Impact of Cloud Manufacturing on New Product Development in the Irish Precision Engineering Sector

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ABSTRACT

The objective of the research reported here is to determine the effects, if any, of Cloud Manufacturing (CM) technology on the New Product Development (NPD) process in the Precision Engineering Sector in Ireland. The "case study" methodology is employed and applied to three progressive SMEs in the Precision Engineering sector in Ireland. The findings indicate that the firm's business processes such as sourcing internal and external resources will be affected. Supply Chain Management (SCM) processes and components, customer and supplier relationship for instance, will also be affected as their level of integration and collaboration is increased with CM. It is suggested that the plethora of capabilities that CM brings, and the more collaborative environment that it offers, will allow for fewer iterations in the design stage and for more rapid prototyping to occur. Thus, designers are better informed of customer requirements in the early stages of design culminating in products of higher quality.

ACRONYMS

SaaS - Software as a Service
NPD - New Product Development
RFID - Radio-Frequency Identification
SME - Small and Medium-sized Enterprise
SCM - Supply Chain Management
XaaS - Everything as a Service
SN - Social Network
CR - Customer Requirements
CM - Cloud Manufacturing

1. INTRODUCTION

Manufacturing is undergoing a major transformation enabled by information technology (IT) and generally referred to as the 4th industrial revolution, or the era of Industry 4.0. In that regard, CM is a major track, being a service oriented, customer centric and demand driven manufacturing model. It provides a new direction for manufacturers to innovate and collaborate across the value chain using cloud-based technologies. CM arises as a novel paradigm for enabling future manufacturing companies to deploy and manage all the manufacturing information over the network in a more collaborative environment.

Cloud manufacturing is ''a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable manufacturing resources that can be rapidly provisioned and released with minimal management effort or service provider interaction'' [1]. 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). CM proposes an efficient approach in which distributed manufacturing resources are encapsulated into cloud services and managed in a centralised way [2]. Clients can use the cloud services per their requirements. Cloud users can request services ranging from product design, manufacturing, testing, management and all other stages of a product life cycle. A CM service platform performs search, intelligent mapping, recommendation and execution of a service. CM's architecture consists of the following layers [3];

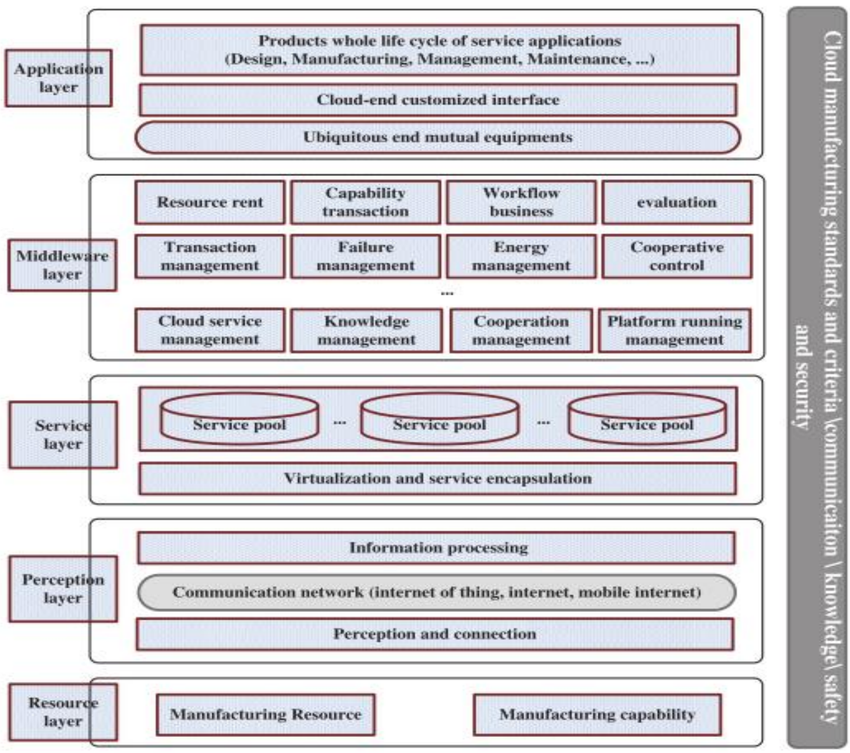

Figure 1 - CM Architecture [3]

Resource layer (R-Layer): R-Layer is the physical manufacturing resources and capabilities layer. There are two types of resources in the CM service platform, physical resources, such as equipment and computers, and manufacturing capabilities which are intangible, such as data analysis methodologies [2]. Manufacturing capabilities are expressed by the combination of manufacturing resources such as these. Any person, institute or enterprise can participate in and contribute their manufacturing resources, capabilities and knowledge to CM service platform [4]. Meanwhile, any enterprise can carry out their manufacturing activities based on these manufacturing resources, capabilities and knowledge.

Perception layer (P-Layer): P-layer is responsible for sensing the physical manufacturing resources and capabilities, enabling them to be connected into the network. The related data and information is processed by using the technologies such as RFID, the Internet of things, etc., to realise the overall connection of various manufacturing resources and capabilities.

Service layer (S-Layer): S-Layer contains virtual resources and services of CM. It is primarily responsible for the virtualisation and encapsulation of the manufacturing resources and capabilities into related cloud services and then forming the services pool. The platform can provide complete support for all tasks and processes involved in constructing and operating a virtual organisation.

Middleware layer (M-Layer): M-Layer primarily provides core functions and service supports for the operation of manufacturing capabilities and services. These include cloud service management, knowledge management, cooperation management, platform running management, transaction management, failure management, energy management and so on.

Application layer (A-Layer): A-Layer is the application layer of CM oriented various manufacturing fields and industries, which provides different specific application interfaces and related end-interaction equipment. Different users can access and use the cloud service in CM on demand.

2. METHODOLOGY

A qualitative approach is utilised here as the research is explorative in nature and aims to contribute towards new theory building. The qualitative accounts produced in case studies help to explore the data in real-life environment, and help to explain the complexities of real-life situations [5]. The multi-case study methodology is employed in this thesis, allowing for a more generic conclusion to be reached [6]. This is based on three case studies of advanced SMEs from the Precision Engineering sector in Ireland (referred to as Alpha, Beta and Zeta). Semi-structured interviews are the key data collection method employed in this study.

All interviews were recorded and transcribed, these transcripts were then sent to the interviewees for inspection, with any ambiguities being clarified ad hoc with the correspondents. Initially a within-case analysis was performed to understand the NPD process used by the firms and the potential impact that CM could have on it [7]. The data was fragmented into sub-categories and this was then categorised into the different stages of the design process. Unique patterns within each one can then emerge before they are generalised across cases. A cross-case analysis was performed to spot common themes between the cases. It will also allow enhanced generalisation of conclusions to be drawn from the cases. The design stages which would be most affected by the adoption of CM were then chosen for further examination.

3. RESULTS & DISCUSSION

3.1. Customer Interaction

By increasing the level of virtual integration of the customers in the design process, and indeed the manufacturing supply chain, certain outbound or inbound deliveries can be eliminated or overall lead time will be reduced. CM can perform

CR analysis effectively, it contains information such as relative importance ratings, competitive market analysis, engineering characteristics and so on. The GUI will display essential information with regards to the status of projects, and allow for customers to even attach a sketch of their idea, allowing the designer to give feedback and elicit more information from the customer [8]. Alpha mentioned that when they are working with customers on new products, they visit the customer on site and perform product testing with them. Alpha and Zeta adhere to the ISO9001 standard which is more customer centric than other standards. During this process, Alpha would bring several prototypes to the customer and the customer would then select the samples that best fits their needs.

With the use of SN and the networked environment that CM offers, the companies can get the correct product criteria earlier on in the design process and not waste valuable resources creating these extra samples. The expense of performing product testing on-site also wouldn't be incurred as prompt analysis of CR's will mean the product is as desired [8]. CM can alter the way that prospective customers request designs, as the intelligent search engine allows for users to submit requests for a product. Companies will find that sources of customers will vary from individual users to original equipment manufacturers (OEMs) looking for a component that is part of a larger scale product. In CM, producers will have to develop new selection criteria in the procurement of parts. The intelligent search engine allows for suppliers/companies/experts etc. to be picked with ease, however relative information regarding historical performance and capabilities is imperative as companies can't afford any interruptions in their SC operations.

3.2. IoT Technologies

Embedded services such as Intel® Curie™ or Samsung Artik™ can help designers get a better understanding of how the product is used by consumers [9]. Combining this with the CM structure means that useful information, or even resources can be easily accessed anywhere they are needed in real-time. Further information about actual, in use, lower and upper boundaries of product usage variables can be collected [9]–[11]. Intelligent prognostics for health monitoring of in-use products after a product has been sold through the adoption of IoT can feedback useful information to the R&D design stage to promote the design of next-generation products. This is something that Alpha were in the thinking process of implementing into some of their products. By utilising this technology, they would be able to see where the wear occurs most in the product over its lifetime and in turn improve the design to combat these effects on components of the product.

With complex products carrying a multitude of operation parameters, correlations of the operational parameters and product output would lead to the generation of better product configurations, thus leading to better overall performance [12]. This technology would also bring the supplier into the design process more as new materials, components etc. may need to be designed as a direct result of this analysis. Alpha and Zeta have a close relationship with suppliers, as mentioned before, they adhere to the ISO9001 standards in QA, while Zeta adheres to EASA Part 21 (G) and AS 9100 Rev C standards. Developing IoT alliances with other organisations will provide capabilities to disseminate information for generating product and process innovation. This will allow manufacturers to close the loop of the product lifecycle.

3.3. Data Analytics

IoT allows for data to be collected from sensors and devices in an unstructured form. This can be turned into usable information which can be utilised for making decisions to improve the performance of the end products. Data can be utilised to analyse historical process data, identifying patterns and relationships among process types, parameters and outputs. In the product planning stage, teams can analyse customer needs, the market and clarify development tasks using IaaS and PaaS such as Amazon EC2, Salesforce and Google BigQuery [8], [13]. These platforms and services will allow teams to store and process the datasets to generate design requirements more effectively and efficiently. This will allow design engineers to elicit customer requirements and preferences using the cloud-based analytical tools. Giving them the capabilities to propose function structures, engineering and economic constraints in the concept design phase [13].

The growing use of software, connectivity, and analytics will increase the need for a new breed of digitally literate industrial engineers and operators with competencies in software development and IT technologies. The correspondents at Alpha, Beta and Zeta are aware of this and regularly perform employee training also regularly attend seminars on new paradigms such as 'Industry 4.0' and 'Smart Factories'.

3.4. Manufacturing Services

In terms of the NPD process, services such as 'Design as a service' and 'Simulation as a Service' will influence the procedures in place in the company [3]. Companies can employ this avenue to outsource or indeed perform the design process of new products to/for other companies depending on their expertise. The ability to outsource will mean a lot less projects get discarded because of low manufacturing process capability. Factors such as this will have to be taken into consideration when determining the cost of a project.

Alpha, Beta and Zeta have designers with high levels of expertise in simulations, analysis etc. Users in CM can take advantage of these capabilities by outsourcing the projects to the respective service providers, saving time and money on design procedures. Current procedures will be altered slightly as inbound requests for design or simulation will come up for 'tender' in the cloud and depending on the capacity of the prospective design team they can accept this request.

3.5. Virtual Reality

The advent of VR and its use in the cloud promises to influence how conventional design processes are carried out, particularly in the concept generation stage on collaborative designs [14], [15]. VR technology provides an integrated, interactive, immersive and intuitive environment that is excellent for the visualised communication purpose. It allows for the visualisation of the concept design in real time and for alterations to be made to the product interactively with customers/design teams in geographically dispersed locations. The networked environment allows designers, customers and marketing analysts to communicate effectively. With the arrival of VR in the cloud, it could allow for interactive discussions to take place in a more cohesive environment.

Alpha mentioned that they had travelled to China for a railroad project to deliver samples and carry out tests on site with the customer. VR proposes to eradicate the need for long distance travelling as 3D images can be quickly transmitted in high quality to the user's screen including for use on mobile devices. Several users can share a viewpoint, design alternatives, or the VR setup in synchronisation, changing the plans of the displayed contents in a virtual space. This close collaboration with customers allows them to have more of an input on the product design in the early phases; meaning that it will be a less laborious process of sending designs over and back, and even visiting customers on site which wastes valuable time and resources in product development.

3.6. Software as a Service

Networked devices such as phones, tablets, laptops and desktops can be utilised to visualise machining simulations running on a remote server. Multiple simulations can be run concurrently on a machine and multiple clients can simultaneously watch the simulation [13], [16]. This is something that Alpha were looking to implement, being able to show customers live simulations and designs while out on site visits with them. However, issues arise with regards to software packages that don't have cloud capabilities thus needing to convert files to different software packages to utilise these capabilities as each CAD system has its own method of describing geometry, both mathematically and structurally. There will always be some loss of information when translating data from one CAD data format to another.

The use of virtualisation and multi-tenancy has the potential to allow for simultaneous concurrency in computer-aided design, engineering analysis, and manufacturing tools. Allowing users in a cross-disciplinary design team to simultaneously create and modify design features of a product [16]. This reduces time-to-market and improves product development and customer service. By shifting to an operational expense model like this for short to mid-term projects, which would be the nature of project's lifespans in CM, there are no long-term financial commitments. This 'pay-per-use' model means that companies have little need to invest much money in hiring engineering experts or purchasing manufacturing equipment [8].

Alpha and Zeta mentioned that they commonly use brainstorming methods and reverse engineering with a test facility in house, as means of generating new ideas. With CM, designers can tap into a knowledge base of previous designs for different applications and use them as sources for concept generation [3], [17]. CM provides the capabilities of intelligent search for design solutions enabled by semantic web technology and SN analysis [9], [13], [18], [19]. They can also easily source experts or crowdsourcing on the platform via mediums such as SN for their input at the conceptual stage. These factors will speed up the conceptual design process and allow for more rapid prototyping to occur, speeding up the overall time-to-market.

4. CONCLUSIONS

The findings indicate that the firm's business processes, for example SCM processes and management activities in product development will be affected. These include processes such as sourcing internal and external resources (e.g. utilising SN for expert's opinions). SCM processes and SCM components, customer and supplier relationship for instance, will also be affected as their level of integration and collaboration is increased with CM. Better strategies for design of products can be achieved due to a more accurate input database fed with data generated from the CM process. This allows for the needs of customers to be taken into consideration more when planning new products. CM has the potential to better utilise resources in the design phase and this offers the possibility for companies to alleviate the common dilemma between product variety and volume.

Furthermore, this enables them to decrease the time-to-market and overall life-span of the product development process, making the "market of one" more of a possibility. It is suggested that the plethora of capabilities that CM brings, and the more collaborative environment that it offers, will allow for less iterations in the design stage and for more rapid prototyping to occur as designers are better informed of customer requirements in the early stages of design, culminating in products of higher quality. The findings also suggest the CM technology related factors and endogenous factors are relevant groups of contingency variables. These variables help to explain the differing levels of adoption of CM technology in the NPD process.

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