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Manufacturing in the cloud: A human factors perspective

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ABSTRACT

Cloud manufacturing adopts a cloud computing paradigm as the basis for delivering shared, on-demand manufacturing services. The result is customer-centric supply chains that can be configured for cost, quality, speed and customisation. While the technical capabilities required for cloud manufacturing are a current focus, there are many emerging questions relating to the impact, both positive and negative, on the people consuming or supporting cloud manufacturing services. Human factors can have a pivotal role in enabling the success and adoption of cloud manufacturing, while ensuring the safety, well-being and optimum user experience of those involved in a cloud manufacturing environment. This paper presents these issues, structured around groups of users (service providers, application providers and consumers). We also consider the issues of collaboration that are likely to arise from the manufacturing cloud. From this analysis we discuss the central role of human factors as an enabler of cloud manufacturing, and the opportunities that emerge.

1. Introduction

Cloud computing offers ubiquitous, on-demand access to shared computing resources that can be rapidly released with minimal effort or service provider interaction (Mell and Grance, 2009). It is most commonly encountered in the use of cloud-based servers where data is no longer stored locally on a dedicated machine, but 'in the cloud' on 'rented space' on remote, distributed servers. Many organisations, including those within the manufacturing domain, now use these external providers as their main mode of data storage and transfer. In addition, cloud computing supports the 'software as a service' (SAAS) model (Armbrust et al., 2010), allowing organisations to move from hosting their own software through to using a shared pool of applications that are hosted, managed and maintained remotely by third parties. This approach can hugely reduce maintenance costs and logistics associated with upgrades, and has been adopted in manufacturing through systems such as cloud-based Enterprise Resource Planning (ERP) applications (Lenart, 2011).

The notion of cloud computing applied to manufacturing is set to evolve with the emergence of cloud manufacturing (Rauschecker et al., 2011; Tao et al., 2011; Xu, 2012; Wu et al., 2013). Wu et al. (2013) define cloud manufacturing as "a customer-centric manufacturing model that exploits on-demand access to a shared collection of diversified and distributed manufacturing resources to form temporary, reconfigurable production lines which enhance efficiency, and reduce product lifecycle costs" (p. 565). Cloud manufacturing moves beyond the idea of simply using cloud computing resources within a manufacturing context, proposing the use of remote, virtualised manufacturing resources, and the sharing of a single manufacturing resource between multiple users, thus delivering 'Manufacturing as a Service' (MAAS) (Rauschecker et al., 2011). In this manner, manufacturing services, including design, simulation and other knowledge-based processes (Tao et al., 2011), can be used on a 'pay-as-you-go' basis.

This new manufacturing paradigm aims to provide heightened levels of quality and value for consumers of manufacturing services, and allows manufacturing service providers to engage in new, flexible arrangements leading to better utilisation of capabilities. It also allows consumers to use third-party manufacturing services without the upfront capital expenditure costs that might otherwise prove prohibitive.

These changes require technical innovation and process change, such as new skills and knowledge to support high flexibility production and assembly, new requirements for user interfaces and user experience of those interacting with cloud manufacturing technology, new forms of technology-mediated collaboration across the supply chain, and a shift in the role of the 'customer' of

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products as their requirements and usage patterns have a more direct influence on design. The individual and integrated effects of these changes on the distributed cloud manufacturing system are, as yet, unknown but are areas that human factors as a discipline is well placed to address.

In this paper we examine the human factors challenges presented by the adoption of cloud computing paradigms within the manufacturing context. We identify the different design and implementation challenges presented by these new forms of work and production and, where possible, suggest existing knowledge or approaches that could be used to address these challenges. This analysis identifies a set of research issues that must be addressed, and principles to be followed. These principles are necessary for the benefits of cloud concepts within manufacturing, and on resulting products, to be realised to maximum effect whilst maintaining a healthy, safe and effective work environment. By providing a structured, multi-user view of human factors issues, this paper contributes a framework for successful, human-orientated cloud manufacturing implementations, and sets out a research agenda for future human factors work within this domain.

2. Human factors and manufacturing in the cloud

Cloud manufacturing is defined as a relationship between the consumer and a flexible array of production services, managed by an intervening architecture that can match service providers to product and manufacturing processes (Tao et al., 2011; Wu et al., 2013; Xu, 2012; Macia-Perez et al., 2012). Cloud manufacturing definitions typically make explicit or imply three groups of actors: *consumers*, who request and use cloud manufacturing processes; *application providers*, who provide the software to enable the manufacturing cloud and associated ICT, and *service providers* who provide, own and operate the manufacturing services. This is represented in Fig. 1.

Through standardised descriptions of products, processes, tooling etc., used to match product requirements to service providers' capabilities (Xu, 2012), product requirements are mapped to a temporary supply chain. While consumer requirements will include product specifications, they may also include specifications of quality, cost, speed of delivery or specific organisational requirements (e.g. for security in cases of products with high commercial sensitivity or military products) (Tao et al., 2009). Likewise, service providers would express their capabilities not just in terms of their ability to physically manufacture products, but also in a number of other criteria relevant for effective supplier matching, such as availability or cost.

If a high number of manufacturing service providers are encouraged to register and engage with the manufacturing cloud, and it is in the interest of the application providers to make this entry process as easy as possible, there is the potential for consumers to be offered choices from a huge and rapidly configurable array of available suppliers. It is also possible that configurations will be nested. For example, a provider of a sub-component for a customer may need underpinning capabilities such as design or simulation services (Wu et al., 2013). For complex products, it is therefore conceivable that there are many layers of manufacturing clouds.

The notion of cloud manufacturing will inevitably change how people work in a manufacturing setting, how they interact within and between organisations, how producers and production lines need to adapt to fit the demands of this new environment, and how effective product design can be maintained and even enhanced within cloud manufacturing. Manufacturing will become more distributed, providing opportunities for rapidly sourcing production facilities. This new model of sharing manufacturing resources throughout the production lifecycle represents a step-change in the nature of manufacturing operations. Many of these developments have implications for how people work, how decisions are made, and how organisations will collaborate and communicate. We would consider these to be human factors challenges. Some of these critical developments that fundamentally change work and work systems are discussed below.

2.1. Concept of decentralisation of services

Cloud concepts in principle move away from a single, all-powerful, service provider to enable a combination of distributed systems. Ironically, the way in which this is so far implemented in

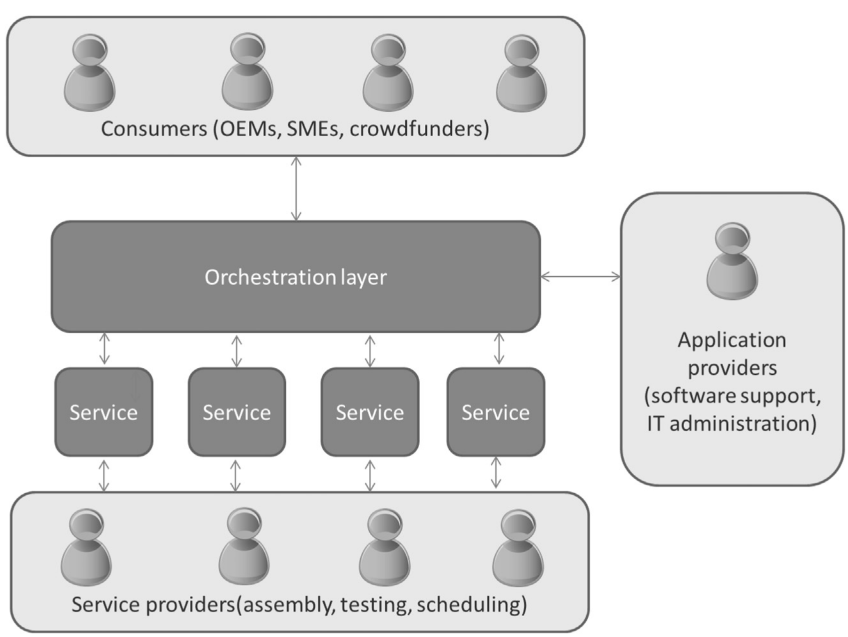

Fig. 1. Schematic of users in relation to simplified Cloud Manufacturing architecture (OEM – Original Equipment Manufacturer; SME – Small to Medium enterprise).