Computers & Industrial Engineering 117 (2018) 60–70

Contents lists available at ScienceDirect

Computers & Industrial Engineering

journal homepage: www.elsevier.com/locate/caie

A delayed product differentiation model for cloud manufacturing

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ARTICLE INFO

Keywords:
Cloud manufacturing
Delayed product differentiation
Inventory management
Postponement

ABSTRACT

Cloud manufacturing (CMfg) enables in-depth customization but raises demand uncertainties. Delayed product differentiation (DPD) is one attempt to solve such problem. However, current DPD approaches are mostly focused on the production of a dominant company, which tend to hold the supply chains with fixed network structures. Nevertheless, CMfg requires more flexible structures (agile supply chain) to facilitate multiple manufacturers to access external resources with various manners. Therefore, linking DPD to CMfg becomes an important research topic, and the paper proposes an optimization model, namely DPDCM, for such purpose. The model is established on the basis of integrating the order-release, generic inventory and sourcing decisions, and is formulated as an integer programming problem, to meet diverse requirements of companies for carrying out DPD in CMfg environment. Case studies on bicycle and industrial-transformer manufacturing have been applied and analyzed, in which genetic algorithm is adopted to obtain near-optimal solutions. It validates the effectiveness, flexibility and universality of DPDCM.

1. Introduction

Cloud manufacturing (CMfg) has recently become popular in manufacturing industry. By virtualizing physical resources as consumable services over the Internet, CMfg creates an integrated, distributed, and service-oriented manufacturing paradigm (Xu, 2012), in which the users (service demanders) – either the original equipment manufacturers (OEMs) or suppliers – can connect to the desirable services via cloud-based applications (see Fig. 1). It enables agile supply chain, of which the network structure is unfixed, in opposite to the conventional supply chain (Wu, Greer, Rosen, & Schaefer, 2013; Jassbi et al., 2016). Under such flexible environment, the manufacturing firms (service demanders) become more accessible to external resources and capabilities, and capable of delivering more in-depth customization solutions (Yu & Xu, 2015). However, the demand uncertainty is highly increased at the same time, which hurts the manufacturing efficiency. Hence, to provide higher varieties of products with efficiency, delayed product differentiation (DPD) is one attempt for CMfg.

DPD means to delay the final customization of a product (the point of differentiation) as much as possible, usually until the arrivals of customer orders, to reduce the manufacturing lead time (Lee & Billington, 1994). It normally divides the entire manufacturing procedure into two stages – generic and customization stages (Li & Tang, 1997; Skipworth & Harrison, 2004). Taking a microwave radio product for example, the microwave units and filters (generic goods) are made at the generic stage, while the radio frequencies (customized goods) are specified at the customization stage (Olhager, 2010). Researchers have proved the effectiveness and practicability of DPD for traditional manufacturing operations (e.g., He, Kusiak, & Tseng, 1998; Song & Kusiak, 2010; Su, Chang, Ferguson, & Ho, 2010; Trentin, Salvador, Forza, & Rungtusanatham, 2011), but so far few has studied the application of DPD to CMfg.

This paper focuses on the formulation of delayed product differentiation for cloud manufacturing (DPDCM). According to the main characteristics of CMfg compared to the traditional manufacturing patterns, DPDCM, on one hand, must be universal enough to fit various types of manufacturing firms (either OEMs or suppliers). On the other hand, it should be flexible enough to satisfy the agile supply chain. Therefore, DPDCM is formulated on the basis of the following key decision strategies.

1. *Order-release decision*: The size of order-release influences the economic lot sizing of the customization stage. It is one of important factors for optimal production. Most current DPD models tend to force the orders to be released one after another at customization stage (e.g., Gupta & Benjaafar, 2004; Su, Chang, & Ferguson, 2005),

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https://doi.org/10.1016/j.cie.2018.01.019
Received 6 January 2017; Received in revised form 7 November 2017; Accepted 22 January 2018

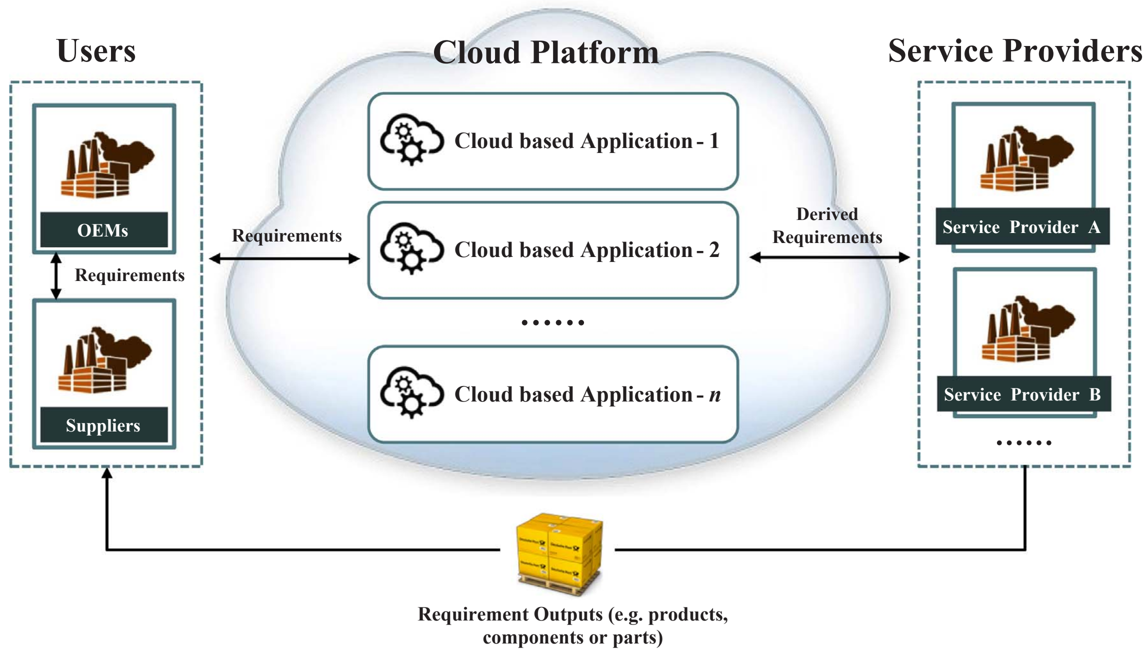

Fig. 1. Supply chain of cloud manufacturing (Wu et al., 2013).

which are fit for the pattern of single-piece production (SP), but fail to satisfy the manufacturing firms inclining to adopt batch production (BP) pattern (e.g., Yu, Ji, Qi, Gu, & Tao, 2015). Hence, to be applicable to multiple manufacturing firms regardless of their applied production patterns, DPDCM should integrate both SP and BP patterns at customization stage and offer the optimal order-release size.

2. *Generic inventory decision:* Manufacturing firms, even the same manufacturer at different manufacturing periods, may confront orders with various due date constraints (e.g., urgent or normal orders), restricting the manufacturing lead times. To universalize the DPDCM to satisfy any due date constraint, using a constantly deterministic generic inventory filled with work-in-process (WIP) items as most traditional models do (e.g., Caux, David, & Pierreval, 2006) becomes inadequate. For urgent orders, it might be better to eligibly stock some additional WIP items than to simply raise the inventory level. For example, storing some already colored parts (e.g., green, red and blue parts) in generic inventory, instead of the generic un-colored parts that needs further colorin, can save the coloring time at customization stage to meet the urgence. Hence, the feasibility of the adjustable generic inventory in DPDCM is studied.
3. *Sourcing decision:* Thanks to the agility enabled by CMfg, manufacturing firms are able to seek or change supply chain partners with a much more convenient manner than ever before. DPDCM tends to increase the flexibility of sourcing decision, helping the manufacturers to optimally determine what to make or not (purchasing from the suppliers) according to their real time production conditions. The validity of such strategy carried out in DPDCM is analyzed.

In conclusion, DPDCM integrates these three decision strategies to ensure the universality and flexibility of DPD applied to CMfg environment. A genetic algorithm (GA) is implemented to seek for near-optimal solutions. The rest of the paper is organized as follows. Section 2 reviews the related literature. DPDCM is explained in Sections 3 and 4. Case studies of bicycle and industrial-transformer manufacturing are given in Section 5, followed by the relevant discussion in Section 6. Section 7 concludes the paper and suggests future work.

2. Literature review

2.1. Cloud manufacturing

Manufacturing is enabled by information and computer technologies (ICT). CMfg is a relatively new manufacturing concept driven by cloud computing (Xu, 2012). Compared to traditional ICT-enabled manufacturing technologies, such as computer integrated manufacturing (CIM) and distributed manufacturing (DM), the distinguished characteristic of CMfg is service-oriented, which virtualizes the manufacturing resources as consumable services (Adamson, Wang, & Holm, 2013; Li et al., 2010; Wu et al., 2013; Xu, 2012). According to this feature, Xu (2012) defines CMfg 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 released with minimal management effort or service provider interaction*".

By far most researchers focus on the formulation of CMfg architecture, platform, model, and framework, attempting to achieve a functional system (e.g. Wang & Xu, 2013; Lu, Xu, & Xu, 2014). Plenty of service-oriented systems with various layer structures are proposed for different requirements and circumstances, such as the 3-layer (e.g. Liu & Jiang, 2012), 4-layer (e.g. Xu, 2012), 5-layer (e.g. Li, Hu, Wang, & Zhu, 2011) and 6-layer (e.g. Xiang & Hu, 2012) systems.

Moreover, some studies are more centered on the service paradigm of CMfg to lead to advanced service-oriented manufacturing, such as the research of service encapsulation and combination (e.g. Ding, Yu, & Sun, 2012; Zhang, Zhang, Liu, & Hu, 2015; Chen et al., 2016) and service planning and scheduling (e.g. Laili et al., 2013; Yu, Zhang, Xu, Ji, & Yu, 2015) for CMfg. For details, please refer to the recent reviews, including Adamson et al. (2013) and Wu et al. (2013).

To sum up, most articles mainly pay attention to the high-level operations of CMfg (i.e. service-oriented architecture and management), while few concerns the low-level operations, such as the production level, representing the execution and realization of the manufacturing services. This paper aims to fill the gap, by proposing DPDCM.