform for manufacturing and product design
- OnShape – A cloud-based CAD system with API and solution providers for manufacturing

The experiences from small batch production in additive manufacturing has shown some things that traditional manufacturing should consider as well. Distributed manufacturing and digital ecosystems require mechanisms for intellectual property protection and mechanisms to support trust (Kurfess & Cass 2014).

3. Analysis of ecosystem types

3.1 Method

A two-stage multiple case study was conducted among metal manufacturers and requirements for an online subcontracting platform was collected in interviews (Boldosova 2015). Based on the results from this study a solution proposal has been developed to fulfil the requirements of such collaborative manufacturing portal. The developed prototype of CloudEcosystem has been implemented to demonstrate some key features.

3.2 Portal types for manufacturing ecosystems

Three main types of manufacturing ecosystem portals have been identified. The main difference of the types is based on value chain position. Each ecosystem portal is hosted by different focal company in the value chain. The types are (1) manufacturer-customized portals, (2) general open manufacturing portal, and (3) machine builder portal.

Type I: Manufacturer-customized portals

Manufacturer portals are hosted by manufacturing companies and host a single manufacturer at the time. Relationship to customer placing an order is dyadic. There are no other participants in the transactions and the value chain is controlled by the manufacturer. The main benefit of using cloud technology is to automatize and systemize the communication process. The process is initiated by placing and order by using:

- Parametric products, which are licensed designs available for customers
- Uploading own models to getting an instant quote
- Buying products which have existing designs or past order history

Benefits for both entities include the following:

- Keeping company identity and customization according to the manufacturer
- Automated price/cost online calculators
- Cost and time savings with online CAD/CAM and order placing mechanisms
- Automated order flow systems

Type II: General open manufacturing portal

General open manufacturing portals are hosting manufacturing services for multiple manufacturers. Technically the cloud system needs to be multi-tenant. For an end-user, this combines offering of several potential manufacturers into a virtual manufacturing portal, where capabilities and capacity may be evaluated with past performance and current pricings. Benefits for the manufacturer are:

- Possibility to increase customer basis
- Platform for automated price/online cost calculator
- Cost and time savings in market communication
- Automated order flow system

For the end user placing orders into the portal the benefits include:

- A possibility to choose from a variety of manufacturers to make an order
- Evaluation of design in terms of manufacturing prices

Type III: Machinery provider portals

In type III, the manufacturing ecosystem is hosted by the company providing machinery. The system is multitenant and the ecosystem is built around the similar machinery located at different manufacturers locations. Machinery provider can offer specific services around the solution including: capacity leasing services, remote monitoring, maintenance services and remote advisory services. When machinery utilization is low, capacity may be leased to other portal members according to smart contracts.

3.3 Synthesis

The purpose, customer focus and main functionality varies on each of the three main types. Type I portals aim for adding sales by simplifying the customer process; Type II portals can profit by selling virtual capacity from the ecosystem and offering cost competitive solutions for small batch manufacturers. Type III portals can focus on capacity leasing and fractional ownership of assets within the ecosystem. Table 1 shows purpose, customer focus and key functionality for each the ecosystem portal type. Based on these, a set of requirements is presented and functionality for ecosystem software design is presented.

Table 1. Portal types for connected manufacturing.

	Type I: Manufacturer portal	**Type II: General open manufacturing portal**	**Type III: Machine provider portal**
Purpose	Add sales; reduce time for offer and order handling Sell parametric product	Make profit by selling virtual capacity	Enable machine sales; Leasing
Customers	Existing customer basis (and new ones)	Makers, small batches	Machine owners who cannot afford to own machinery capacity
Functionality	Offer, order intake	Online pricing, selling designs orders, feedback, payments	Tool for monitoring actual use

4. CloudEcosystem - Prototype system design

CloudEcosystem is a prototype reference implementation for manufacturing ecosystem portal. Each portal type presented have own characteristics and requirements for implementation. The common parts include functionality of managing users and their roles, managing the asset hierarchy of machinery and process for order-fulfilment. In order to test the requirements, CloudEcosystem prototype system was designed to highlight needed features of cloud-based ecosystem.

The first phase was to map a service blueprint diagram to demonstrate process steps at both customer end-user side as well as the operations side completing the manufacturing related activities. Figure 1 shows an example of service blueprint with line of interaction and line of visibility between these two sides. In the first stage, the end-user draws the model and uploads it to manufacturing portal. Model validations can be performed automatically or manually in CAM to ensure manufacturability of the product model. The main outcome is the cost estimate which should be generated quickly by each potential manufacturing entity (company, factory, machine). The end-user can then compare possible solution providers and place an order. An order confirmation is generated by using default delivery times or queried from external productional planning system. Sales order goes to production queue and status updated can be delivered to end-user to show transparency and visibility of the supply chain. Finally, upon delivery, a message to invoicing service is launched.

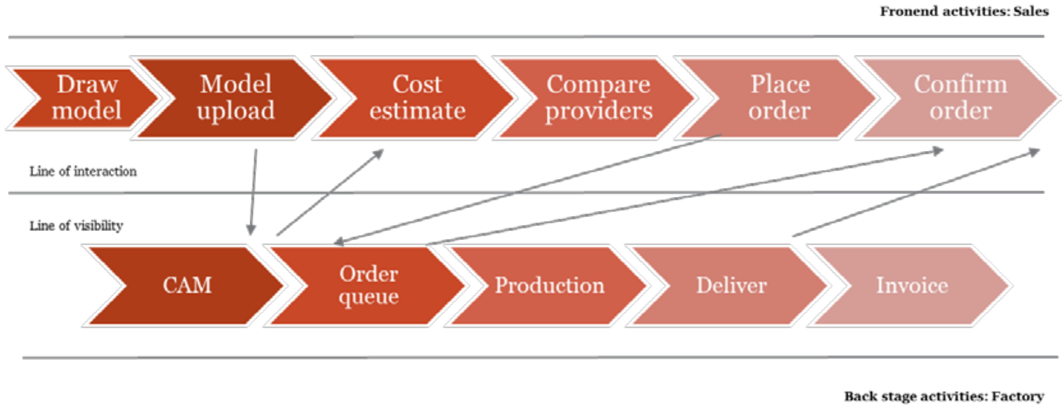

Figure 1. Service blueprint of manufacturing order fulfilment.

From software engineering perspective, this functionality (described in context of figure 1) is needed for both manufacture portal as well as generic open customer portal case. Similar software components can be used in both configurations. Figure 2 illustrates the user groups and high level use case groups for such system. The main user groups are:

(1) End-customer placing manufacturing orders and comparing manufacturability options
(2) Designers creating new products for marketplace to be licensed
(3) Factory manager managing the order-fulfilment
(4) Machine provider maintaining and monitoring proper machinery use

This architecture running on the cloud platform enables various configurations. Each manufacturer may have its own portal and offer functionality for order-fulfilment, on the other hand a generic open manufacturing portal can query prices from each factory and offer visibility toward the end-customer.

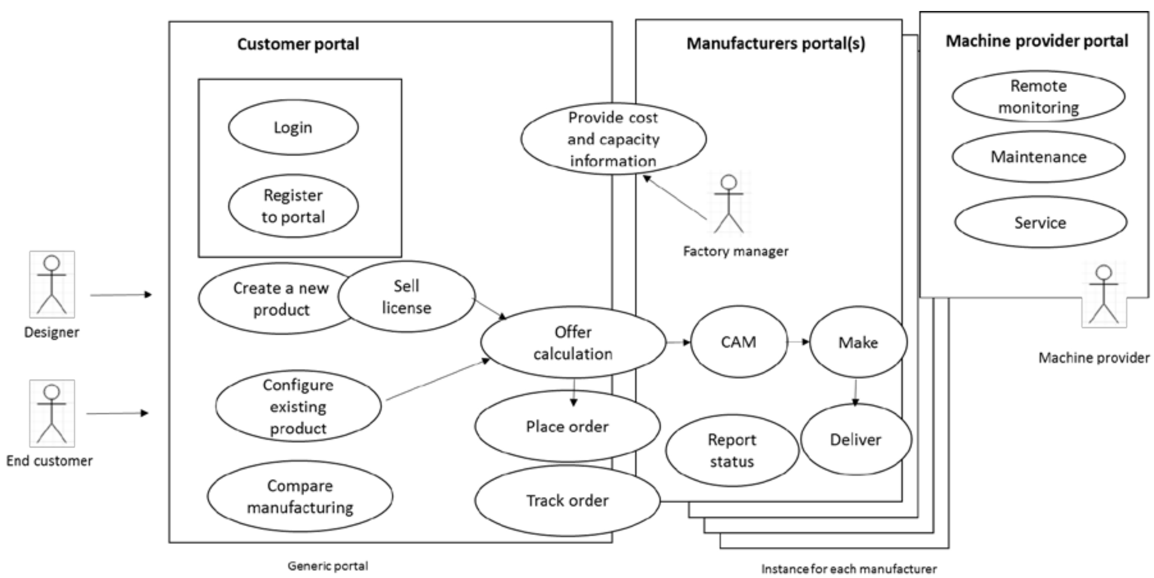

Figure 2. Use cases and functionality.

Figure 3 shows user interface screenshots from the initial prototype version which would be able to complete the process from user authentication, design upload or selection, price estimation, comparison of manufacturers and order placement. Part geometry can be visualized, parameterized and limited edits are possible as well. Confirmed orders are tracked and information about the supply chain updates is kept in the portal. Manufacturing assets can be presented in hierarchy or linked together to form a line type of layout for the delivery.

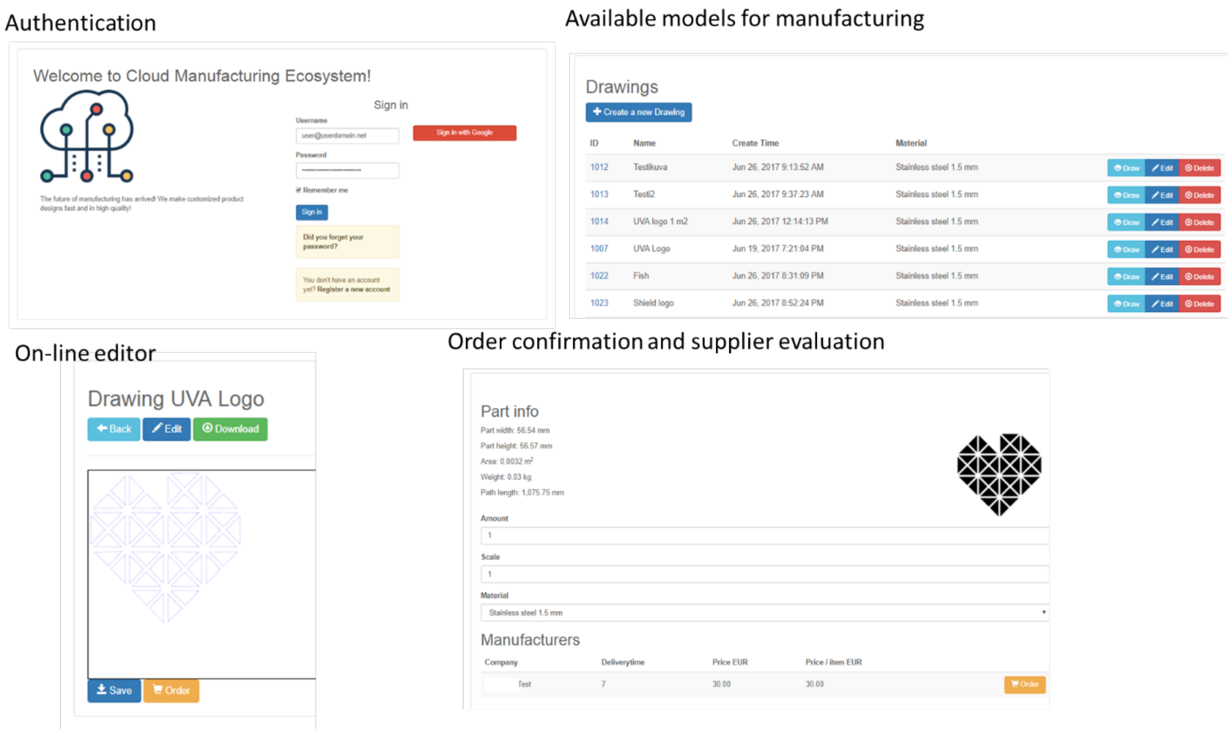

Figure 3. User interface mock-up of a manufacturing portal.

Figure 4 illustrates a simplified entity-relationship domain model which may link the needed elements for both portal types. The left part of the diagram shows the parts that need to be stored centrally and the right part the elements which are maintained by each manufacturer in the ecosystem case. This structure allows sharing the load among several server computers and keeping manufacturer related sensitive information stored in a separated location.

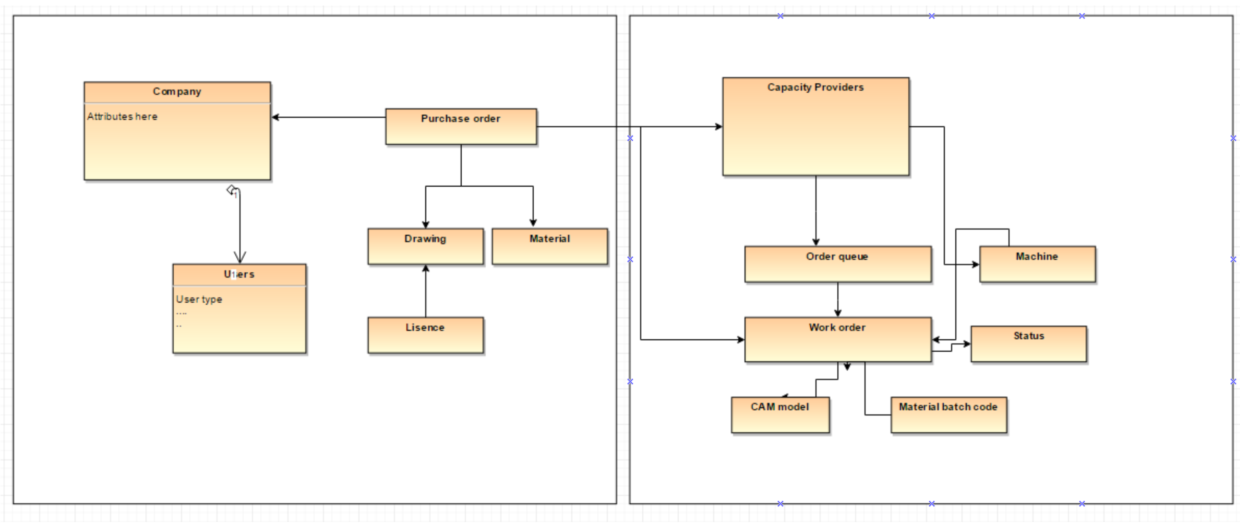

Figure 4. Domain model of interactions between manufacturer and generic portal.

The transactions between customer portal and service provider can be implemented by using SOA. The software components completing the task can be distributed on different computers. Figure 5 shows an example of communication flow needed to process the tasks from cost estimate request to order completion.

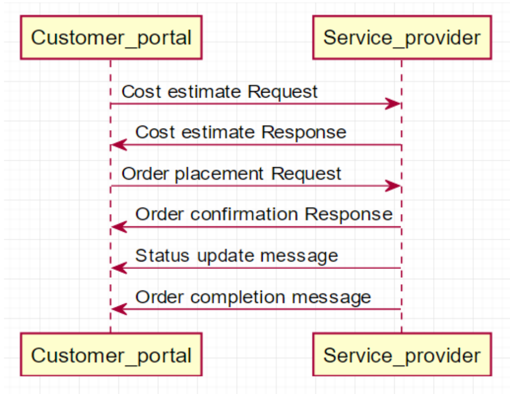

Figure 5. Transactions between customer portal and service provider.

5. Conclusions

Scalable cloud based computing infrastructures empower building multi-tenant manufacturing environments with functionality supporting ecosystem like interaction. Current leading industrial solutions are coming from additive manufacturing domain as many supporting software has been built on cloud from the beginning. Similar functionality can be built to support traditional manufacturing processes such as cutting, milling, extruding, welding and assembly operations in various industries. The experiences from 3D printing and other advanced digital manufacturing should be enhanced for other manufacturing technologies.

The CloudEcosystem prototype model designed shows that a generic data model support the key requirements for three different portal types. The main challenges are handling the interactions between customers, designers and manufacturers in a common system and provide a mechanism for handling product design, order fulfilment and quoting processes in an efficient and automated way. Cloud based architectures allow an efficient “manufacturing as a service” infrastructure with separation of multi-tenant global part with factory level software entities. Three identified portal types are all possible scenarios for implementing manufacturing as a service.

Further research should be paid on techniques supporting manufacturing license handling and safe intellectual property rights in a distributed ecosystem. Linkage to financial side such as invoices, letters of credits, escrow systems and payments is also interesting and present some key characteristics in mobile phone ecosystems. In the future, these functionalities should be tested in real environments for all three ecosystem types.

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Biography

Petri Helo is a Research Professor of the Logistics Systems Research Group at the University of Vaasa, Finland. He received his PhD in Production Economics from the University of Vaasa, Finland in 2001. He is also involved in developing logistics information systems at Wapice Ltd. as a partner. His area of expertise is the use of information technology in the supply chains. He has published several research papers in international journals and conference proceedings.

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Rayko Toshev received his MSc Management of Information Technologies from Sofia University, Bulgaria and MSc International Finance and PhD in Industrial Management degrees from University of Vaasa, Finland. He is currently acting as a project researcher in cooperation with TEKES – the Finnish Funding Agency for Technology and Innovation and is teaching operation strategies, technology management and ERP-SAP courses at University of Vaasa. Rayko is currently working with advanced manufacturing technologies including 3D printing and VR/AR applications for operations.