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Cloud Manufacturing

Strategic Alignment between Manufacturing Industry and Cloud Computing

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Julkaisun nimike
Pilvivalmistus: valmistuksen ja pilvilaskennan strateginen linkki

Tiivistelmä

Pilvilaskenta (cloud computing) on saavuttanut suosiota viimeisen vuosikymmenen aikana monilla eri aloilla. Tämä väitöstutkimus käsittelee pilvilaskennan ja valmistavan teollisuuden välistä yhteyttä ja pyrkii osoittamaan, miten pilvitekniikan käyttö voi tukea valmistavia yrityksiä kehitettäessä kilpailukykyä.

Viime aikoina pilvivalmistusta on ehdotettu tutkimuksissa vastauksena erilaisiin valmistuksen haasteisiin, kuten esimerkiksi asiakaskohtaiset maantieteellisesti hajautetut skaalautuvat joustavat järjestelmät. Uudet teknologiat, kuten asioiden Internet (IoT) ja palveluperusteiset arkkitehtuurit (SOA) ovat integroituneet tähän älykkääseen valmistusviitekehikkoon. Monet yritykset epäröivät siirtyä pilvivalmistukseen. Tämän taustalla on osaamisen puute ja haaste linkittää liiketoiminnan ja pilvivalmistuksen strategiat.

Tämän vuoksi tutkimus keskittyy pilvivalmistuksen käsitteen ymmärtämiseen ja tarkastelee pilvivalmistuksen mahdollisia toteuttamistapoja. Seitsemän kuvailevaa tapaustutkimusta on käsitelty neljässä erikokoisessa ja eri toimialan yrityksessä. Tapauksissa on analysoitu tapoja liittyä erilaisiin pilvivalmistuksen ekosysteemeihin.

Pilvivalmistus on määritelty tässä tutkimuksessa kollaboraatioalustaksi. Yritykset tekevät yhteistyötä eri kumppanien, toimittajien ja asiakkaidenkin kanssa tavoitteenaan tietty liiketoimintamahdollisuus. Pilvivalmistusalusta (Cloud manufacturing platform-CMP) mahdollistaa valmistavien yritysten resurssien ja kyvykkyyksien jakamisen, valmistuspalveluiden jakamisen ja tukee tasapainoista yhteistyötä yritysten välillä. Strateginen yhteys näiden välille on esitetty Cloud manufacturing strategic model (CMSM)–mallissa. Tämän mallin avulla yritykset voivat mukautua erilaisiin ympäristöihin tehokkaasti ja pystyvät säätämään liiketoimintatavoitteitaan.

Asiasanat
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Cloud Manufacturing: Strategic Alignment between Manufacturing Industry and Cloud Computing

Abstract

Cloud computing is a popularly multidisciplinary term in current decade. This thesis deals with the junction of cloud computing and the manufacturing industry and shows how the cloud can support manufacturers in developing substantial competitive advantages.

Recently, cloud manufacturing is proposed in research to deal with current manufacturing challenges, such as customer-driven strategy, geographical distributed factories, and scalable and flexible manufacturing, etc. State-of-the-art technologies such as internet of things, cloud computing, big data, service-oriented architecture, etc., are integrated to uphold this intelligent manufacturing framework. However, many companies have doubts about moving to cloud manufacturing owing to their inadequate knowledge about it and a lack of skills to align their business with cloud manufacturing strategies.

Therefore, this research mainly focuses on proving a comprehensive understanding of cloud manufacturing, and investigating possible implementations of cloud manufacturing. Seven exploratory cases studies were applied in four companies in various fields and sizes to provide a conceptual approach for manufacturers to think critically about adapting their business to a cloud manufacturing ecosystem.

Cloud manufacturing is defined as a system of collaborations in this research. Companies are able to collaborate with various partners, suppliers, and even customers to fulfill a specific business opportunity. Cloud manufacturing platform (CMP) is an integrated platform that enables manufacturers to share resources/capabilities, provides manufacturing services, and also supports harmonious collaboration. A proper alignment strategy, named cloud manufacturing strategic model (CMSM) was proposed to allow companies to adapt to this environment efficiently and easily achieve their business objectives.

Keywords
Cloud computing, cloud manufacturing, strategy alignment model

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I have talked a lot about “cloud” in the past four years. Finally, the “cloud” feds away, and “Every cloud has a silver lining.” However, doctoral study is all about work hard and have fun. This is my attitude towards everything around me during this long journey.

I was thinking about this acknowledgment for a long time. But now, I am sitting here actually writing down my gratitude to the people who did help me along the way, I found the list is too long to name each of them.

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Helsinki, June 2016

Yuqiuge

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Abbreviations

B2B	Business-to-Business
CIM	Computer Integrated Manufacturing
CMP	Cloud Manufacturing Platform
CMSM	Cloud Manufacturing Strategic Model
CNC	Computer Numerical Control
CPS	Cyber Physical System
CRM	Customer Relationship Management
EI	Enterprise Integration
EIS	Enterprise Information System
ERP	Enterprise Resource Planning
GE	General Electric
HPC	High-performance computing
IaaS	Infrastructure as a Service
ICT	Information and Communication Technology
IDC	International Data Corporation
IoB	Internet of Business
IOM	Input & Output Model
IoM	Internet of Manufacturing
IoS	Internet of Services
IoT	Internet of Things
IoU	Internet of Users
IoX	Internet of Everything
IT	Information Technology
KPI	Key performance indicator
MES	Manufacturing Execution System

NIST	National Institute of Standards and Technology
OEM	Original equipment manufacturer
PaaS	Platform as a Service
PERA	Purdue Enterprise Reference Architecture
PPC	Production Planning and Control
QoS	Quality of Service
R&D	Research and Development
RFID	Radio Frequency IDentification
RMA	Remote Monitoring and Assistance
RP	Research Problem
RQ	Research Question
RT	Research Theme
SaaS	Software as a Service
SAM	Strategic Alignment Model
SLA	Service Level Agreement
SM	Strategic Management
SMEs	Small and Medium sized Enterprises
SOA	Service Oriented Architecture
SS	Service Science
TQCSEFK	fastest Time-to-market, highest Quality, lowest Cost, best Service, cleanest Environment, greatest Flexibility, and highest levels of Knowledge
VF	Virtual Factory
WSN	Wireless Sensor Network
X2C	Everything to Cloud
XaaS	Everything as a Service

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1 INTRODUCTION

1.1 Background

In the current internationalization and globalization of business, the market demands are volatile due to unpredictable customers' demands, diversified product range, shorter lead times and shorter lifecycles of products and services (Francisco, Azevedo & Almeida 2012). To accommodate this dynamic business environment and faced with considerable challenges in these turbulent economic times, organizations need to make continuous changes in all aspects.

Additionally, information and communication technology (ICT) is playing an increasing role in improving efficiency, effectiveness, and productivity in manufacturing industry. New business demands are forcing the development of dedicated ICT solutions. By reviewing the evolution of manufacturing industry, changes can be observed from traditional manufacturing, such as the assembly line (the 1900s), Toyota production systems (the 1960s) and flexible manufacturing (the 1980s), to intelligent manufacturing, such as reconfigurable manufacturing (the 1990s), web-based and agent-based manufacturing (the 2000s), to today's smart manufacturing (the 2010s) (Wu et al. 2014). Business models have changed through all the epochs of manufacturing according to the ICT evolution. ICT offers new possibilities in the reconstruction of traditional industrial paradigms towards a new level of intelligence in manufacturing enterprises.

Meanwhile, ICT signifies new challenges concerning the scope of business. The main requirements of modern manufacturing models are not only focusing on TQCSEFK (i.e. fastest Time-to-market, highest Quality, lowest Cost, best Service, cleanest Environment, greatest Flexibility, and high Knowledge) value-added networks (Tao et al. 2011a), but also are more and more oriented towards digitalization and servitization (Lu, Xu & Xu 2014). Therefore, with the combining effect of both business and technology, and the connecting efforts of both the internal and external organization, some manufacturing paradigms have been raised to elevate the manufacturer's capability to face all these changes in the business environment.

Although different paradigms emphasize different aspects, they aim to improve the manufacturing business model from two aspects, namely level of information sharing and integration and level of ICT involvement (Hao & Helo 2015). The shared information can be bill of materials, structure, specification, product plan, and so on (Qanbari et al. 2014). Information integration means agreeing on the information sharing format and framework (Romero et al. 2009). Moreover, the level of ICT involvement indicates to what extent ICT is used within the enterprise to support its business activities. In the action to solve complex manufacturing problems and organize distributed manufacturing among different enterprises on a larger scale, the collaboration formations are more decentralized and dynamic rather than static hierarchical structures (Kankaanpää et al. 2010).

Inspired by previous research, the manufacturing paradigms are described in this paper by the level of geographical distribution of all stakeholders and level of ICT involvement in their business, as plotted in Figure 1. The relative position of each paradigm also implies its positioning among them. The paradigms are lean production (Shah & Ward 2003), agile manufacturing (Yusuf et al. 1999), global manufacturing (Ulieru et al. 2000), virtual manufacturing (Shi & Gregory 2005; Lomas & Matthews 2007), digital manufacturing (Mahesh et al. 2007; Chryssolouris et al. 2009), computer integrated manufacturing (Kwak & Yih 2004; Kahraman et al. 2004), holonic manufacturing (Van Brussel et al. 1999; Leitão & Restivo 2006; Giret & Botti 2009), networked manufacturing (Mitsuishi & Nagao 1999), and grid manufacturing (Tao, Hu & Zhang 2010). (More detailed discussion regarding these manufacturing paradigms can be found in Section 2.5.2)

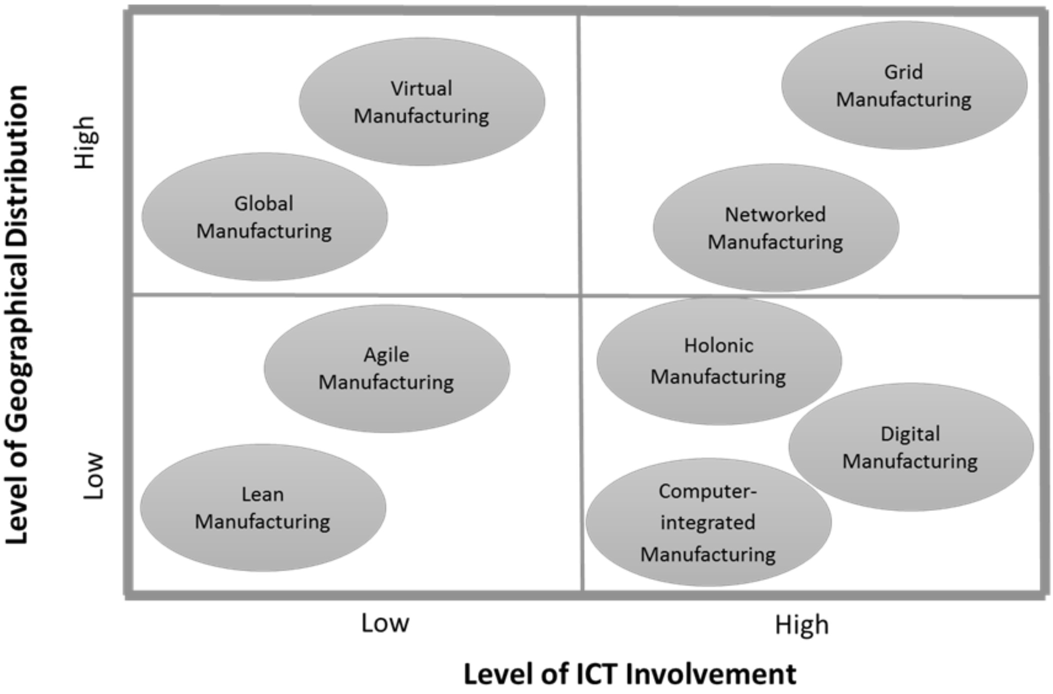


Figure 1. The evolution path of manufacturing paradigms (Adapted from Hao & Helo 2015)

Nonetheless, the existing concepts cannot meet the demands of higher quality production and a more flexible collaborative network. Although current manufacturing concepts attempt to achieve the business collaboration at the enterprise level, the obstacles to achieving actual manufacturing process integration remain in the collaboration network.

In order to establish a collaboration network that incorporates machinery, shop floor systems and various production facilities, and also to fundamentally improve the manufacturing processes, cyber-physical systems (CPS) were proposed to embody decentralized and autonomous elements from both information (from computing systems) and material (from the physical world by networked sensors, devices, and software) (Rajkumar et al. 2010; Sokolov & Ivanov 2015; Wang et al. 2015). The elements communicate through information sharing and are supported by many new computing and networking technologies (Baheti & Gill 2011; Lee 2008). Most of the new factory concepts based on the CPS principle share attributes of cooperative collaboration network and connection with ICT (Mezgár 2011; Sokolov & Ivanov 2015). This phenomenon can yield a power-shift from the hierarchical business model to a collaborative business model, which can afford higher level of agility, creativity, and connectivity to keep the companies' competitiveness in today's environment (Wu et al. 2013). Consequently, based on the appearance and the maturity of CPS, it is time to think again about a new paradigm.

Industrie 4.0 (a.k.a. Industry 4.0) appeared in Germany to describe the fourth generation of industrial evolution. It creates a 'virtual copy' of the physical world and enables enterprises to make decentralized decisions and it facilitates the development of the smart factory (Hermann, Pentek & Otto 2015). The Chinese 'Internet Plus' Strategy proposed by the Chinese government in 2015 is an action plan to integrate various internet-enabled technologies, such as cloud computing, big data, the internet of things (IoT) and mobile technologies with traditional sectors, and to generate new business models, including modern manufacturing and innovative manufacturing business (Tang 2015). The industrial Internet is a similar concept proposed by General Electric (GE) to invest in the integration and alignment of technologies and industrial business (Agarwal & Brem 2015), and this terminology is mostly used in the U.S. It underlines the value of CPS in manufacturing process prediction, intelligent monitoring and control, and planning. It is very obvious that the trends of future manufacturing industry are transforming manufacturing businesses from physical production to new technology-based integrated manufacturing solutions. Several similar concepts have also emerged, such as integrated industry (Hilger 2014), smart manufacturing (Davis et al. 2012), and so on. The trends in both technologies and terminologies are shown in Figure 2.

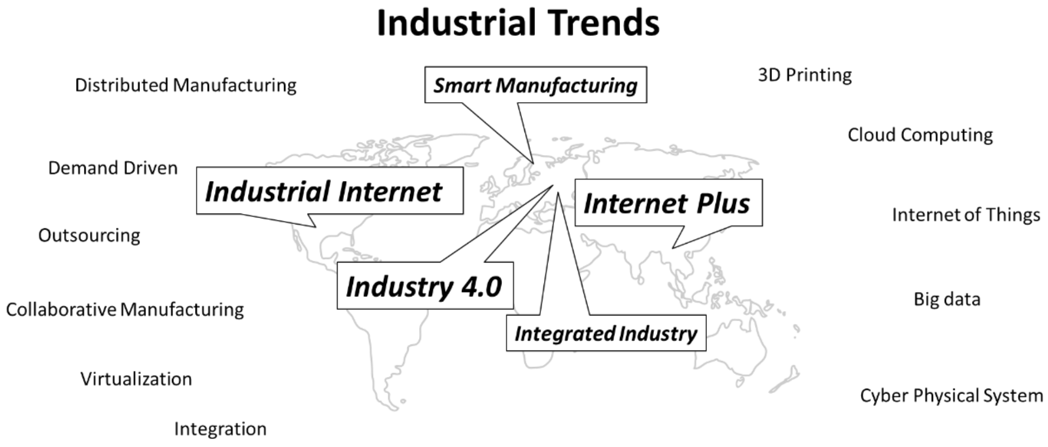


Figure 2. Industrial trends in recent years

Cloud computing is one of the top ten technology trends based on Gartner's prediction in 2015. It has been regarded as one of the major technical enablers and new business strategies for the manufacturing industry (Tien 2011; Xu 2012). According to the estimation of the research company IDC (International Data Corporation), the 'cloud' will improve the productivity of manufacturers over the next decade (Adiseshan N.D.). By 2020, 80% of global IT (information technology) spending will be allocated to cloud computing and big data analytics (Cattaneo 2012).

Cloud computing per se is not an invented concept but a collection of different existing technologies. Cloud computing is a multidisciplinary research field (Xu 2012) that stimulates both technological-oriented and business-oriented evolution. Therefore, cloud computing adoption can cause a paradigm shift of both IT infrastructure and business infrastructure, particularly in IT efficiency and business agility. The cloud can produce computing results almost instantaneously; therefore it can achieve business agility. When considering the industrial sector, the benefits and advantages of cloud computing are innovation, mobility, and collaboration. Cloud computing is an ideal model for delivery of collaborative solutions. Therefore, it is being widely utilized in today's industry and society.

In the manufacturing sector, two types of cloud computing adoptions have been described in previous research, i.e., manufacturing with the direct adoption of cloud computing as a technology, in other words the manufacturing version of cloud computing, and secondly, industry-specific vertical cloud (James & Chung 2015), namely cloud manufacturing (Xu 2012; Xu 2013). Figure 3 summarizes the scope of cloud computing adoption in the manufacturing industry.

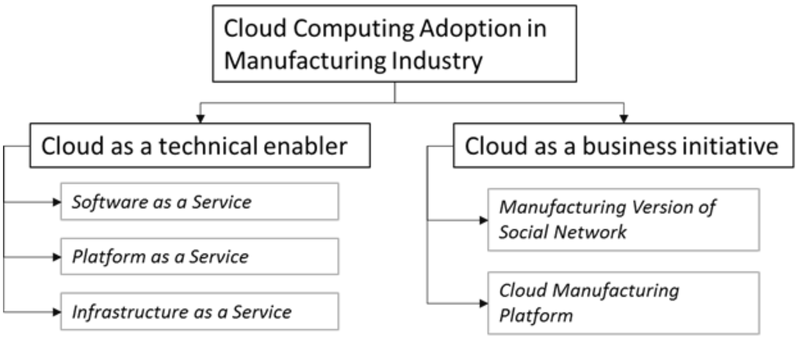


Figure 3. The scope of cloud computing adoption in the manufacturing industry

First, in terms of the direct adoption of cloud computing, user companies do not need to purchase dedicated hardware and are able to eliminate the initial IT investment cost, and the end users can access configurable computing resources (e.g. networks, servers, storage, applications and services) based on demand, and pay the services based on usage (Tien 2011; Park & Jeong 2013). Besides the cost-related benefits, other major advantages are scalability and flexibility. The computing resources can be rapidly provisioned and deployed in a flexible and customized way. The provisions are also scalable based on the real-time demand. Normally, the cloud services are classified in three distinct categories based on their purpose: Software as a Service (SaaS), Platform as a Service (PaaS) and Infrastructure as a Service (IaaS). SaaS and IaaS are the favorite solutions (Hao & Addo-Tenkorang 2014). Moreover, SaaS, such as cloud-based ERP (Enterprise Resource Planning) and cloud-based B2B (Business-to-Business) solutions, are the favored manufacturing solutions (Adiseshan N.D.; Xu 2012).

Second, cloud computing is adopted as a metaphor. Under this circumstance, not only the computing resources are provided as services, but also the entire manufacturing business. Cloud manufacturing is a new concept based on 'share-to-gain' philosophy to represent an intelligent manufacturing model (Wu et al. 2013). Cloud manufacturing emerges naturally as a sequence of successful cloud computing implementation. Its main characteristics can be highlighted as service-oriented, knowledge-based, high performance, and energy efficient (Li, Zhang & Chai 2010; Wu et al. 2013; Wang 2015). In this model, the synergies of the combination of state-of-the-art technologies, such as cloud computing, big data, and IoT, etc., provide a secure and reliable service platform at relatively low prices in supporting the whole manufacturing lifecycle (Li, Zhang & Chai 2010). Whilst cloud computing serves the computing purpose and shares computing resources, cloud manufacturing serves the manufacturing purpose and shares a wide number of manufacturing resources with users.

Building on NIST (National Institute of Standards and Technology)'s definition of cloud computing, numerous scholars have proposed definitions of cloud manufacturing in recent years, including Li, Zhang & Chai (2010), Xu (2012), Wu et al. (2013b), and Wang & Xu (2013). These works give an initial overview of the cloud manufacturing concept. There are several groups researching in this area from China, Europe, the United States and New Zealand, among others. In these regions, manufacturing is considered as the pillar industry in their national economy. Typical examples of projects are key technologies in the cloud manufacturing platform (2009–2013) (Li, Zhang & Chai 2010), ManuCloud (2010–2013) (Meier et al. 2010), ADaptive Virtual ENTerprise ManufacTURing Environment (ADVENTURE) (2011-2014) (Hao, Shamsuzzoha & Helo 2012), ManuFuture (Jovane, Westkämper & Williams 2008). The emergence of relevant concepts in cloud manufacturing are promising to transfer the benefits and profits of cloud computing to the globalized, distributed, and servitization manufacturing.

According to a survey of cloud-based collaboration by CurrentAnalysis, only 11% of manufacturers used cloud services and implemented cloud-based collaboration in various formations (CurrentAnalysis 2014). At present, cloud manufacturing implementation is still in its initial stage. Many companies are still facing obstacles in terms of understanding cloud manufacturing. There has been a growing number of research in the managerial and technological fields of cloud manufacturing since it was first coined in 2010. Most of the research topics are conceptual and focus on key enabling technologies. Some of them aim to technically implement cloud computing in manufacturing concerns, such as in service systems, while others focus on resource sharing, service models, and so on (Ren & Cao 2013). In general, there are two levels of cloud manufacturing service systems:

- Lower level: this is a manufacturing version of the social network (Gould 2014) that can support business sharing (Wang & Xu 2013b). It acts likes a web portal and provides real-time communication and information exchange. The final products or mature business services are categorized and published in this portal by providers. Searching and matching algorithms are used to help the demanders allocate best fit products or services, and suitable products or services are locally provided to demanders. Alibaba, ThomasNet, and GlobalSpec are a good example of this level of service system.

- Higher level: This is a B2B cloud manufacturing platform (CMP) that provides a full integration of back office with shop floor and offers collaboration in the manufacturing process across different factories. This CMP also includes providers and demanders. But they are not focusing on final products along, instead the manufacturing resources and capabilities are virtualized and encapsulated as services (Wang & Xu 2013b). These services are requested by demanders to accomplish the manufacturing activities. CMP offers a fundamental framework that aids in managing all activities that occur during the collaborative manufacturing process (Laili et al. 2012).

1.2 Research Objectives

In this research, cloud manufacturing is examined through the combined theoretical lenses of services science (SS), enterprise integration (EI), and strategic management (SM). This research provides an enhanced understanding of the circumstances whereby companies are willing to adopt cloud manufacturing for their business. Successful cloud manufacturing implementation means establishing full understanding about a series of intermediate processes, which including interoperations and interactions among separate enterprises, from raw material to finished products (James & Chung 2015). Furthermore, when the cloud manufacturing environment is increasingly complex, no single comprehensive solution that can be applied to all circumstances. Consequently, it is of importance to analyze how companies adopt and select cloud manufacturing solutions, and also how this new technology affects companies' business strategy or business infrastructure. After all, it is not the technology itself which creates value but the business processes that make good use of the technology.

More specifically, two primary research problems (RP) are formulated in this dissertation:

- ***RP1: What are the implications of the cloud in manufacturing industry?***
- ***RP2: How do manufacturers leverage the cloud to shape and support their business strategies?***

These RPs highlight that this dissertation is focused exclusively on cloud manufacturing and its related issues. They are mainly answered by a conceptual framework of cloud manufacturing, and also a cloud manufacturing adoption strategic model, respectively.

According to the increasing amount of research in this competitive area, new efforts are being continuously made by researchers and practitioners. Although many concepts, models, and methods have been developed for some years, most of them are partial approaches, focusing only on some aspects. There has thus far been no report on an integrated cloud manufacturing environment. Therefore, it is very necessary to step forward and elevate the research to a new level. With this study, there is an attempt to meet this need and extend the current cloud manufacturing literature using an alternative research method. Four specific research objectives are constructed to serve as basis for guiding this study:

- To gain a comprehensive understanding of cloud manufacturing.
- To study the effect of cloud computing on the manufacturing industry from both the business and the technical perspectives.
- To investigate possible implementations of cloud manufacturing.
- To provide a conceptual approach for manufacturers to think critically about adopting their business in a cloud manufacturing environment.

With these purposeful objectives, this dissertation should not only be of academic interest but also have important managerial implications.

1.3 Research Motivation

It is crucial to define the motivations of research. There are several main reasons for undertaking this research:

- The research is very timely: Since cloud manufacturing is still in its initial stage of evolution, it will be gradually unfold and fully revealed. Because of the novelty of cloud manufacturing, it ensures that this research has built a leadership position and will not be outdated within at least five years. Especially for Europe, which is standing at a crossroads in moving to a new business pattern of industrialization, it is very critical to carry out research in this area.

- The research is very necessary: Wu et al. (2013b), Li, Zhang & Chai (2010), Tao et al. (2011b) and Huang et al. (2012) emphasize the challenges associated with cloud manufacturing implementation; for instance, lack of standards for describing cloud services, lack of technologies to support run-time scheduling, optimization and collaboration, and also safety and security problems. These references imply that it is essential to conduct more research and develop concerted solutions in this field.

- This research contributes theoretically: Liu et al. (2011) and Lu, Xu & Xu (2014) indicate the importance of thinking diversified cloud manufacturing deployment models for different-sized manufacturing enterprises. For instance, large-sized enterprises may choose an internal cloud while the small and medium sized enterprises (SMEs) may choose the external cloud, and dynamic expanding enterprises can choose federated cloud. Xu (2013) and Wu et al. (2013b) also point out that one critical issue that needs to be addressed is identifying effective operation modes (i.e., private, public, hybrid, and community cloud) and strategically leveraging all the cloud deployment models. However, only considering the cloud deployment is not enough. Cloud manufacturing is facing calls for closer collaboration between discrete manufacturers. Cloud manufacturing is not only about cloud deployment, but also other options. Camarinha-Matos et al. (2008) emphasize the importance of high level integration in flexible collaboration strategy. It is critical to achieve common goals, mutual trust, and the ability to manage inter-organizational processes. Therefore, it is important to expand the current research scope and move to a new research direction.

- This research contributes practically: Furthermore, as a result of the increasingly rapid changes in both technology and business, manufacturers are seeking an approach to tackling the issues and challenges in planning and deploying a cloud manufacturing environment in concert with their specific business strategies and business priorities. Similar in a cloud manufacturing environment, despite all the hype surrounding cloud manufacturing, it is not a simple task to adapt the cloud approach to a traditional manufacturing business paradigm. Companies are facing some obstacles to adopting a cloud approach, i.e., they are in different stages of cloud solution acceptance and they have different technological structures in adopting cloud infrastructure. Therefore, it is important to avoid a one-fits-all solution and thereby compromise the business benefits. More specifically, different companies have different business conditions and thus require different cloud solutions (Lu, Xu & Xu 2014). Therefore, it is imperative to ensure alignment in terms of the strategic objectives of cloud manufacturing. It is important to design a strategical alignment model for discrete manufacturers to accelerate the cloud computing adoption, and achieve intelligent management and efficient collaboration across the value chain.

- This research will stimulate further studies: Even though comprehensive research is conducted, the research findings are still at the beginning stage. Therefore, further research related to both theory and practice in cloud manufacturing will be recommended.

1.4 Research Method

In order to answer the two research problems pre-defined in Section 1.2, four case companies were included to explain the concept of cloud manufacturing and to illustrate the entire cloud manufacturing process. Interviews and workshops with various industrial managers and workers were organized to obtain specific primary data and to initiate dialogues between the researcher and managers. A set of meetings was carried out to elicit the system implementation requirements. More detailed, closely-knit case specifications were described in seven individual papers published in different international journals.

The overview objectives of the first publication were to define the scope of cloud manufacturing and to demonstrate the cloud manufacturing implementation to a large size company. The second publication explored the collaboration relationship between SMEs, and designed a cloud-based manufacturing information system platform to support all the cloud manufacturing activities. The third publication, in conjunction with the fourth publication, jointly discussed the impact of big data in the manufacturing industry, and also provided a solution to implement cloud-based data storage. The fifth, sixth and seventh publications presented the designs and applications of the Cloud Manufacturing Platform (CMP) in different contexts to support different manufacturing services.

Additionally, this research also evaluates the alignment between cloud strategy and manufacturing strategy for realizing the benefits of cloud manufacturing. The cloud manufacturing strategic model (CMSM) is designed to help organizations extend their processes and IT architecture from cloud of record to cloud of engagement, from lean and efficient to agile and effective. Equally important, CMP is designed to support the mix of structured and unstructured manufacturing processes. CMP becomes critical factor in today’s diversified business environment. Moreover, the CMP implementation map is a framework to enhance cloud manufacturing performance backed by technology components that can be road mapped into any enterprise environment. Jointly, the CMP, CMP implementation map, and CMSM provide guidance for aligning technology capabilities or ‘pillars’ with business priorities.

The contributions of this dissertation are twofold. First from the scientific aspect, the findings and relevant theories created in this dissertation can fill a research gap in the area of adopting cloud services in enterprises to improve their business, and provide a new solution for enterprise integration. It also extends the scope of service science by intensively elaborating the concept of manufacturing as a service. Moreover, the research on cloud manufacturing and the knowledge explored in this dissertation can be easily transferred to other kinds of enterprise systems in other industries. The knowledge is convertible, meaningful, and referential. Secondly, from the practical aspect, it will provide support to organizations, not only large size companies, but also SMEs, which are attempting to expand their business and collaborate with other SMEs. In terms of cloud service providers, they can obtain more knowledge about cloud manufacturing as a whole picture and network. They can provide better services to the cloud service consumers over the cloud manufacturing platform.

This dissertation can be beneficial to researchers, who are attempting to tackle the primary issues of cloud manufacturing and need information and insight in a useable way. It is also suitable for people who have difficulty in moving into CMP, so that guidance such as CMP implementation map, is needed. These are the key drivers that will be addressed through CMSM.

1.5 Structure of the Study

This study presents essential literature related to cloud manufacturing and different approaches to adapting to a cloud manufacturing environment. It also introduces the main issues related to how to align business strategy with manufacturing strategy in cloud manufacturing from the organizational viewpoint:

- Chapter 1 presents the research background and research motivation
- Chapter 2 identifies the theoretical foundation and a systematic literature review related to cloud manufacturing, existing definitions, as well as research and development activities in both academia and industry.
- Chapter 3 explains the main methodology applied in this research. An appropriate research model is designed based on the research paradigms.
- Chapter 4 explores the author's contribution by presenting the findings of the included seven individual publications. Qualitative case studies are developed to the main research problems. This chapter builds a further framework for the research by presenting a comprehensive conclusion developed from RP1.
- Chapter 5 explores the issues of research and also extends the current state of cloud manufacturing strategies by addressing RP2. A strategic alignment model is designed to help enterprises moving towards cloud manufacturing.
- Chapter 6 outlines the research conclusions and discusses the benefits of the proposed strategic alignment model for managers.

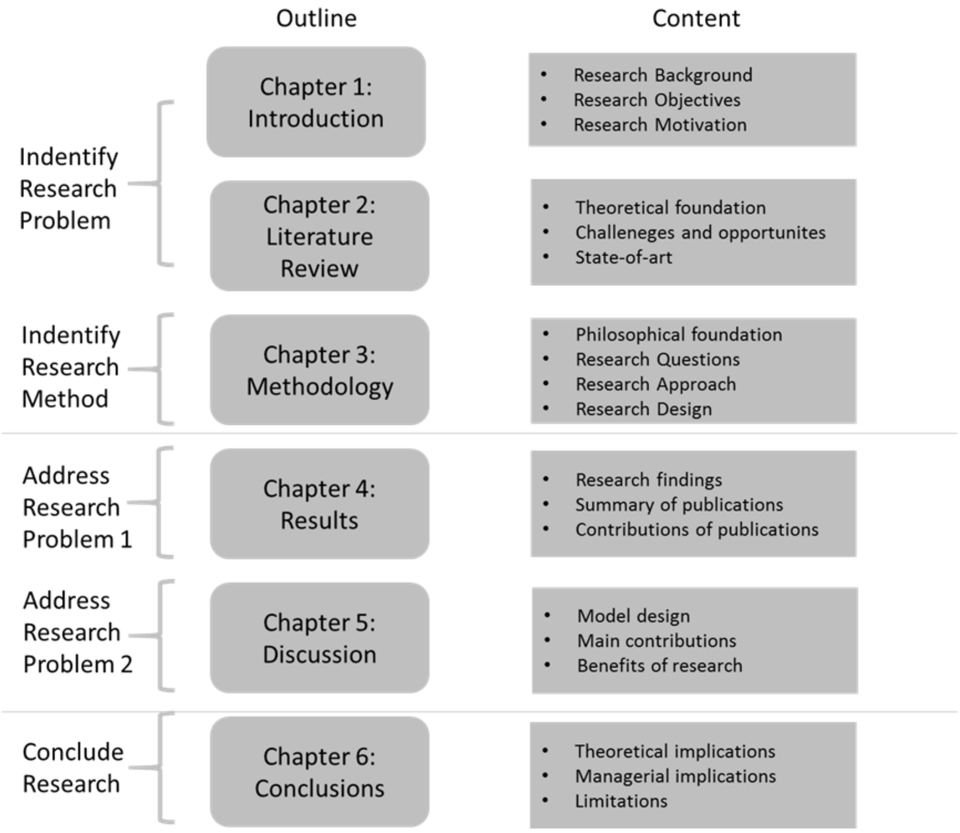


Figure 4. Outline of the dissertation

2 LITERATURE REVIEW

This chapter aims to present the relevant literature in this research context and to build the theoretical foundation for this research.

2.1 Conceptual Framework

The major two aims of this study are to design an integrated solution for the cloud manufacturing environment and to propose an approach for manufacturers to think strategically and make the move to cloud manufacturing. Although much significant and insightful research has been found in recent years, theoretical challenges and issues remain in current research. Scientific foundations for supporting the modeling, analysis, and design of cloud manufacturing have not yet been fully developed. This section mainly focuses on discussing the theories and determining the scope of this research.

Theories give the research credibility and serve as a foundation to understand the development of knowledge. As White (2009) indicated, a theory is a contested term, and while many people write about it, they do not always refer to exactly the same thing. According to Bryman (2008), the research foundation can be depicted by means of ontology. Evolution in the manufacturing domain is an integration of enterprise business and information systems at both strategic and operational levels beyond the scope of operations research. Particularly in the context of cloud manufacturing, cloud computing, as a multidisciplinary research term, intensifies current business structures and improves enterprise information systems (He & Xu 2015).

After a thorough study of different theories in the literature, this research is conducted based on three main theories: Service Science (SS), Enterprise Integration (EI), and Strategic Management (SM). SS is an interdisciplinary approach and it is a combination of engineering and management science. EI represents the technology aspect, while SM represents the manufacturing strategy and management aspect. These theories jointly define the breadth and depth of this study, and they provide an ultimate direction for cloud manufacturing-related research:

- **Service Science**: services are value-added intangible business activities to support business process (Cardoso, Voigt & Winkler 2009). Manufacturing industry has already undertaken a major transition to services in both the sales and business structure (Hidaka 2006). The objectives in SS are to analyze services, manage services, raise the productivity of services, and explore a framework for service innovation (Hidaka 2006). It is not only about customers' high-level requirements, but also about better value creation through a shift from providing products to providing services (Baines et al. 2009). As suggested by Bell (1973), knowledge-based services would elevate manufacturing to a new level and act as a growth engine for the manufacturing economy (Bell 1973). SS is the key theory in this thesis. It implies the development trend of cloud manufacturing from only selling final products to providing manufacturing resource and capabilities as services.

- **Enterprise integration**: EI has emerged as an extended research domain since computer integrated manufacturing (CIM) was developed in the 1990s. There are two sub-themes in EI research: 'enterprise modelling and information technology' (Panetto & Molina 2008). EI defines the approach to model the activity flow that enable organizations to integrate and coordinate their business processes and information systems (Li et al. 2012). Over a decade, more and more enterprises have carried out enterprise modeling. In this research, the main focus is to define collaboration models among different companies, and EI is an important base for establishing understanding of collaboration activities.

- **Strategic management**: SM is about decision making and linkage between business strategy and operation strategy (Hayes & Wheelwright 1984). In the manufacturing industry, the strategy acts in supporting the consistency between business and the manufacturing processes, for competitive advantages (Blackstone & Cox 2005; Dangayach & Deshmukh 2001). SM in this research serves as a coordinated approach to facing the challenges in moving towards cloud manufacturing ecosystems.

With the development of technology, it is becoming more and more complicated to design enterprise information systems (EIS) in manufacturing environment, and they have lower interoperability (Li et al. 2012), the EI should be considered at three different levels: from the function, to the system, and to the organization. In the meanwhile, more and more manufacturers shift their business towards a service-oriented, and customer-driven paradigm (Lartigau et al. 2015). The entire concept of cloud manufacturing is to provide an EIS to integrate and share different services among manufacturers. In recent years, emerging technologies such as cloud computing, Web 2.0, WSN (Wireless Sensor Network), RFID (Radio Frequency IDentification), or other cutting-edge technologies make it possible to develop a suitable integrated EIS. It is thus believed that SS can offer insights into effective cloud manufacturing service platform design, accelerating the business model changes through exploration of the cloud manufacturing concept. In the early stage, services in manufacturing refer to different value-added activities, such as maintenance and assistance (Hidaka 2006). However, in the cloud manufacturing context, the scope of services is extended: it not only increases customer values, but also increases companies' values, partners' values, and in other words, this new business ecosystem with new manufacturing business and technical strategy is beneficial to all the parties related. Many earlier studies have often investigated cloud manufacturing from many theoretical aspects. But most of the research adopt single theory lens. In this study, different theoretical perspectives will be combined and used as an integrated theoretical lenses to investigate cloud manufacturing and to generate a holistic view of cloud manufacturing. By doing so, it will contribute to improving the effectiveness of cloud manufacturing and to enhance the process of moving to cloud manufacturing. Figure 5 presents an overview of the conceptual framework of this study.

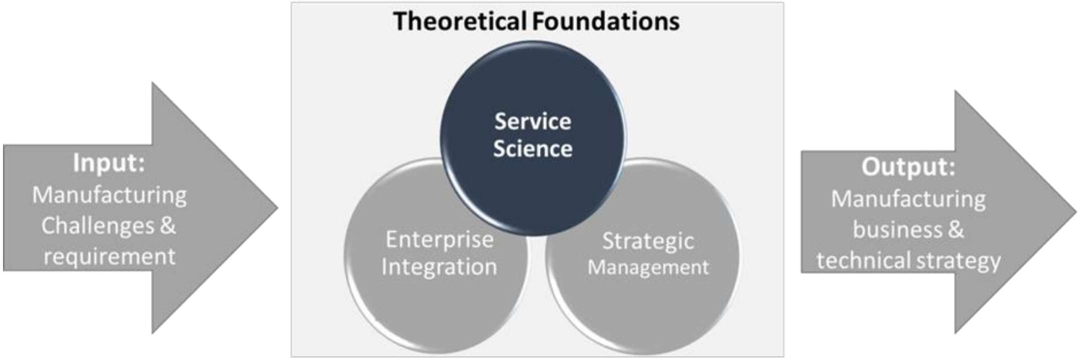


Figure 5. Conceptual framework of the dissertation

As mentioned, the theories provide the holistic theoretical structure of research model. Therefore, the logic of this research is to find out the challenges and requirements in the manufacturing industry, and then exam them through the theoretical lens. The output of this study should be the manufacturing business and the technical strategy. To fulfill this requirement, the next step is to find out the manufacturing trends and challenges.

2.2 Manufacturing Industry Trends and Challenges

In recent years, internet technology, IT, and other relevant technologies have been fast developed and widely applied. Future scenarios of the manufacturing industry place ICTs at the core of its development. Innovation in the manufacturing industry needs to speed up to respond to the development of ICTs in order to heighten product quality and reduce problems and other obstacles.

In today's globalization manufacturing business, many companies have changed their business model from highly centralized vertical operations to horizontally integrated operations. The companies did not produce everything locally but needed to work in tandem globally with other companies such as suppliers, partners, and customers (Gould 2014). But current manufacturing solutions have not made the transition to support distributed operations. There are three main prevailing tendencies in manufacturing industry: more and more partners are involved, more and more dynamic and complicated customer requirements are appearing, and business processes are becoming more and more distributed (globalization) (Ford et al. 2012). Four prevailing tendencies are identified in previous research (4A) (Liu & Jiang 2012), and all these trends drive the requirements and development directions for the next generation of distributed manufacturing environment:

- Active: Means to achieve concurrency in all operations to rapidly respond to the changing market, reduce products' time-to-market, and to shorten the product's lifecycle (Romero et al. 2009; Shamsuzzoha, Helo & Kekale 2008)

- Agile: Refers to the ability to be more adaptive to different business scenarios. Besides effectively responding to changing needs, it also important to be flexible at the business level and to be reconfigurable at the system level (Romero et al. 2009). It is critical to minimize spare time and to maximize the usability of resources/capabilities, and consider human factors to increase end-user workforce productivity.

- Aggregative: Means integrating all the partners from disparate locations, and supporting a closer relationship with each other. The integration mainly refers to the data integration to improve internal communication within a company and external communication across different companies (Chituc & Restivo 2009). Aggregation and communication are achieved by run-time information flows, instantaneously transforming data gathered from diverse sources into insightful knowledge for supporting effective decision-making.

- All-aspects: Means covering all the aspects of the manufacturing industry to enhance the overall business process efficiency, to target manufacturing processes and related activities not only within a particular company but also in a network of companies in the whole supply chain (Chituc & Restivo 2009).

However, the current manufacturing environment involves several issues, and some of them have a direct impact on the manufacturing paradigm. Due to issues of lack of open and flexible architecture, lack of effective operational mechanisms and efficient tools, lack of strong management mechanisms, and also lack of reliable safety solutions (He & Xu 2015), new substantial challenges are set for the manufacturing industry, namely the 4S's:

- Standardization: Many different machines, systems, information and people are distributed through the whole manufacturing process, so that a standard is required to integrate decentralized resources and control centrally. The purposes of standard are to define product structure, to establish central management across manufacturers, and to integrate distributed production (Qanbari et al. 2014). More specifically, a standard of data exchange between organizations is required (Helo & Szekely 2005). Standardization is the foundation of solving another three challenges.

- Sharing: Data sharing among different companies is very critical (Helo & Szekely 2005). In order to create collaborative manufacturing environment, distributed information should be able to be interpreted and acquired by different companies. However, information sharing is very difficult to achieve for many reasons: not only the huge amount of data, confidentiality of information, and the complexity of knowledge, but also the geographical distribution of existing partners' information systems (Valilai & Houshmand 2013). Lack of efficient integration tools and the complexity of manufacturing collaboration processes hinder information sharing (Valilai & Houshmand 2013).

- Security: Security is always a major concern of users. All data must undergo integrity and quality checks to ensure security (Veas et al. 2013). Cloud infrastructure can provide a security platform which can meet the need for development and security of high-end manufacturing equipment. Cloud-based remote access is a solution for plant-floor networks and it intensifies the understanding of how the IoT translates into practical use. It is important to set up security rules to protect against opening up plant networks to cloud-based remote access.

- Scalability: Scalability is one of the critical issues still not fully addressed yet (Wu et al. 2013b), because it can be considered horizontally (in term of flexible increase or decrease cloud manufacturing instances) and vertically (in term of flexible increase or decrease the manufacturing resource). Scalability must be implemented at certain levels in different situations (Wu et al. 2013b).

All these aforementioned prevailing trends (4A) and issues and challenges (4S) set requirements for a new manufacturing paradigm and a better-integrated collaboration tool with business systems, as shown in Figure 6.

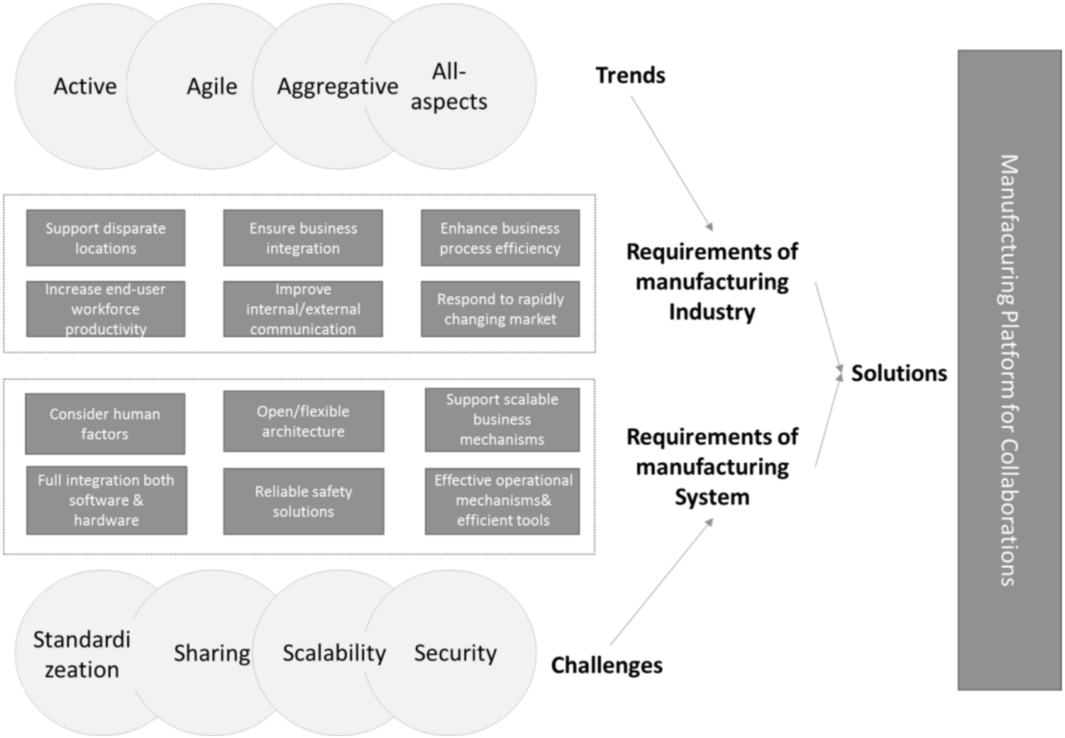


Figure 6. Issues in current manufacturing industry

Besides all the functional requirements in the manufacturing industry, there are several non-functional requirements related to more stringent regulatory mandates, such as emission standards, green behavior, banned materials, etc. (Kang et al. 2013).

With all the effort to address these limitations and requirements, it is required to have a platform to support a new model in the manufacturing industry. In competitive business, collaborative approach enable manufacturing companies to expand their business with more capacity. Therefore, they can quickly responsive to the changing business. This collaborative manufacturing environment can be achieved through sharing product data and information. Besides, manufacturing agents usually are involved to enable a collaborative environment, to ensure agility in satisfying customers' requirements, and to allow the autonomous and distributed companies working in tandem (Lartigau et al. 2015; Valilai & Houshmand 2013).

Although the new manufacturing model consists different geographically distributed partners, each partner works with its own resources and capabilities directed to particular functions in manufacturing process. Despite the IT evolution and improvements facilitate the exchange of knowledge and manufacturing information in this business model, there is a long way to enable management of different manufacturing operations from multi-companies, multi-plants, multi-locations, with multi-site planning and control. However, many traditional EIS supporting the local manufacturing operations are designed to work as standalone agents, they cannot solve complicated problem when the manufacturing operations are in distributed locations (Valilai & Houshmand 2013). Therefore, there is a need for a fully integrated solution.

2.3 Cloud Computing in the Context of Manufacturing

In this new industrial wave, the manufacturing industry is supported by new technologies, i.e. Internet, analytics, and also integrated with assets, i.e. machines, facilities, and fleets. IT and related smart technologies are enabling a major transformation in the manufacturing industry. Cloud computing is one such technology. NIST defined cloud computing as (Mell & Grance 2009):

"a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g. networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction."

The key characteristics of cloud technologies are available in distributed environment and dynamically reconfigurable. Adopting companies can request the cloud resource to meet their demand. Under this everything-to-cloud (i.e. X2C) trend, everything is virtualized as a service (i.e. XaaS), e.g. SaaS, PaaS and IaaS.

Cloud computing is the evolution of several technology 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, and so on. Because it is a multidisciplinary research field, the business oriented evolution should be consider as well (Foster et al 2008). Implementing cloud computing means a paradigm shift of both the business and IT infrastructure (Xu 2013).

In reality, many companies are struggling to achieve cost effective manufacturing strategies. Cloud computing gradually becomes one of the major enablers for the manufacturing industry to achieve their business goal in high-level collaboration. It is reasonable and possible for manufacturing businesses to embrace the concept of cloud computing to give rise to the manufacturing version of cloud computing, i.e. ‘cloud manufacturing’ (Xu 2013). Cloud computing can transform the traditional manufacturing business model to produce an innovation business model with the help of intelligent factory networks. Naturally, the distributed manufacturing resources can be also virtualized and encapsulated as manufacturing services that be managed centrally. This service model can easily integrate and provision everything at low cost, and achieve high automation with flexibility (Xu 2013; Wang & Xu 2013; Chen, Chen & Hsu 2014).

Of course, Downing & Schultz (2015) point out that the benefits of cloud computing tend to be more than simply cost saving, but focus on more strategic topics, for instance, supporting collaboration, making the manufacturing more agile and adaptable, providing more possibilities of mobility, making it easier to supply IT support for operations from a central location, etc. (Field 2015). Cloud computing can give two competitive advantages to manufacturing: cumulative economic benefits and innovative technological benefits, as shown in Table 1.

Table 1. Economic and technological benefits of cloud computing to manufacturing industry

Economic benefits	
Cost efficiency: no duplication of software/hardware and no unnecessary IT investment	Ren et al. 2014;
More responsive business solution: continuous availability, easy access to information and easy to accommodate the business needs	Parker 2011
Business model transformation: a new service delivery model, strong alignment with business capabilities and business model transformation	Qanbari et al. 2014; Parker 2011; Talerico 2014
Increased visibility: not only internal visibility but also across companies boundaries, particularly when different partners are involved	Shacklett 2010
Technological benefits	
Standardized communication: it can be achieved by a flexible and scalable virtual platform	Chen, Chen & Hsu 2014; Ren et al. 2014
Consolidated infrastructure: enabling data integration and centrally managed IT resources, and eliminating geographical constraint	Field 2015; McDonald 2014
Connection with shop floor: creating a virtualized layer based on physical resources at shop floor layer and integrating the distributed product lines to enable collaborations	Qanbari, Li & Dustdar 2014; Qanbari et al. 2014

In addition to all the benefits brought above by cloud computing for manufacturing, a main contribution is its collaboration support capabilities. It is important to create an understanding of cloud computing in the manufacturing industry as a technological innovation.

Cloud computing is a disruptive technology that leverages many other existing technologies, such as utilities computing, parallel computing, and virtualization (Wu et al. 2014). All these technologies jointly support the IT atmosphere of cloud-enabled manufacturing, and also act as a catalyst to enable business transformation. Big data is another concept profoundly influence the development of the manufacturing industry. Big data refers to the management of massive data collected from the manufacturing assets, such as sensors and microchips, and transforming these valuable data to decision making information. Big data analytics can support activities related to IoT and also CPS. IoT technology can virtualize and control the physical world by effectively connecting and communicating, while CPS connects the physical world with cyber systems. Big data analysis is used to tackle most of the data relevant challenges and issues. Big data is a new method for business intelligent and resource sharing (Tao et al. 2014). In a recent study on supply chain trends, about 60% of the respondents actually had planned to invest in big data analytics in product lifecycle management within the next five years (Handfield et al. 2013).

Cloud computing and big data have both been widely studied and applied in the manufacturing sector. At the same time, HPC, SOA, virtualization technology, embedded technology, etc., have provided new methods to address the bottlenecks faced by the existing manufacturing industry. All the important technologies and their impact on the manufacturing industry are listed in Table 2.

Table 2. Relevant technologies

Relevant Technologies	**Impacts on Manufacturing Industry**	**References**
Cloud computing	It is the most essential and fundamental concept in cloud-based manufacturing, and provides both IT infrastructure and a new business model.	Xu 2012
Big Data	It deals with an enormous amount of data collection generated by IoT connections and CPS activities. IoT connects smart devices in the manufacturing industry and enables the interconnection of different objects, while CPS integrates computation and physical processes in manufacturing. The emerging of big data ensures that the manufacturing resource/capabilities are instrumented.	Wang et al. 2015
High-performance computing (HPC)	HPC is used to solve large-scale and complex manufacturing issues and carry out parallel collaborative manufacturing. Currently, grid computing and parallel computing are expanding the capability of HPC, and providing more technical possibilities for distributed manufacturing activities.	Tao et al. 2011a; Zhang et al. 2014
Service Oriented Architecture (SOA)	It is an architectural approach to cloud-based manufacturing, and provides a collection of technologies, i.e. web service, ontology, and semantic web for the construction of a virtual manufacturing and service environments. In cloud-based manufacturing, all the manufacturing resource/capabilities are provided as services. This architecture can ensure the communication between different services through standard interfaces and protocols.	Tao et al. 2011a
Virtualization	It is a key enabler in cloud-based manufacturing. This intelligence technology provides a virtualized service to users, and the	Wu & Yang 2010

	services are generated based on the physical manufacturing resources/capabilities. Virtualization can enable sharing, management, and collaborative activities.	

2.4 Cloud Manufacturing

The role of cloud computing has shifted beyond its technology impact and business influence. It brings opportunities to the manufacturing industry. Therefore, a fully integrated cloud computing solution in manufacturing should also enable seamless global business management. It should include comprehensive support for enterprise collaboration and instant real-time communication in all aspects of the manufacturing operations. It should be easily adapted from traditional production to discrete manufacturing to complex, and concurrently discrete manufacturing processes.

Cloud manufacturing contains different definitions and perspectives. In general, it converges different elements, as demonstrated in Figure 7. This holistic concept illustrates the scope of cloud manufacturing. It is a consolidated core for all the elements requirements in the manufacturing industry:

- Manufacturing users: both factories and business partners are users of cloud manufacturing. However, the end users can be individuals from any level of the organization.

- Manufacturing technological applications: all the required software, data storage, computing tasks, etc. that can be deployed on the cloud computing platform (Wang & Wang 2015).

- Manufacturing resources: a collection of devices, equipment, machine tools, robots, monitors, etc. that are provided by distributed factories and centralized in the resourcing pool, and can be shared with others (Wang & Wang 2015).

- Manufacturing capabilities: they refer to working abilities defined based on task demands and business opportunities (Luo et al. 2013).

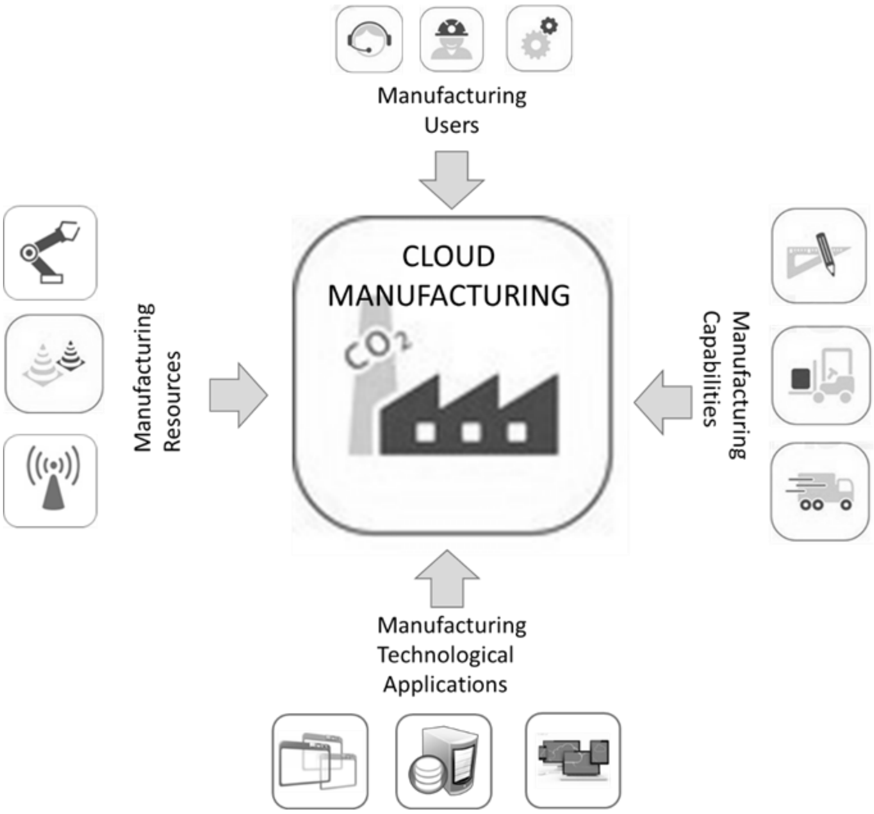


Figure 7. Holistic view of cloud manufacturing

The purpose of cloud manufacturing is to provide a collaborative work environment for companies and their partners in the entire manufacturing ecosystem. Users acquire for the services and associated resources to complete their manufacturing tasks. By using cloud-based technologies, all the heterogeneous and regional distribution manufacturing resources/manufacturing capabilities are virtualized and digitalized, and present through the cloud manufacturing with its cloud resource pool (Luo et al. 2013). Cloud manufacturing aims to orchestrate and allocate such distributed manufacturing resources/capabilities and render production services for users to seamlessly enable manufacturing on demand (Qanbari, Li & Dustdar 2014).

Although no legal entity exists beyond this collaboration, cloud manufacturing covers all the processes across the entire production lifecycle and provides all types of manufacturing resources as services. To implement a system to support all the activities of cloud manufacturing, a cloud manufacturing system is needed. The development of this system should be synchronized with the enterprise integration and manufacturing strategic management. It should support the servitization by considering products, resources and all related elements in the manufacturing process.

Purdue Enterprise Reference Architecture (PERA) is a reference model of enterprise architecture targeting the manufacturing environment. The PERA functional hierarchy model has three decision-making levels: business planning and logistics, manufacturing operation, and control. ISA-95 standard defines the information flow between the MES (Manufacturing Execution System) and various heterogeneous connected systems. Based on the study of other architecture, a cloud manufacturing framework is proposed by Qanbari et al. (2014). The pyramid maps the data flow from the shop flow to the back office in five distinct levels, namely, the manufacturing virtual applications layer, manufacturing core services layer, manufacturing execution system layer, manufacturing service bus layer and manufacturing infrastructure resource layer (Qanbari et al. 2014). They are organized from the most basic to the most sophisticated.

Figure 8 illustrates the information flow and operating principle based on input & output model (IOM). IOM takes the input and output variables into consideration, and reveals the interactions of the system and its environment (Bi et al. 2014). In cloud manufacturing, the input is manufacturing resource and capability which include all relevant elements that play a part in a manufacturing lifecycle (Ren et al. 2015).

The cloud manufacturing activities are based on every partner's own input, from the physical facilities (i.e. materials, energy, etc.), physical actions (manufacturing activities), execution plan (schedule and availability), to the collaboration rules (to what extent they attempt to collaborate with other companies). The output of cloud manufacturing is services that providing to customers. The services provision in cloud manufacturing is considered from virtualized resource, virtualized capabilities, operation process and collaboration states. The cloud manufacturing environment can be mainly decomposed into four layers: the infrastructure layer, including all the resources to fulfill the manufacturing requirements; the competency layer, including all the capabilities of production; the control layer, including manufacturing operations and actual execution; and the management layer, responding to the collaboration and relationship with other partners.

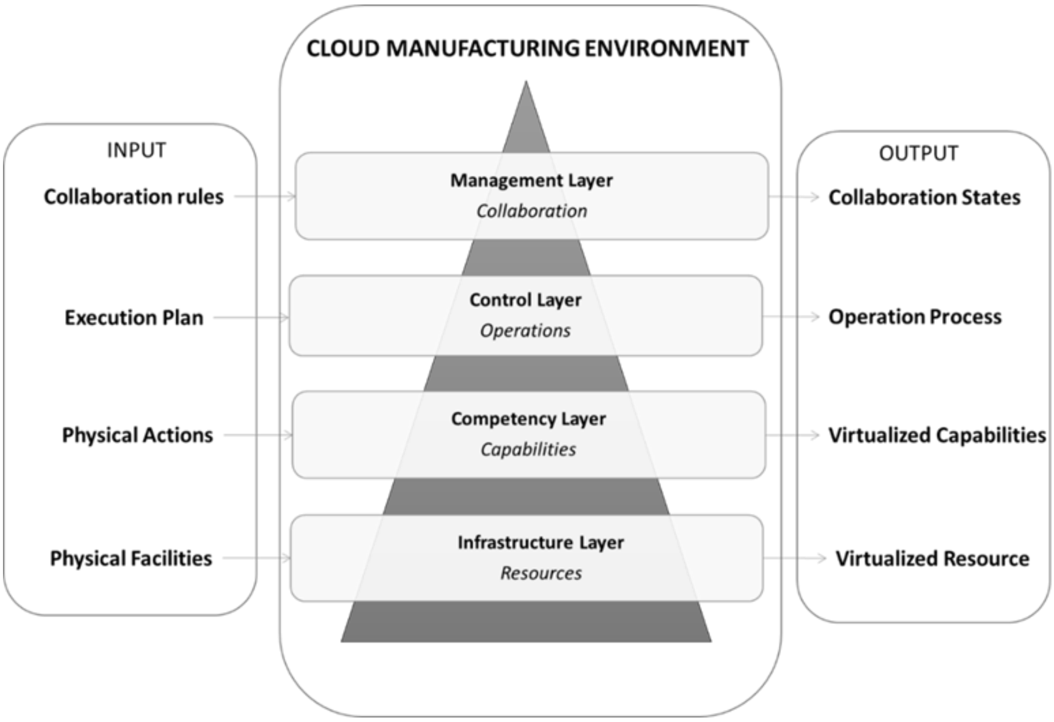


Figure 8. Cloud manufacturing framework

The cost of implementing solutions in all layers is prohibitively expensive for most SMEs. Cloud-based solutions will help SMEs by providing scalable solutions regardless of the company's size. Early adopters are increasingly considering cloud manufacturing as solutions when implementing a wide array of EIS, not only owing to its competitive prices, but also a variety of other advantages of cloud computing. The benefits of cloud manufacturing can be summarized in the following respects: closer partner relationships, flexibility, additional data analysis capabilities, efficiency, and, of course, cost savings (see Table 3).

Table 3. Benefits of cloud manufacturing

Value Disciplines	Cloud Manufacturing
Closer partner relationships	All partners are more transparent and equal to each other
Flexibility	The decision on the capital investment and capacity expansion are flexible
Additional data analysis capabilities	Accelerated data analysis by more data availability
Efficiency	Parallel processing mechanism
Cost savings	Relatively low initial investment and usage costs

It is not possible to make the challenges entirely disappear. However, cloud manufacturing strategy is the core to face up to and overcome the challenges. The enterprise needs to have a strategy or plan to adopt and implement cloud manufacturing. This strategy can provide some serious considerations around how cloud manufacturing can leverage business capabilities with IT capabilities. The strategy can ensure that the value of an investment is fully realized and all the challenges are addressed.

2.5 Research Contributions in Cloud Manufacturing

Current cloud manufacturing research is in its initial stage. Based on literature review, the common research topics are about cloud manufacturing concept, general system design and key technologies to enable the structure (Tai & Xu 2012; Chen 2014). However, the research has rarely focused on the manufacturing point of view (Chen 2014). Although both cloud manufacturing and cloud computing emphasize the sharing of resources from the technical perspective, the characteristics of manufacturing make the implementation of cloud manufacturing more complex than cloud computing from the business point of view (Tai & Xu 2012). Therefore, there is a need for research on manufacturing-oriented cloud manufacturing also supplemented by technology.

2.5.1 Definitions and Taxonomy

Cloud manufacturing research can be discussed from four different views: functionality, resource, information, and manufacturing process (Lv 2012). However, the function view and resource view are generally used by most researchers to describe their understanding of cloud manufacturing (He & Xu 2012). Some previous papers focus on technical interoperability, whereas others address environmental and organizational issues (Panetto & Molina 2008). But cloud manufacturing addresses both simultaneously. Table 4 distinguishes the concept of cloud manufacturing presented by different researchers.

Table 4. Comparison of definitions (Listed in chronological order)

Reference	**Definition of cloud manufacturing**
Li, Zhang & Chai 2010	*"Cloud manufacturing is a service-oriented, knowledge-based smart manufacturing system with high efficiency and low energy consumption"*
Tao et al. 2011b	*"Cloud manufacturing is a new service-oriented manufacturing model, and it integrates different technologies such as networked manufacturing, cloud computing, IoT, virtualization and service-oriented technologies to support collaboration, sharing and management of manufacturing resources"*
Mezgár 2011	*"Cloud manufacturing is an integrated supporting environment both for the sharing and integration of resources in an enterprise. It provides virtual manufacturing resource pools, which foster the heterogeneousness and the regional distribution of resources by way of virtualization. Cloud manufacturing provides a cooperative work environment for manufacturing enterprises and individuals and enables the cooperation of enterprises"*
Tai & Xu 2012	*"Cloud manufacturing is a new service-oriented, efficient and energy-saving, knowledge-based, networked intelligent manufacturing model. Heterogeneous manufacturing resources can be virtualized and deployed on the cloud service platform, and they are shared by different complex collaborative manufacturing demands. The services are used to offer support for all stages in the full lifecycle of manufacturing, covering product design, simulation, experiment, fabrication, and logistics. The aim of cloud manufacturing is to organize effectively all kinds of manufacturing resources separated in different enterprises"*
Kłosowski 2012	*"Cloud manufacturing is 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) which can be rapidly provisioned and released with minimal management effort or service provider interaction"*
Wu et al. 2013b	*"Cloud manufacturing is 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, reduce product lifecycle costs, and allow for optimal resource loading in response to variable demand customer-generated tasking"
Qanbari et al. 2014	*"Cloud manufacturing is a distributed manufacturing execution model, where underlying resources envisaged in the internet of things are elastically exposed and utilized as cloud services, then composed and orchestrated for utilization as cloud services, then composed and orchestrated for a manufacturing task in an on-demand fashion"*
Ren et al. 2014	*"Cloud manufacturing is a smart networked manufacturing model that embraces cloud computing, aiming at meeting growing demands for higher product individualization, broader global cooperation, knowledge-intensive innovation and increased market-response agility"*
Chen et al. 2014	*"Cloud manufacturing is a computing and service-oriented manufacturing concept developed from existing advanced manufacturing models, architectures, and enterprise information technologies under the support of IoT, service computing, virtualization, and advanced computing technologies"*

By summarizing and comparing all the definitions, it is clear that a shared understanding is the manufacturing resources (hardware and software) and capabilities transformation, from physical products into intangible cloud-based services, and then managing services over the Internet (He & Xu 2015).

2.5.2 Comparison with Current Manufacturing Paradigms

Although the concept of cloud manufacturing is new, the fundamental concepts, such as virtual enterprise and distributed manufacturing concepts, have been in existence for some time, and some of the proposed systems and frameworks bear visible traces of cloud manufacturing or make contributions to cloud manufacturing systems. This section discusses some of these research outcomes.

Several new manufacturing paradigms have been proposed in recent years to solve manufacturing problems and overcome the classical manufacturing challenges. In this section, different research intensification on new manufacturing paradigms is presented. In parallel, the differences with cloud manufacturing are discussed in Table 5.

Table 5. Other manufacturing concepts proposed recently

Concepts	**Main references**	**Definition/Characteristics**	**Difference to cloud manufacturing**
Crowdsourcing	Ren et al. 2014 ; Wu et al. 2012	It is based on an 'idea competition' model. A particular business problem is outsourced to the general public or a large targeted group, and expertise can all participate to get the best results/solutions.	Customers have vague ideas about their product, no specific target services providers. It mainly focuses on collaborative design process.
Networked manufacturing	Park & Jeong 2013	It refers to the integration of distributed resources for a small-scale collaborative environment for a single manufacturing task.	The centralized operation management of the services is lacking in this business model. It limits in the choice of different operation modes, and embedded access of manufacturing equipment and resources.
Agile manufacturing	Yusuf, Sarhadi & Gunasekaran 1999; Chituc & Restivo 2009; Helo, Xiao & Jiao 2006	It creates the environment to enable a quickly respond to customer needs and market changes while still controlling costs and quality. The four main characteristics of agile manufacturing are visualization, market sensitivity, integration cooperation, and being network-based.	Emphasizes the adjustment to unexpected changes or events, but it mainly focuses on enterprise-wide operations. Cloud manufacturing also covers external operations (cross-enterprise).
Virtual Manufacturing	Chen et al. 2014	Different computer models and simulation technologies are used to digitalize the manufacturing processes and	In cloud manufacturing, it covers not only network supported manufacturing process, but also points

		the production of products.	out business collaborations
Grid Manufacturing	Tao et al. 2011b; Ai et al. 2013	Provides a supportive environment to coordinate distributed and heterogeneous manufacturing resources.	Grid manufacturing focuses on resources integration, but cloud manufacturing also considers resource distribution.
Holonic manufacturing	Chituc & Restivo 2009	A holon is an autonomous and cooperative manufacturing block with hierarchical control manufacturing information and physical objects.	It is short of standards to be widely accepted, it only covers manufacturing partially. In contrast, cloud manufacturing covers the entire manufacturing processes.

However, these most of models concentrate on discussion of applications along product lifecycle manufacturing (Lartigau et al. 2015). In the research area of networked and virtual manufacturing, the limitations are flexible operation model, real-time access of physical resources, and security (Lartigau et al. 2015). Helo, Xiao & Jiao (2006) highlight three requirements of structural changes in agile management operations: the collaboration and synchronization of partners, utilization of ICTs, and a new supply chain infrastructure and operations model. Hence, the research focus should move towards more advanced business model, cloud manufacturing.

3 METHODOLOGY

The research methodology employed in this dissertation is presented in this chapter. It includes the definition of research questions, philosophical foundation, and details of research approach and design. Moreover, data collection and analysis methods and research quality control are assessed.

3.1 Research Questions

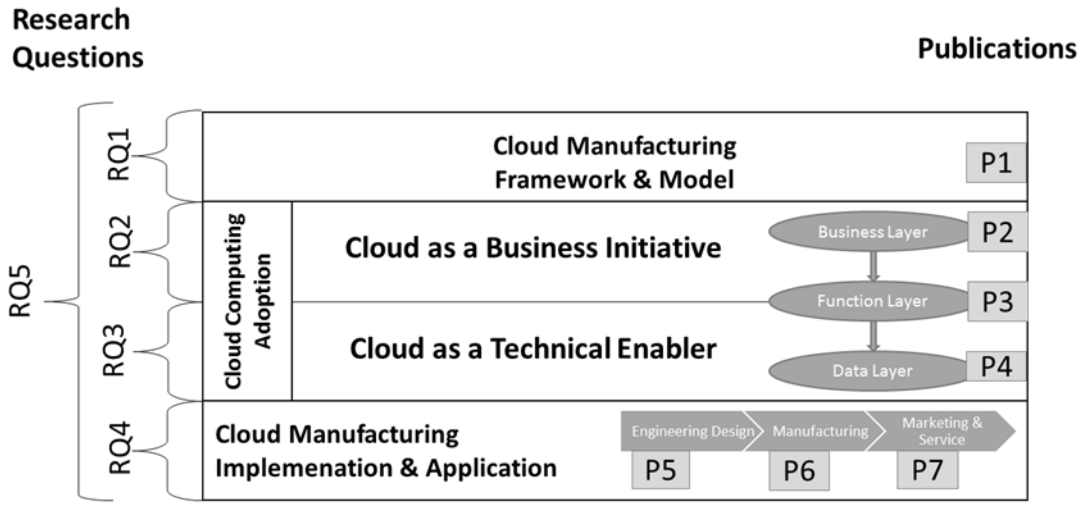


Figure 9. General view of the research questions and approach used in this dissertation

The problem statement defines and presents the issue to frame specific questions. In this dissertation, five research questions (RQ1-RQ5) were designed based on pre-defined research problems (RP1 & RP2) to establish the link between this research and other previous research. Seven publications (P1-P7) were included to address these research questions. An overview of the relationships between the research questions and publications is delineated in Figure 9.

In this research, cloud manufacturing is a complicated concept with multi-granularity features. It is supported by cloud-related technologies, and enables collaboration and communication among enterprises and individuals for the entire manufacturing process based on demand. As cloud manufacturing is not a well-defined field of study, most research areas within this field are delineated by assumptions. The priority is to define the scope of cloud manufacturing. The first research question is as follows:

> ***RQ1: What is the concept of cloud manufacturing?***

Cloud manufacturing is a repository of multidisciplinary knowledge from the viewpoints of both business and technology. From the business perspective, it is potentially creating new business models (Wu et al. 2012). From the technical perspective, it makes use of internet- and cloud-based architectures, and manages the manufacturing resources for sharing and collaboration (Laili et al. 2012). Cloud manufacturing leverages cloud computing in existing manufacturing business models and IT infrastructure. Therefore, RQ2 & RQ3 are structured as follows:

> ***RQ2: What are the overarching business opportunities of cloud manufacturing?***
>
> ***RQ3: What are the primary technical implications of cloud manufacturing?***

Customer relationship management (CRM) is one of the first business applications to have been deployed on the cloud to streamline the workflow and communication with customers. In addition, Enterprise Resource Planning (ERP) is another important application deployed on the cloud, and it is used to coordinate the various business functions of a manufacturer. But there are more applications for different business purposes. However, prevailing research that deals with cloud computing and cloud manufacturing domains does not cover how to implement cloud manufacturing in practical terms, and does not have any methodology to show how to build up a robust architecture to achieve the goal in steps (Talhi et al. 2015). Therefore, RQ4 is intended to show some examples of cloud applications in supporting business for the manufacturing industry.

> ***RQ4: How to implement and transform applications to cloud manufacturing?***

It is important to determine how much benefit a company can obtain from moving those systems to the cloud. In order to take full advantage of the potential of cloud manufacturing, it is imperative to determine how it can be employed and how its applications can be implemented to promote sustainable competitive advantage. It is important to remember that migrating to the cloud does not have to be an ‘all-or-nothing’ proposition. All the business related considerations, such as operations, partnerships, and industry value chains, need to be taken into consideration (Downing & Schultz 2015). Therefore, it is important to determine how to leverage the cloud to shape and support business strategies, and make sure that the cloud manufacturing strategy is appropriate for the business goal.

> ***RQ5: How can manufacturers anchor a cloud manufacturing strategy within its business context?***

When looking retrospectively, there are five major research themes (RT). These research themes closely correspond to the research questions and are derived from analysis of prior research. The research themes that outline the results of the research are cloud manufacturing concept (RT1), cloud manufacturing business implications (RT2), cloud manufacturing technological implications (RT3), cloud manufacturing applications (RT4), and cloud manufacturing adoption strategy (RT5). The relationships of research themes (RT), research problems (RP), research questions (RQ), and publications (P) are demonstrated in Figure 10.

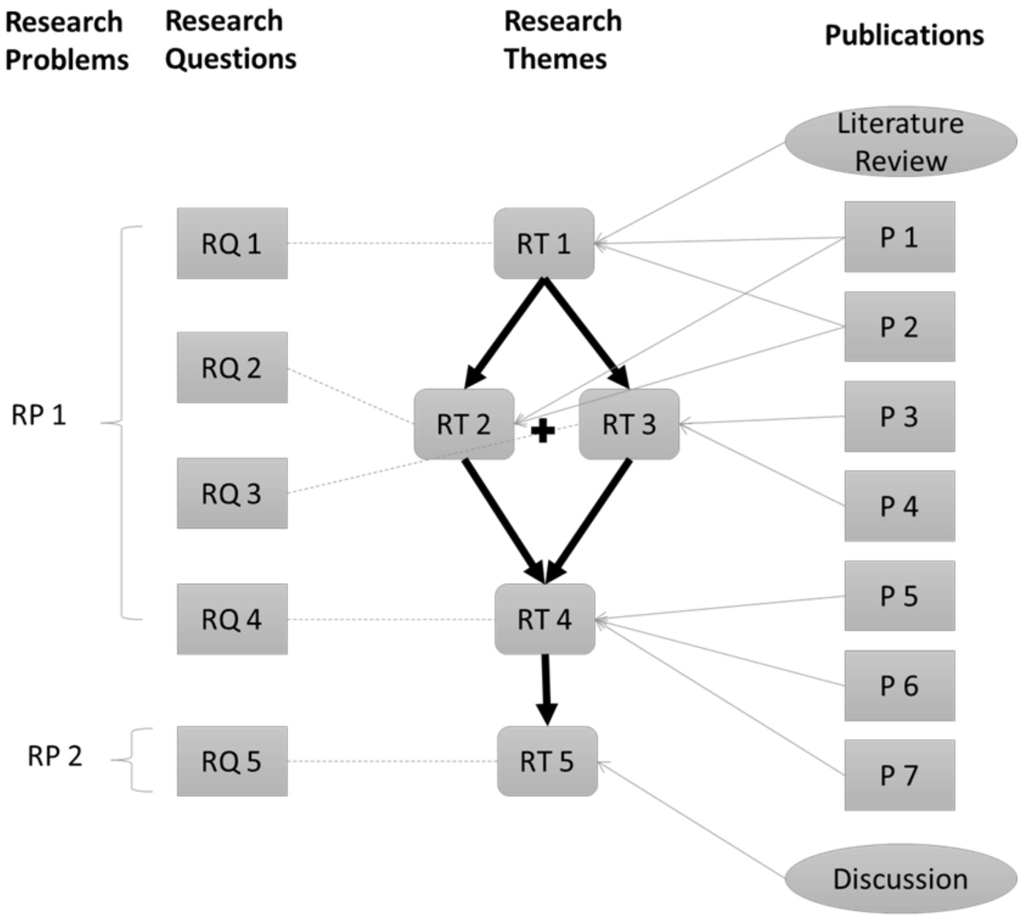


Figure 10. Overview of the research themes and how the selected publications are positioned

3.2 Research Strategy

Research is a systematic investigation to interpret collected data and to understand a particular phenomenon or to answer specific questions (Mackenzie & Knipe 2006). The research onion (Saunders et al. 2009) is a metaphor of the research design process. It illustrates all the research paradigm elements and helps researchers to understand the research process and guide them to make research decisions (Saunders & Tosey 2012). The research paradigm explains the way researchers studying and interpreting relevant knowledge (Mackenzie & Knipe 2006). Table 6 systematically categorizes the research process according to six dimensions, which represent all the layers of the research onion, from the outermost layers to the subsequent inner layers. The core of this onion is the selection of techniques used to obtain data, along with the procedure to analyze these data (Saunders & Tosey 2012).

Table 6. All layers of the research onion elements and their associated options

Research Onion Layers	**Options/Traditions**
Research Philosophy	Epistemology: Objectivism; constructionism; subjectivism; Ontology: Positivism; Realism; Interpretivism; Pragmatism.
Research Approaches	Inductive; Deductive; Abductive.
Research Methodologies	Quantitative approach (Roots in positivism); Qualitative approach (Labeled as interpretivism).
Research Strategies	Experiment, Survey, Case study, Grounded Theory, Ethnography, Archival Research; Action Research; Narrative Inquiry.
Time Horizons	Cross sectional; Longitudinal
Data Collection Methods	Sampling; Secondary Data; Observation; Interviews; Questionnaires

Research philosophy is a fundamental set of beliefs that guide research actions, and it represents researcher's stand point of knowledge (Saunders & Tosey 2012). Research philosophy has two branches: epistemology and ontology. Epistemology leads an imperative position in many kinds of research (Crotty 1998; Eriksson & Kovalainen 2008) and it helps to determine the researcher's view regarding what constitutes adequate knowledge. Ontology is the study of how something existed by its nature.

The nature of the relationship between theory and research is an important factor. The deductive approach means formulating hypotheses based on theory and then guiding research to examine particular phenomena. On the other hand, the inductive approach means using empirical material to conduct research leading to theoretical results (Bergman 2008). Most researchers use a mixture of both approaches in their research processes, which means abductive reasoning. When researcher's objective is to discover new things, they use inductive and abductive approaches; on the other hand, the deductive approach is fruitful when developing propositions from new theory and attempting to test the theory in the real world (Dubois & Gadde 2002).

Based on the different scientific paradigms, two main research methodologies are: quantitative approaches (originating from positivism) and qualitative approaches (originating from interpretivism) (Eriksson & Kovalainen 2008; Gummesson 2000). They are considered from different research philology.

In most of information systems research with the aim of designing and implementing innovative business solutions, a design-oriented approach is chosen (Österle et al. 2010). The main goal of this research is to use design-oriented research to create a holistic understanding of cloud manufacturing, and to provide guidelines for the innovation and operation of cloud manufacturing platforms. This research follows the subjective interpretive approach. A qualitative case study is adapted to follow inductive reasoning from specific cases to general theory. Case study approach is an optimal option when the theories are still in the formative stage (Benbasat et al. 1987). Qualitative research focuses on understanding the key features of the cloud manufacturing phenomenon and its ecosystem. This research mainly focuses on 'what' and 'how' questions that belong to exploratory research. Therefore, case studies are used in this research.

3.3 Research Approach

Case study research is often used to examine the characteristics of a real-life case and to answer the questions of 'why', 'what' and 'how' (Meyer 2001). It emphasizes both the details of research and holistic knowledge based on empirical sources (Tellis 1997; Eriksson & Kovalainen 2008; Meyer 2001).

There are two main challenges with case studies, namely generalization (Gomm et al. 2000) and unexpected conditions of object during the process of the case study (Dubois & Gadde 2002). However, they are beneficial when other companies facing similar problems and struggling with similar challenges. It is important to follow an appropriate approach to face the challenges.

Different data collection methods are applied in case studies to get research data from different aspects, such as interviews, questionnaires, and observation. The combination of a quantitative spirit and qualitative data can produces better results (Yin 2009; Flyvbjerg 2006; Voss et al. 2002; Eisenhardt 1989; Eriksson & Kovalainen 2008).

Normally, case studies can include a single case or multiple cases, but single-case studies limit the generalizability and produce information-processing biases (Eisenhardt 1989; Leonard-Barton 1990; Eriksson & Kovalainen 2008; Yin 2009). Therefore, to counter the bias of a single case study, this study builds on a complementary in-depth investigation of four original cases to generalize the results. The case studies defined real-world industrial scenarios.

In-depth multiple case studies were selected as the primary method of this research to examine the concepts and issues related to cloud manufacturing. However, the case study is a loose research design; it requires appropriate decisions on the research process. One of the critical steps in forming a series of case studies for this research was to obtain a common approach for all the case companies. Both Eisenhardt (1989) and Yin (2009) outline the processes of conducting case studies. These generally accepted frames were adapted in this research and a case study process was created to build up theories.

Figure 11 presents the five phases of the research methodology, and these research practices were organized following this structure. This research steps meet the conditions defined for the case study method described by Eisenhardt (1989) and Yin (2009).

The first phase focuses on defining the research questions and selecting the cases. The research questions helped to define the scope of this research. Certain case selection criteria were identified to choose the case companies. The second phase focuses on defining the business case and the interview procedure. This step limited the scope of each case, and the initial situation and an overview of the companies were presented. The third phase includes the actions of conducting interviews with key users from the case companies. All the collected data were analyzed within the cases. The main objective of the fourth phase is to find out relevant conceptual frameworks and identify current prevailing trends through an intensive literature review, simultaneously understand the case companies, and then generalize the research results which can contribute to the theory. The final phase is to establish the final discussion and specify future research.

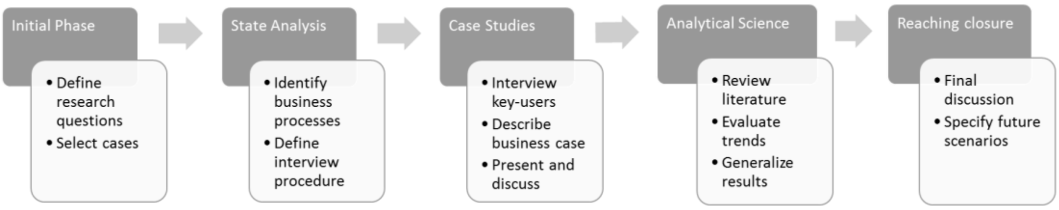


Figure 11. Five stages of the research methodology

3.4 Case Studies Design

Structured interviews were conducted in this research with management personnel from the case companies. Information about the companies' business objectives, manufacturing strategies, potential partners, and specific business requirements were analyzed, collected, and compared. Domain experts such as managers, employees, workers, etc., were interviewed to gather details about the current manufacturing process. The interviews were designed and performed according to Yin (2009)'s semi-structured interview guide. The interviews were organized as face-to-face personal meetings. This approach eliminated possible misunderstandings during the data collection process. Additionally, workshops and follow-up meetings were organized with domain experts to verify and validate the data collection. By such a series of actions, a comprehensive understanding was created about the requirements, challenges and development opportunities of cloud manufacturing.

There are various strategies with regard to the case selection process. However, the strategies are not necessarily mutually exclusive (Flyvbjerg 2006). The interpretation of a carefully selected case can provide valuable information, because various perspectives have been considered (Flyvbjerg 2006). The replication approach for case studies is different with the process of survey replication (Eisenhardt 1989). The findings of each case study will be used as data in other case studies, although each individual case consists of unique evidence, facts, and conclusions (Yin 2009). The summary of case studies should be the results part of the research as has been done in this particular research.

Although there are many aspects of manufacturing as there are in any sector, there are also similarities with those in business. For example, all manufacturers have customers and suppliers, they follow certain processes, and they look to increase efficiency and reduce waste. Thus, in order to rationalize the requirements for the collection process and formulate the case study process for this research, there are several choices involved in the selection of the cases. In this study, the cases companies were carefully selected to illustrate cloud manufacturing from different aspects and to understand different operation processes. To obtain a comprehensive understanding of the core of cloud manufacturing, the case selection included different dimensions and various factors. Therefore, four dimensions were considered when selecting appropriate case companies:

- Different business fields
- Different business sizes
- Different business focuses
- Different levels of collaboration among the partners and customers

Table 7 defines the selection of the case studies. These are of great use for organizations to gain a specific insight into their market positioning, collaboration situations, and in the end lead to a sound collaboration strategy and future direction in cloud manufacturing. Each case company represents some unique characteristics of cloud manufacturing and all the cases together enrich and complete each other, and maximize the applicability of the research results. They jointly bring new insights to the topic under investigation.

Table 7. Case company selection and reasoning of the selection

Case Company	Company Name	Sector/Field; Size	Focus on Organizing	Reasoning	Publications
CC1	PrimaPower	Machinery industry, large size	It is a worldwide manufacturer, which developing, manufacturing, and marketing different types of sheet metal processing machinery and solutions, such as laser processing, punching, shearing, bending, and automation.	Services are an important part of this company's solution and its activities. Its target is to provide a professional and effective support to its customers all over the world. Thus, it needs an integrated solution to support its internal and external management. Therefore, this company was selected to generate an overview conceptual understanding of cloud manufacturing.	1, 5, 7
CC2	ABB Oy Distribution Automation	Power and automation industry, large size	It develops and manufactures protection and control solutions of power products, ranging from single switches to complete electricity grids that support utility and industry customers.	Its products and solutions are applied in different countries and environments; and it is inevitable to partially adjust these products to changing requirements. Thus, it always collaborates with other suppliers (normally SMEs) and manufactures its products at different sites. For this company, it is important to take care of its supply chain. Therefore, this company is a target user of cloud manufacturing. It was selected to identify the business requirement of cloud manufacturing.	2, 4

CC3	Azevedos Indústria SA	Cork transformation industry, medium size	It designs, develops, produces, and sells equipment and machinery in casting, bending, milling, CNC (Computer Numerical Control), image process, etc. for the Cork Transformation Industry. It also provides post sales assistance for a wide range of production machinery.	Due to lack of competencies in some operations and the desires of increasing productivity by reducing delivery time to customers, this company outsources activities that are not covered by in-house competencies. Therefore, this company is a target user of cloud manufacturing. It was selected to identify the business requirement of cloud manufacturing.	2, 4
CC4	The Switch	Renewable energy industry, medium size	It provides permanent magnet generators and full-power converters for the global wind power market. Customized technologies and applications are also provided to add value to its customers.	This company provides innovative technology, new business services, and flexible business models to its customers. Hence, it attempts to establish agile partnerships with its customers to serve their dynamic business requirements. The R&D (Research & Development) is centralized but the near-customer partners are selected to perform the production related activities. It requires a cloud manufacturing to manage its relationships with partners and monitor its production. Therefore, this company was selected and its business processes were described to demonstrate the manufacturing process in cloud manufacturing.	6

3.5 Data Collection and Analysis

Data collection is a critical part, and it is very important to evaluate and select an appropriate data collection method based on the research purpose (Bryman 2008). This study includes interviews and workshops from the case companies to collect primary data. The interview results were transcribed and arranged in written format. This primary data were collected as a foundation for the required analysis.

Applying inductive logic is suitable for this particular research, which aims to build a combination of all the cases and to understand the phenomenon of cloud manufacturing. This research includes seven publications, and each publication address different research questions. Every case used in each publication is slightly different to the others and focuses on different issues. The method and results of each publications are presented in the second part of this dissertation. Table 8 shows the summary of publications.

Table 8. Summary of publications

	Publication 1	Publication 2	Publication 3	Publication 4	Publication 5	Publication 6	Publication 7
Title	Cloud Manufacturing Towards Sustainable Management	Virtual Factory System Design and Implementation: Integrated Sustainable Manufacturing	A Holistic Analysis of Cloud Based Big Data Mining	Cloud-based Data Storage for Data Management in Virtual Factory	Cloud manufacturing approach for sheet metal processing	Toward a cloud-based manufacturing execution system for distributed manufacturing	The role of wearable devices in meeting the needs of cloud manufacturing: a case study
Channel	IGI Book chapter: Business Transformation and Sustainability through Cloud System Implementation	International Journal of Systems Science: Operations & Logistics (Available online)	International Journal of Developments in Big Data and Analytics. Volume 1 No. 1 2014, Pages 60—68	Palgrave Macmillan Book Chapter: Cloud System in Supply Chains	Production Planning & Control (Accepted)	Computers in Industry Journal, Volume 65, Issue 4, May 2014, Pages 646–656	Robotics and Computer-Integrated Manufacturing (Available online)
Objectives	Defined the scope of cloud manufacturing and demonstrated implementation of cloud manufacturing in large size company. It also discusses cloud manufacturing achieving sustainability.	Designed a VFIS to help the SMEs collaborating with each other. It is interesting to aware VF as a foundation of cloud manufacturing.	Discussed the impact of big data and cloud computing in the manufacturing industry.	Provided a solution to implement cloud-based data storage in the VF environment to cope with the challenges of distributed supply chain.	Discussed the production plan and control in terms of cloud manufacturing and provided a system to solve practical optimization problems in PPC.	Designed a system to link the back office with shop floor and improved the machine utilization & rapid capacity scalability in cloud manufacturing.	Adopted a holistic approach to present some opportunities for wearable technologies as a supporting tool for cloud manufacturing applications.

Cases	Method	Data collection	Dataset	Analysis	Researcher role	Research Question
CC1	Case study	Interview; session observation	4 meetings with 1 R&D manager.	Qualitative analysis	1st author: extensive literature review, participation in the observations and analysis.	RQ1, RQ2
CC2,CC3	Case study	Interview; workshop; text documents related to companies; prototype	7 meetings with 4 industrial managers.	Qualitative analysis	1st author: literature review, participate in analysis of data.	RQ1, RQ2
/	Grounded theory, state analysis	Extensive literature review	Literature from various journals.	Literature review	2nd author: literature review, participate in analysis of data	RQ3
CC2, CC3	Case study	Interview; workshop; text documents related to companies; prototype	7 meetings with 4 industrial managers.	Qualitative analysis	1st author: literature review, participate in the analysis of data.	RQ3
CC1	Case study	Requirements collection; session observation; prototype	2 meetings with 12 domain experts; request for proposals with a list of requirements.	Qualitative analysis	2nd author: extensive literature review, participate in the data analysis.	RQ4
CC4	Case study	Requirements collection; Prototype	Request for proposals with a list of requirements.	Qualitative analysis	3rd author: extensive literature review, participate in the data analysis.	RQ4
CC1	Case study	Interview; session observation	2 observations of 2 operators' daily work, and 4 meetings with 2 R&D managers and 1 software engineer.	Qualitative analysis	1st author: extensive literature review, participation in the observations and analysis.	RQ4

3.6 Quality Control in Qualitative Case Studies

In every qualitative research, it is important to perform quality control and evaluation. Classic criteria for study quality are considered from three aspects (Eriksson & Kovalainen 2008):

- Reliability refers to designing the research in a repeatable approach, so when other researchers intend to conduct the same study, they can get similar results and findings.

- Validity refers to testing the accuracy and genuineness of conclusions drawn from the research.

- Generalizability tackles the issues of applying the method or results to a wider context one way or another.

In this research, an article based collection is selected as the dissertation approach. Several in-depth case studies were conducted to guarantee reliability and validity, and combining the results from different case studies can guarantee the generalizability. The quality control was conducted throughout the whole research process. Firstly, multi-source of evidence can increase the validity of this research. In the research design phase, replication logic was used in the multiple case studies. This is to perform external validity and ensure the study’s findings can be generalized beyond the case studies. Secondly, in order to ensure the quality of the qualitative study and the quality of the primary data collection, most of the interviewees were contacted in advance and had explained to them the key features of the research. Thirdly, collaboration in the research was important to ensure reliability. For instance, several researchers in a professional academic environment were participating the case studies, and the final research results were also validated by one of the co-authors.

4 RESULTS

This chapter presents summaries of all the publications with their objectives and contributions. Each of the selected publications contributes in its own way to the overall research results. The findings of each publication are summarized in Table 9.

Table 9. Summary and contributions in brief

	Contributions to the dissertation
P1: Cloud Manufacturing Towards Sustainable Management	● Introducing cloud manufacturing and its characteristics ● Developing a conceptual model of cloud manufacturing to foster internal collaboration of large organizations ● Emphasizing information exchange and communication across the whole manufacturing collaboration ● Pointing out the role of cloud manufacturing in supporting R&D, MES, and shop floor
P2: Virtual Factory System Design and Implementation: Integrated Sustainable Manufacturing	● Emphasizing the importance of collaboration in manufacturing industry to achieve sustainability and flexibility ● Designing the architecture of virtual factory to support SMEs working collaboratively in an integrated virtual environment ● Developing a cloud-based virtual factory (VF) platform to manage geographically distributed manufacturing activities across manufacturing lifecycle ● Providing a dashboard design idea to demonstrate the communication platform
P3: A Holistic Analysis of Cloud Based Big Data Mining	● Presenting big data and its relevant challenges ● Describing the importance of big data analytics in term of supporting cloud manufacturing integration and collaboration
P4: Cloud-based Data Storage for Data Management in	● Presenting the challenges of supporting manufacturing integration and collaboration ● Emphasizing the importance of implementing cloud-based data management solution in a virtual factory

Virtual Factory	environment ● Providing cloud-based data storage to manage various types of data from various resources
P5: Cloud Manufacturing Approach for Sheet Metal Processing	● Proving an overview of cloud manufacturing in a sheet metal forming company ● Presenting a cloud-based production planning and production system for sheet metal processing ● Illustrating the interoperability of various manufacturing systems ● Providing multiple level production optimization as a service in cloud manufacturing
P6: Toward a Cloud-based Manufacturing Execution System for Distributed Manufacturing	● Pointing out the importance of an integrated solution in a single platform to support distributed manufacturing ● Designing a cloud-based MES for distributed manufacturing ● Achieving the integration of ERP and MES systems to support the whole cloud manufacturing lifecycle ● Using private cloud deployment to decrease the security risk
P7: The Role of Wearable Devices in Meeting the Needs of Cloud Manufacturing: a Case Study	● Supporting the field service management in terms of cloud manufacturing ● Considering humans as a resource on the shop floor and providing a knowledge integration framework in cloud manufacturing ● Designing of a cloud-based help center and providing remote monitoring and assistance to customers

It is worth noticing that the terminology virtual factory (VF) was used in P2 and P4. The different between VF and cloud manufacturing is mainly because of different perspectives. Cloud manufacturing explains more the relationships between different manufacturers and how they collaborate in tandem. VF refers to the dynamic combinations of various manufacturing services to customers. Customers can access all the services as they are provided by one organization and shown as one facility. The customers will not be aware of the physical location or nature of the infrastructure providing the service. The use of different terms depends on the perspective and purpose of the research. The definition of cloud manufacturing should be synonymous with the VF.

4.1 Cloud Manufacturing Concept

Cloud manufacturing is proposed for the whole product realization lifecycle, from pre-manufacturing, manufacturing, to post-manufacturing (**P1; P2**). Cloud manufacturing is mostly concentrated on the 'integration of distributed resources' and the 'distribution of integrated resources' (**P5**) and providing all manufacturing resources as services based on customers' requirements. In cloud manufacturing, the definition of services is extended to a broader scope. The manufacturing services are not limited to the conventional end-user-oriented domain, but cover all phases of the manufacturing lifecycles, from design, simulation, production, testing, maintenance, after-sales services, logistics and integration. The cloud manufacturing lifecycle, from JOIN, SEARCH, PLUG & PLAY, is in accordance with the product lifecycle (**P1; P2**).

There are two principles of cloud manufacturing: autonomy and aggregation. Organizations or individuals in this cloud manufacturing environment are autonomous, but they are aggregated together based on their needs from cloud manufacturing (**P2**). However, cloud manufacturing makes it possible for different manufacturers to share their best practices and their unique or spare manufacturing resources/capacities in an industry-specific resources pool. All the companies can manage, schedule and optimize the cloud/manufacturing resources/capabilities and share them with other companies.

A company can act different roles in a cloud manufacturing platform depending on its business scope, business goal, and business structure. Agents are the primary controllers in the cloud manufacturing platform. They collect orders and publish business requirements. Partner factories, which are suitable and specific to the production process, are searched by the agent. The best fit partner factories are screened with strict specification checking. The selected partner factories are temporarily procured to the manufacturing processes (**P1; P2**).

Cloud manufacturing is considered as 'a system of collaborations', as shown in Figure 12. The general idea is to provide a cooperative work environment in the entire manufacturing ecosystem. This model enables both internal and external communication and collaboration across multiple companies. With the support of the cloud, manufacturing resource pools can manage geographically distributed manufacturing resources by collecting and reallocating them. Production services are distributed to other factories to seamlessly enable manufacturing process on demand.

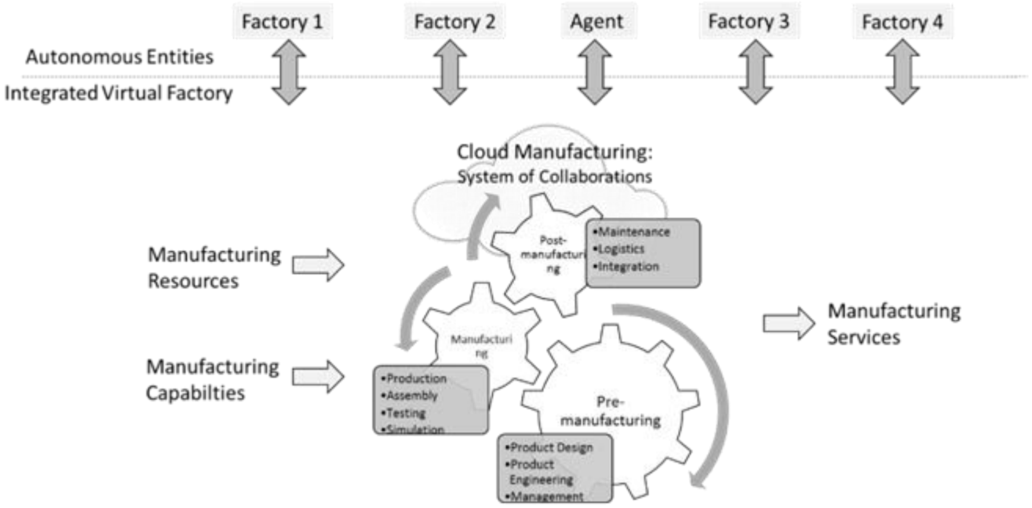


Figure 12. Cloud manufacturing concept

4.2 Cloud Manufacturing Business Implications

Cloud manufacturing aims to break two significant constraints for multiple collaborating manufacturers: geographical distributed and temporality. It can achieve both business and manufacturing collaboration between enterprises by the sharing and integration of various manufacturing resources. Cloud manufacturing offers transparent resources and support automatic processes. It increases the level of business transparency and flexibility by dynamic configuration and portability. Cloud manufacturing can be designed for collaboration and can be used to facilitate communication. This collaboration can be discussed from two aspects: intra-communication and inter-communication. Case 1 in **P1** describes how cloud manufacturing implemented for large global manufacturers that have multi-manufacturing sites distributed across the world, can ultimately integrate distributed production lines. Case 2 and Case 3 in **P2** illustrate how geographically distributed manufacturers can collaborate together to fulfill specific customers' requirement. However, the manufacturers are self-organized individual companies. **P1** and **P2** together show how cloud manufacturing implemented for different size companies, and cloud manufacturing formation can be of benefit both for single factories and also for multiple factories working together.

The cloud manufacturing conceptual model is designed based on these three levels (Figure 13). These three levels (**P1**) utilize the entire product lifecycle information from product design, manufacturing process, and after sales services to the customer. The two surrounding bands indicate vertical information integration (across different organizations, e.g. customer, partners) and horizontal information sharing (across different departments, i.e. internal collaboration from digital order process, dynamic product design to product development process):

- Manufacturing resource level: provides the manufacturing resource and capability as services in the whole lifecycle of manufacturing to users. The resource level contains virtualized physical resources managed within a resource pool.
- Technology support level: provides a basic operation technical support environment, which includes data storage resource, e.g. cloud database.
- Business management level: is a business process and commerce transaction definition layer that enables communication between different business partners and stakeholders. This level provides the management capabilities required for all types of services. It provides a holistic view of the infrastructure and end-to-end visibility.

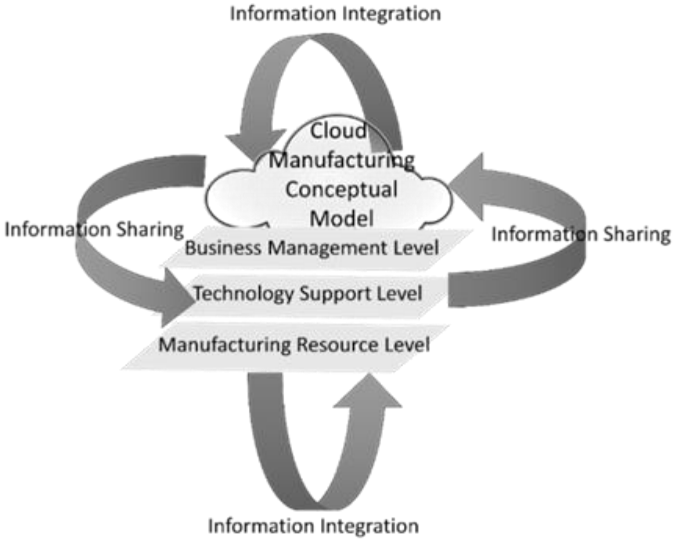


Figure 13. Cloud manufacturing business implications

4.3 Cloud Manufacturing Technical Implications

The scope of manufacturing industry extends not only from the physical product but also to handling product data and information. Information is the glue for collaboration and cooperation, and also for QoS (Quality of Services). It is the input of every service and the output of services. Companies are making efforts to achieve effective business decision-making by accurate data-driven insight. **P3** and **P4** describe cloud-based databases and the coming trends in big data. A data model is a way to achieve collaborative integration. Cloud computing can help outsourced manufacturers to concentrate on process integration and data visibility in different business processes and also minimize data transfer.

Many companies have realized that big data and cloud-based data storage are a game changer for the manufacturing industry (**P3**). Considering the benefits of integrating data streams from multiple manufacturing companies, customers and partners could enable collaboration and eliminate heterogeneity. There are two key features of data management in a cloud manufacturing environment, as shown in Figure 14:

- First, the amount of data is massive (**P3**) and the number of devices and sensors is increasing along with their capability of information processing. Normally, data are continuously generated by embodies technologies and attached markings, such as, barcodes, data tags, augmented code, RFID, and so on, and then the data are streamed back and collected by systems. The velocity of data aggregation and processing are also increasing.
- Second, the types of data are extremely varied (**P4**) because geographically dispersed data have a wide variety of locations, sources, types, and purpose. Moreover, when the data are constructed as different production information, they can be used for different functions. Therefore, constant data integration is paramount.

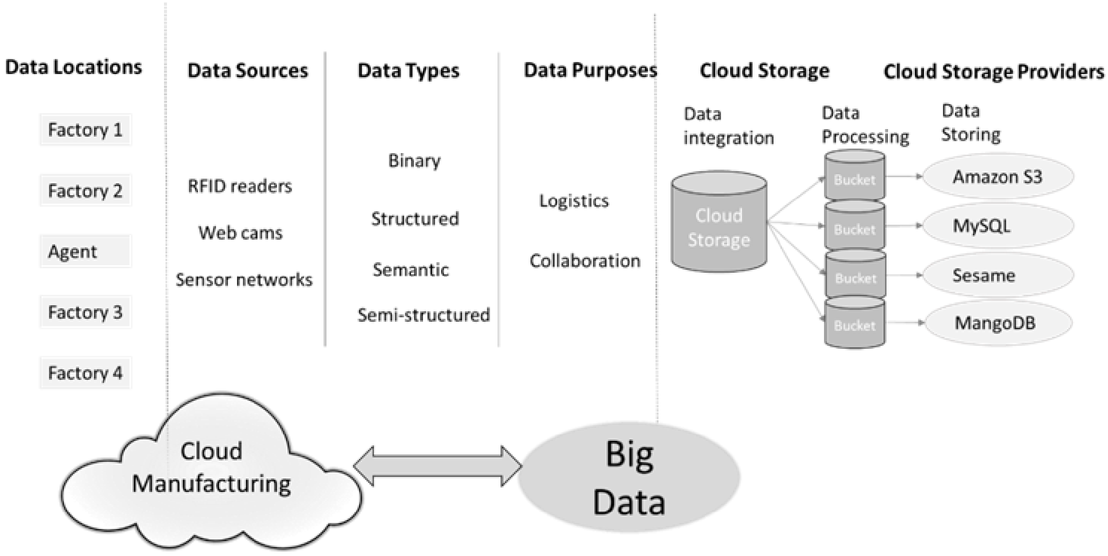


Figure 14. Cloud manufacturing technological implications

P3 & P4 describes the advent situation, where a massive amount of historical data, either semi-structured or unstructured, is generated when devices changing status. The great deal of data needs to be efficiently and properly managed, organized, stored, and analyzed. It is vital to provide a constant data integration solution and highly available analytical methods and tools (**P3**). The problem is that different data sources have different data formats, so **P4** demonstrates a cloud-based data storage system with different data buckets to integrate all the data. The main aim of this part is to improve access to unstructured data and processes.

4.4 Cloud Manufacturing Applications

This research theme points out the implementation of cloud-based applications in a cloud manufacturing environment. In **P1** and **P2**, the cloud manufacturing platforms are designed for both internal collaboration for large size organizations (ultimately integrated-distributed production lines), and external collaboration for SMEs (cross-factory manufacturing governance). **P5**, **P6** and **P7** demonstrate how to implement cloud-based applications to solve particular cloud manufacturing problems. **P5** focuses on production planning and control (PPC), **P6** focuses on manufacturing execution systems (MES), while **P7** focuses on customer services, remote monitoring and assistance (RMA), respectively. These applications were chosen because they served different departmental needs with large numbers of users. Therefore, there was a need to quickly implement these cloud-based solutions.

To achieve cloud manufacturing, there is a need for a real and deep knowledge of current procedure in manufacturing enterprises and of future needs as well as various stages of production activities. P2-P7 show the business requirements from different companies as CMP potential users, and also show how cloud-based applications can be delivered from CMP and meet the manufacturing-specific requirements. It is very critical to fulfill the key implementation requirements of CMP and translate the requirements into the operations of achieving cloud manufacturing, as follows:

- Providing an interactive form: P2
- Enabling a partner selection mechanism: P2
- Web portal-based solutions with dashboard and key performance indicator (KPI) monitoring: P2

- Data security and backup: P4
- Providing interface with real-time access to resources: P5
- Integrating enterprise systems in SaaS model: P6
- Enabling operator collaboration in a virtual environment: P7

The cloud manufacturing platform needs to be enhanced with different IT supporting tools: here in the case studies, PPC, MES, and RMA are introduced. All these cloud-based solutions jointly promise a seamless integration of information flow throughout the company and the entire supply chain:

- PPC provides a real-time view of the production lines. CloudPPC is capable of serving multiple levels of optimization in planning, control and collaboration for distributed manufacturing (**P5**).

- MES facilitates machine and device monitoring on the shop floor. CloudMES provides real-time information and communication in the shop floor. Both managers and operators can access information for management purpose and for operation purpose. Only inter-integration down to shop floor level can support production related inter-enterprise integration. It links manufacturing related strategic planning and direct execution information with enterprise resource related management and control information (**P6**).

- RMA monitors the operators and supports the maintenance process. In the pursuit of illustrating the potential benefits of wearable technologies in the field of cloud manufacturing on the shop floor, **P7** presents an interesting demonstration. Smart glasses, as one of the key wearable technologies, provide more mobility to operators, and unify the manufacturing shop floor to the top floor. This new technology expands the collaboration scope in a cloud manufacturing environment, and enables remote operation and remote monitoring, as well as effective collaboration on troubleshooting related issues. These technologies can both monitor the status of machines in their daily operation and also centrally provide remote assistance to operators (**P7**).

Figure 15 presents cloud manufacturing fulfilling different functional requirements, and different cloud manufacturing applications implemented to utilize the cloud manufacturing environment in supporting companies' business objectives. Of course, the number of cloud-based applications is growing. They are not limited to the business requirements mentioned in this research. The applications shown here demonstrate the potential and possibility of applications across a wide spectrum of cloud manufacturing.

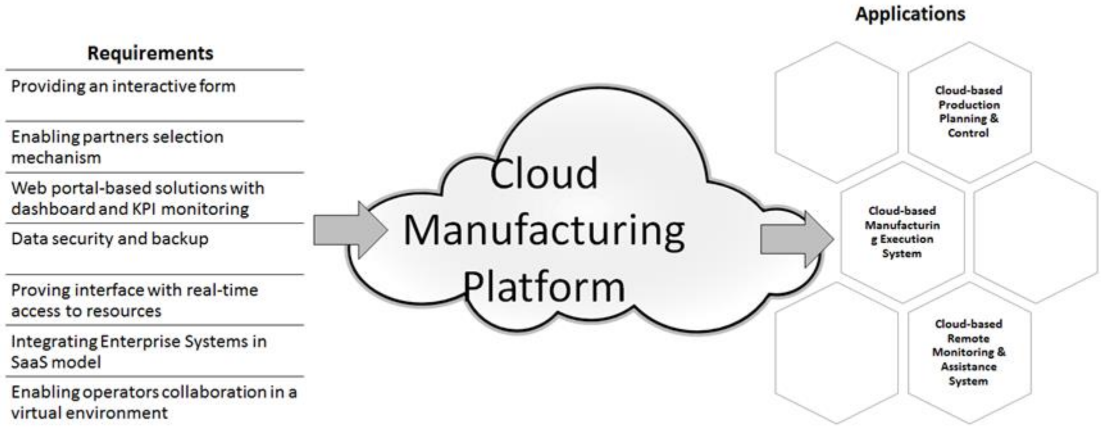


Figure 15. Cloud manufacturing applications

4.5 Summary and Contributions

The seven publications are used to address different research themes and answer different research questions. The key findings of all the publications redefine the concept of cloud manufacturing and also expand the scope of manufacturing industry from different aspects. They help to construct a clear view of cloud manufacturing and describe the transformative journey of manufacturing industry.

Figure 16 shows the scope of cloud manufacturing and demonstrates how it is shifting from traditional manufacturing, to intelligent manufacturing, to smart manufacturing, and to today’s cloud manufacturing:

- Traditional manufacturing: only focuses on physical production activities;
- Intelligent manufacturing: an IT-driven manufacturing environment, using production automation to improve the manufacturing processes;
- Smart manufacturing: an information-driven manufacturing environment to increase the flexibility of manufacturing processes, using information to connect different factories;
- Cloud manufacturing: collaboration-focused manufacturing strategy to enable different factories and organizations to pool and provision their resources/capabilities, to be able to respond to a particular business

> opportunity; not only building up a bridge between factories, but also setting up communication and real collaborations.

This IoX (internet of everything) concept brings together users, manufacturing processes, machines, and all required data and relevant information, and also makes all elements more valuable and more connected in cloud manufacturing than ever before. Table 10 explains the spectrum of cloud manufacturing by describing each IoX. The internet of manufacturing (IoM) is the general term consisting of IoT, IoU, IoS and IoB. These four IoX are co-existing and realize the formation of each other.

Table 10. Definitions of new spectrum of cloud manufacturing

IoX	**Definitions**
IoM	Manufacturers are connected by a collaborative platform, namely the cloud manufacturing platform.
IoT	More ability to monitor the connected and automated machines and their performance in real time, and to manage the manufacturing assets, thereby, achieving virtualized manufacturing.
IoU	All factories are users and all individuals involved are end users (i.e. providers, consumers, and operators in manufacturing), and they are connected at different levels to fulfill a system of collaboration.
IoS	All enterprises can generate their own business-oriented cloud manufacturing services based on their manufacturing resources, capabilities, technical applications, etc. These services are virtualized to enable the business process and are provided to other factories.
IoB	Business opportunities in the global-wide environment are collected and enable the creation of cloud manufacturing.

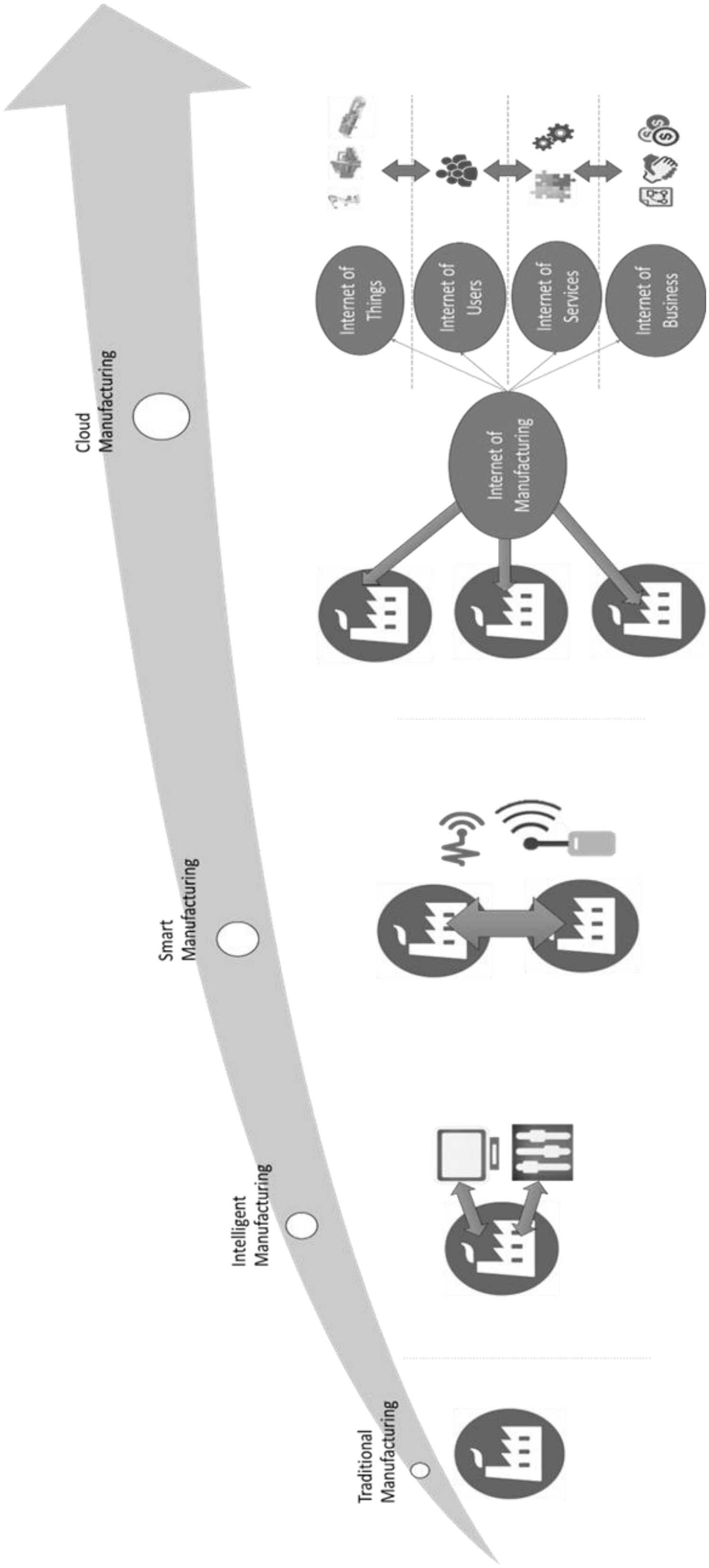


Figure 16. The spectrum of cloud manufacturing

5 DISCUSSION

This dissertation was concerned with understanding the theoretical aspects of cloud manufacturing and its related practical issues. It revealed a number of interesting observations through four complementary case studies. The seven publications were mainly focused on addressing the first research problem and creating a comprehensive view of cloud manufacturing.

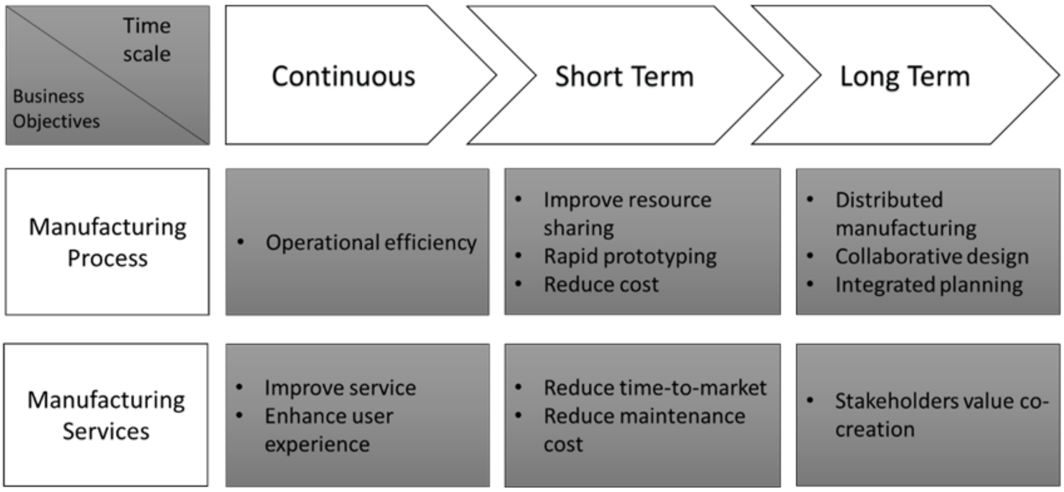
Supposedly, although cloud computing has evolved from its traditional technological orientation towards a business strategic role industry, it still lacks a fundamental framework to understand the potential of the cloud for most of the companies to embrace business evolution, especially in the context of manufacturing industry. It is challenging to say using one cloud manufacturing platform (CMP) will be better than another, where it is radically dependent on the organizational behavior towards achieving the particular business goals (Almulla & Yeun 2010). Especially in a cloud manufacturing ecosystem, multiple organizations are involved and tend to be more integrated and interoperable, and they face obstacle analysis, understanding and solving problems due to their size, complexity, and their relations (Panetto & Molina 2008). Many companies are not clear about how to transform their business model towards cloud manufacturing or the CMP.

In fact, cloud adoption is an IT directive business decision. Therefore, it seems very important to align cloud adoption decisions with business strategies. Both of the IT managers and business executives need to recognize the business goals and objectives that lead company to implement cloud manufacturing (Alkhlil, Sahandi & John 2013). Therefore, the second part of the research problem is about providing a strategy to help organizations move to cloud manufacturing.

To address the second research problem and provide suggestions on how to leverage the cloud technology and manufacturing business, and align technology capabilities with companies' business strategies, four steps are taken in this discussion part. First, the benefits of cloud manufacturing are discussed. Second, the essentials of cloud manufacturing are summarized. Third, the cloud manufacturing implementation keys are described. Fourth, a cloud manufacturing strategic model (CMSM) is provided to leverage the technologies for enterprises adopting a cloud manufacturing environment.

5.1 Benefits of Cloud Manufacturing

Cloud manufacturing aims to achieve an innovative ecosystem of manufacturing enterprises. It will be the most effective way to open the door to future business and reduce the market entry barriers. This dissertation demonstrates different variations in the approach towards cloud manufacturing. Different companies adopt cloud manufacturing for different reasons and to pursuit different benefits, such as those shown in Figure 17.



Time scale / Business Objectives	Continuous	Short Term	Long Term
Manufacturing Process	• Operational efficiency	• Improve resource sharing • Rapid prototyping • Reduce cost	• Distributed manufacturing • Collaborative design • Integrated planning
Manufacturing Services	• Improve service • Enhance user experience	• Reduce time-to-market • Reduce maintenance cost	• Stakeholders value co-creation

Figure 17. The potential benefits of cloud manufacturing

The benefits of cloud manufacturing can be summarized in two areas: the benefits to the manufacturing process and the benefits to manufacturing services, by three different time scales:

- From the manufacturing process point-of-view: the potential benefits of cloud manufacturing are in operational efficiency. All the partner factories and actors can utilize collaboration and communicate with others at distributed locations. Therefore, the operation efficiency can be heightened. The short term benefits are improving resource sharing based on the particular business requirements. The design and engineering process can be improved and be faster to the prototyping phase, hence reducing costs on a general level. The long term benefits are supporting distributed manufacturing, collaborative design and integrated planning. Cloud manufacturing can readily facilitate communication across a widely dispersed global production process. In this collaboration system, distributed manufacturing activities can be integrated by standard regulation and all the partners are verified.

- From the manufacturing services point-of-view: the potential benefits of cloud manufacturing are to improve service and then enhance the user experience. In a cloud manufacturing environment, staff at different locations can share ideas and provide feedback on working efficiently. Services such as remote training, guidance and remote assistance ultimately improve the user experience. The short term benefits are reducing time-to-market, and also lowering the maintenance cost. In a longer term perspective, stakeholders' value co-creation is achieved across the manufacturing process. Cloud manufacturing facilitates rich interactions with customers and other partners by promoting information sharing.

5.2 Cloud Manufacturing: System of Collaborations

By taking a close look at different implementations of cloud manufacturing in real case companies and studying previous research, cloud manufacturing is named as 'system of collaborations'. Cloud manufacturing intents to achieve collaboration by integrating and coordinating the distributed manufacturing resources/capabilities.

Collaboration is a very broad and encompassing term (Barratt 2004) and needs to be achieved at different levels: at field level, management level and corporate level (Panetto & Molina 2008). In previous research, collaboration means information exchange, resource sharing, and the capacity of companies to pursue mutual benefit and to achieve a common purpose (Mezgár 2011). In the cloud manufacturing concept, collaboration covers activities such as cooperation, interoperability, and integration. Cooperation means different partners do things together; interoperability is about agreed-upon the technological framework and their business ontology; and integration is beyond both and about integrating applications and data (Xu 2012). The goal of collaboration in cloud manufacturing is to deliver improved closer business relationships in distributed manufacturing industry.

The collaborative model shown in Figure 18 represents both manufacturing business granularity and information granularity. The extent to which collaboration levels are concentrated depends on the objectives of organizations and their information sharing levels. There are a variety of forms of potential cloud manufacturing collaboration, and their processes can be integrated at different organization levels: corporate management level, internal management level, and field management level. All the levels are connected with each other. In order to generate shared knowledge and resources, the collaboration can also be logically partitioned by its information degree: operational level, tactical level, and strategic level. Creating an understanding of this collaborative model can lead to faster cloud manufacturing realization.

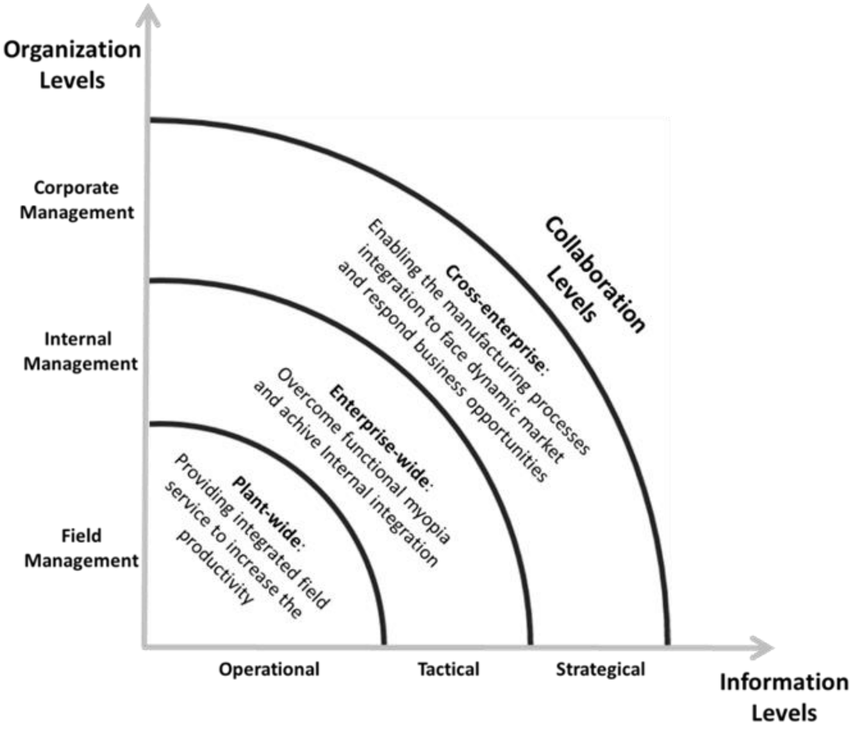


Figure 18. Model of cloud manufacturing collaboration levels

Table 11. Model of cloud manufacturing collaboration across organization levels and information levels.

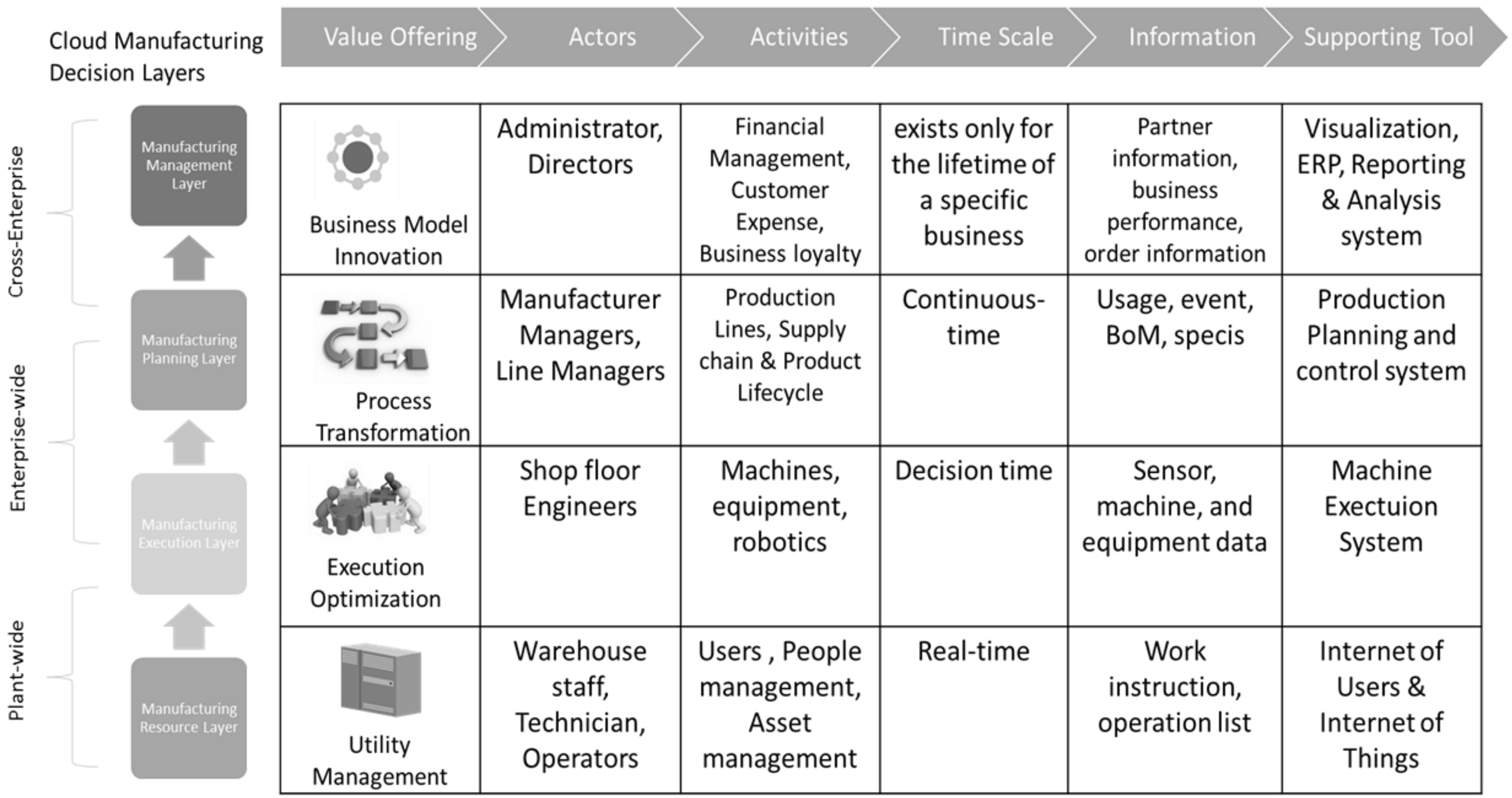
Collaboration Levels	Explanations
Cross-enterprise Collaboration	The most common collaboration model in cloud manufacturing is the collaboration of different partner factories, suppliers, broker agents, and even customers' companies. All the organizations join together to face a dynamic market, and achieve sustainable development. Strategic information is required to support business process integration, such as partner information sharing, knowledge sharing, regulations, standardization, etc. In this ecosystem, partner factories which are more involved in this fast-paced environment can find the right partners more easily than ever before. Broker agent organizations can understand the business needs and draw in the right partners, who can provide the right services to make things happen.
Enterprise-wide Collaboration	For an individual organization, especially a large size enterprise, the goal is not only to collaborate with other partners, but also improve its internal management, respond to global operations, and achieve functional internal integration. Every department must have joint objectives, shared resources, and a common vision to achieve the business goal. This internal integration consists of different functions within a company. Therefore, tactical information about real-time business and integrated planning are very critical.
Plant-wide Collaboration	The fundamental infrastructure of a manufacturing organization is its field service management, such as scheduling, shop floor activities, and connections with the back-office system. The intentions of collaboration at this level are to increase productivity and reduce cost of service, to enhance visibility across multiple shop floors, and to create value-added services for the customer to experience based on smart devices connected to the cloud.

Collaboration in a cloud manufacturing is not just about establishing information sharing environment and message exchange relationship at the operational level, it should be considered through the companies. If the cloud manufacturing implementation is not thought through at these three levels together, then the performance benefits of cloud manufacturing collaboration will be limited.

5.3 Cloud Manufacturing Platform (CMP) Implementation

As stated previously, the proposed collaboration level model is used to define the manufacturer movement towards a cloud manufacturing collaborative strategy. The dimensions are related to the objectives of a manufacturing company and the information sharing levels. Consequently, the rationale here is to define the decisions for moving towards a cloud manufacturing platform in four layers (i.e., manufacturing management layer, manufacturing planning layer, manufacturing execution layer, and manufacturing resource layer) that allow a company to explicitly position its journey towards cloud manufacturing.

In order to utilize a cross-enterprise collaboration level, such as business integration and decision making, the CMP should be implemented at both the manufacturing management layer and manufacturing planning layer. For enterprise-wide operational management and the production planning level's objectives, the CMP should be implemented across the manufacturing planning layer and manufacturing execution layer. For plant-wide actual control and execution over the manufacturing facilities on the shop floor, the CMP should be implemented in the manufacturing execution layer. Simultaneously, integration plant-wide needs intelligent devices and sensors to drive production agility and efficiency, and this should be implemented at manufacturing resource layer.



Value Offering	Actors	Activities	Time Scale	Information	Supporting Tool
Business Model Innovation	Administrator, Directors	Financial Management, Customer Expense, Business loyalty	exists only for the lifetime of a specific business	Partner information, business performance, order information	Visualization, ERP, Reporting & Analysis system
Process Transformation	Manufacturer Managers, Line Managers	Production Lines, Supply chain & Product Lifecycle	Continuous-time	Usage, event, BoM, specis	Production Planning and control system
Execution Optimization	Shop floor Engineers	Machines, equipment, robotics	Decision time	Sensor, machine, and equipment data	Machine Exectuion System
Utility Management	Warehouse staff, Technician, Operators	Users , People management, Asset management	Real-time	Work instruction, operation list	Internet of Users & Internet of Things

Figure 19. Cloud manufacturing platform implementation map

Each layer is assigned to a particular phase of the manufacturing process and they are assessed through six dimensions, which are illustrated in Figure 19. More specifically, it is crucial to be precise in every dimension:

- Value offering indicates the value proposition offered to a company when the collaboration level is achieved.
- Actors point out the decision makers and who directly benefit when the collaboration level is achieved.
- Activities indicate the main business activities for manufacturing to implement cloud manufacturing.
- Timescale implies that the decision-making and the lifecycle of collaboration are different with respect to time standard. For instance, business layer collaboration only exists for the lifetime of a specific business opportunities.
- Information refers to the information and data that are required to implement cloud manufacturing.
- Supporting tool refers to the systems and technologies required to implement cloud manufacturing. Because the number of applications is increasing, and the needs of different functional blocks are also increasing, it is important to implement correct and accurate applications to monetize information across a wide spectrum and integrate with the cloud manufacturing platform.

Take the case companies mentioned in the methodology section (cf. Section 3) as examples. The company CC1 moved towards cloud manufacturing in order to establish a collaborative working environment, and focus on the business of improving customer relationships, providing more services to their customers, and increasing the productivity of the machines. Based on these business objectives, CC1 can implement cloud manufacturing at the manufacturing management layer. Customer-focused services such as remote monitoring, remote training, and remote assistance are deployed at the manufacturing resource layer.

5.4 Cloud Manufacturing Strategic Model (CMSM)

Owing to the sophisticated diversification of manufacturing business models and cloud operational model, it is difficult to prepare one unified strategy that would be applied to all companies implementing cloud manufacturing (Kłosowski 2012). It is important to distinguish between these different levels of cloud manufacturing, otherwise it is difficult to achieve the potential benefits of cloud manufacturing.

In order to support companies’ cloud manufacturing implementation, a roadmap to cloud manufacturing is needed to align with their own business operation, manufacturing processes and services. Companies need to clearly identify their current and future capabilities. It is important that they adopt only the technologies that fit with their manufacturing management strategy and enable them to improve business performance.

The direct impact of cloud manufacturing on the business model is that it profoundly changes the ways manufacturing collaborate with each other. In this paper, a cloud manufacturing strategic model (CMSM) for conceptualizing and directing the emerging area of strategic management of cloud manufacturing is developed. This model, as shown in Figure 20, defines four fundamental blocks of strategic decision, namely manufacturing strategy, cloud strategy, manufacturing infrastructure and process, and cloud infrastructure. Each block has its own underlying dimensions. These four domains are designed based on Henderson and Venkatraman’s (1993) strategic alignment model (SAM). However, the strategy decision logic of cloud manufacturing is more complex and challenging.

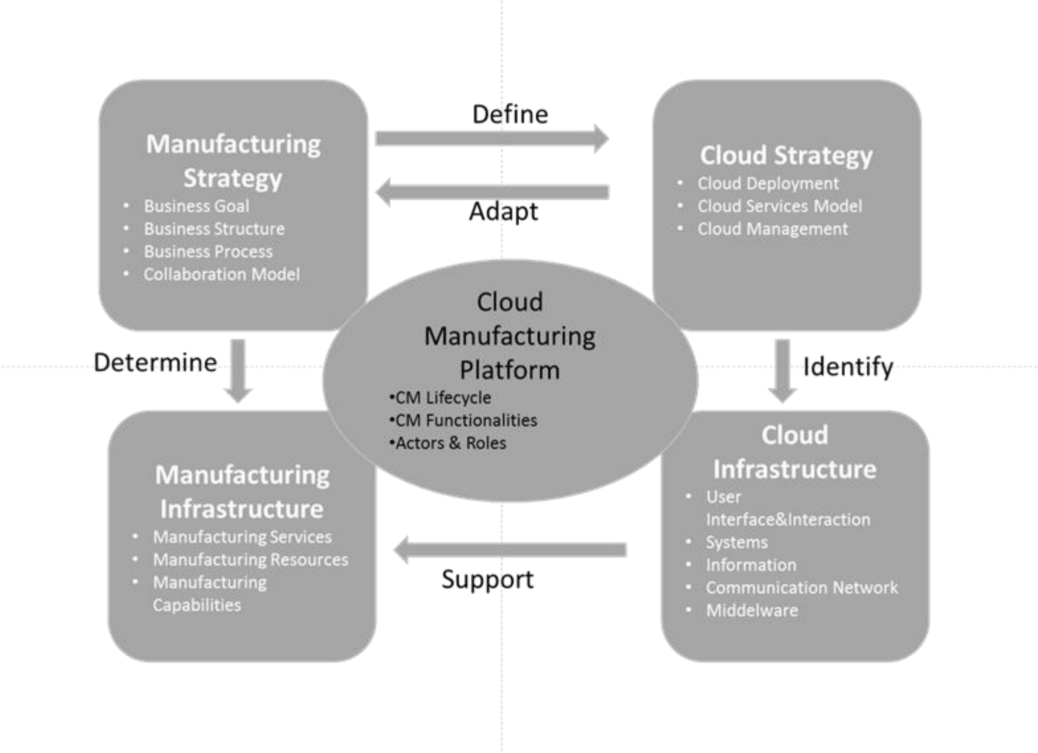


Figure 20. Cloud manufacturing strategic model

- Manufacturing Strategy: The first phase is to assess the manufacturer's business strategy, because it is important to establish a coherent business strategy before implementing an integrated solution. The business strategy includes distinctive aspects of the manufacturer's business goal (i.e. fulfilling the business demands in a rapid and flexible way), business structure (i.e. the company's organization architecture), business process (i.e. the decision-making and manufacturing process), and collaboration model (i.e. the collaboration levels of the company) and should thus significantly influence a manufacturer's decision to adopt a new cloud strategy. Cloud strategy is defined based on this manufacturing strategy, and vice versa, each manufacturing strategy needs to be adapted to cloud strategy.

- Cloud strategy: In order to compete with other companies in cloud adoption, manufacturers must interlink their manufacturing strategy and cloud strategy, and also link with collaboration models. Once the manufacturing strategy is clearly defined, it is time to assess the cloud opportunity and readiness, such as the cloud deployment and cloud services model. Two main factors impact the decision regarding public or private cloud: company's business size and its business structure. The security and safety standards are also essential. The decision to use a cloud model for delivering services (i.e. IaaS, PaaS, and SaaS) depends on the company's business needs or requirements. All these decisions related to the cloud strategy will jointly build up an integrated cloud working environment that can facilitate collaboration framework to fulfill cloud manufacturing business goals (Raj & Periasamy 2011). Of course, the decision to adopt cloud computing is not only about outsourcing resources and services, but also actually has an impact on the growth of the business.

- Manufacturing infrastructure: In the cloud manufacturing's resource pool, the variously dispersed manufacturing resources/capabilities are virtualized and transformed into cloud services. For manufacturers that intent to provide their resources to resource pool or require more resources from others, it is important to define what cloud services can be shared and what cloud services are needed to fulfill a company's particular business goal. Firstly, the spare facilities which might be very expensive or rarely used assets can be shared to the cloud resource pool and provided as manufacturing services; secondly, their unique/competitive resources can be outsourced to the cloud. These cloud services need to be effectively managed and coordinated in a centralized way to ensure the cloud manufacturing performance and operation.

- Cloud infrastructure: The choice of architecture in terms of user interface and interaction should be considered. Common interfaces are very important when multiple systems are integrated for collaboration. Different cloud infrastructures are chosen to fulfill different business goals in the changing enterprise environment. Of course, most companies usually have different requirements regarding the privacy of data management. Manufacturing must consciously build the cloud infrastructures that align with their key cloud strategy and also support the manufacturing infrastructure.

- Cloud manufacturing platform: It provides all the functionalities to support the cloud manufacturing lifecycle. The company can decide which processes/phases of its production lifecycle need to be supported by cloud manufacturing. Different sized companies need to be aware of their roles. A big company can host a platform to benefit their customers' companies by accelerating the integration of business and IT investment. Also, the company can host the platform to integrate internal business by improving the information flow between the shop floor and other internal departments. Furthermore, a big company can host cloud manufacturing to increase efficiency between enterprises throughout its supplier network.

The cloud can help manufacturers in their operations and communications, therefore it is important to identify which cloud model is most appropriate and how to move forward to cloud manufacturing. Of course, IT managers need to develop essential business skills to align the cloud with business strategy, and vice versa for business executives to develop IT skills. It is important to develop an understanding of manufacturing strategy along with business and operation, and produce a roadmap aligned with a strategy and infrastructure for business (Alkhlil, Sahandi & John 2013). Defining CMSM is an essential step towards achieving the success of cloud manufacturing, and gaining competitive advantage in business. CMSM can provide the right path forward and help managers understand how to manage their cloud manufacturing effectively and efficiently in order to realize all of the expected significant merit of cloud manufacturing.

Based on the cloud manufacturing strategic model (CMSM) in Figure 20, here are two examples of choosing a cloud manufacturing implementation approach.

- Private Cloud: For instance, when the cloud manufacturing is set up for large size companies, and their in-house manufacturing resources and capabilities are distributed in branch companies, subsidiaries, research centers, or different departments. The goal is to promote the utilization rate of its own resources. The provider and demander are both inner members of an enterprise, the operator can be headquarters.

- Public Cloud: For instance, for startup companies at an early stage or for SMEs which want to concentrate on their business and conduct their business activities aggressively, they can adopt the public cloud with cloud manufacturing solution provider to save on initial costs. The entire manufacturing resources/capabilities are distributed in and owned by different SMEs. Idle resources from different companies are then integrated to the platform. The provider and demander are SMEs, and the operator/solution provider is the owner of the cloud manufacturing platform.

5.5 Summary and Contributions

This chapter illustrates the system of collaboration in cloud manufacturing ecosystems, and describes a broad spectrum of cloud manufacturing (Figure 19). It maps the cloud manufacturing implementation of the cloud manufacturing environment which was discussed earlier in this dissertation. It can be evaluated based on the manufacturing lifecycle from product design, manufacturing, marketing, to after-sales service. Companies can decide where they are most comfortable along the spectrum, and create new activities based on their needs. Positioning companies at one end of the spectrum or the other is not the only option.

Furthermore, the decision on where to host and manage different types of services depends on a number of factors. Therefore, it is very necessary to have a cloud manufacturing strategic model (CMSM) (Figure 20). The CMSM can be used in an efficient way to build a robust CMP. CMSM will develop a generic knowledge model and explain explicitly how to cope with CMP implementation issues and challenges, and it also shows the potential advantages for further strategic decision support.

This CMSM applies to all plant-wide, enterprise-wide, and cross-enterprise scenarios that cover the range of the increasingly connected value chains used by manufacturers today. They define a reusable set of building blocks that can help companies realize the business value each pillar supports. Given a business scenario in manufacturing, these building blocks can be ‘assembled’ across the pillars and integrated with existing enterprise assets to achieve specific business goals. By combining components, Original equipment manufacturer (OEMs) and suppliers can more quickly benefit from solutions and evolve into more dynamic and adaptive manufacturing enterprises.

6 CONCLUSIONS

This chapter summarizes the theoretical and managerial implications of this research, and also presents the research limitations and proposes further research suggestions.

The findings of this research were derived from seven individual publications, and also a synthesized understanding of cloud manufacturing gained during the research process. The primary aim of this research was to provide a comprehensive view of cloud manufacturing and to suggest an approach for manufacturers to move towards cloud manufacturing platform implementation. This study made four main contributions: 1) it gave empirical evidence of what cloud manufacturing is; 2) it identified both the business and technical impact of the cloud on manufacturing industry in terms of business, technology, infrastructure, company structure, etc.; 3) it illustrated applications of cloud manufacturing and its platform; and 4) it clarified how to move into cloud manufacturing. Table 12 summarizes the research problems and relevant research questions, with answers to address each one.

Table 12. Summary of research problems and answers

Research Problem 1: **What are the implications of cloud in the manufacturing industry?**	
Research Question 1: What is the concept of cloud manufacturing?	It is a system of collaborations, defining different types of collaborations in cloud manufacturing ecosystems, such as cross-enterprise (external level) enterprise-wide (internal level) and plant-wide (fundamental level) collaboration
Research Question 2: What are the overarching business opportunities of cloud manufacturing?	It is an intermediate agent serving multiple companies to adapt to ever-changing requirements, and supporting all the activities (design, planning, production, control, maintenance, etc..) from raw material to finished products among all the users (both partner factories, broker agents, partners, customers, and individual users (e.g. operators, technicians, etc.)
Research Question 3: What are the primary technological	The technological implications are addressed from the data management point-of-view. In cloud manufacturing, it is very critical to implement IoT and

implications of cloud manufacturing?	CPS. However, there are challenges to dealing with the large number of data generated by this IT infrastructure. Cloud computing and big data are two important concepts. A new data processing method is proposed to deal with the unstructured and distributed data.
Research Question 4: How to implement and transform applications to cloud manufacturing?	A set of support tools are designed and developed to help cloud manufacturing platform implementation and build up new business models for the manufacturing of complex products. It is an integrated platform which can support different functionalities in the form of CloudPPC, CloudMES, and CloudRMA, and it provides a series of more sophisticated services with broader diversity.
Research Problem 2: **How can manufacturers leverage the cloud to shape and support their business strategies?**	
Research Question 5: How can manufacturers anchor a cloud manufacturing strategy within its business context?	Cloud manufacturing platform (CMP) implementation map and cloud manufacturing strategic model (CMSM) are provided to help any companies to think about their movement to cloud manufacturing (manufacturing strategy -> cloud strategy -> manufacturing infrastructure -> cloud infrastructure)

6.1 Theoretical Implications

In previous literature, there is an inadequate holistic view about approach, methodology and framework for cloud manufacturing. From the academic perspective, this dissertation is the cornerstone of cloud manufacturing theory. It explicitly states that cloud manufacturing is an umbrella term that encompasses many types of manufacturing services and applications. This dissertation is a unique item of research that provides a 'rolled up' view and fresh thinking about the complete opportunity provided by cloud manufacturing. Based on analysis related to cloud manufacturing, it also provides a foundation for future manufacturing industry in general. Cloud manufacturing is not simply migrating from manufacturing-related software to the cloud, but it emphasizes collaborative relationships across various factories from the distributed production process. When companies adopt cloud manufacturing as their business strategy, it enables a new business model to complement their business goals.

This dissertation extends existing knowledge of servitization (service science), enterprise engineering (enterprise integration), and enterprise architecture (strategic management) that were the foundation of this dissertation.

- Service science: By analyzing servitization in the context of cloud manufacturing, service is not only an add-on to the main products, but a central part of the value creation process in the whole business process. It is important to look at the unique opportunities and challenges, and provide the needed services to partners. However, it is also very critical to think about service science as a 'means' to achieve business productivity.

- Enterprise integration: In the different levels of collaboration in cloud manufacturing, enterprise integration is a core concept. Similarities and differences between enterprise architectures are pervasive, and they cannot be perceived. Therefore, before enterprise integration, it is important to understand the whole industry and eliminate obstacles to its acceptance and use.

- Strategic management: In terms of the strategic management principle, it is important to address the alignment of business strategy and technology for implementation. The research and development focusing on business or IT separately are insufficient in the current complex business environment.

6.2 Managerial Implications

Cloud manufacturing can provide practical impacts on the manufacturing industry and support agile partnership, particularly for SMEs which are too small to fulfill customers' requirements independently and want to collaborate with other SMEs. This dissertation can be beneficial to managers from industry in two main aspects.

First of all, cloud manufacturing is a vague concept without a clear and common understanding by most companies in industry. Companies face obstacles in trying to develop ideas and take action. They are struggling when it comes to identifying and implementing cloud manufacturing scenarios. This dissertation has explicitly addressed this issue by providing a systemized knowledge of cloud manufacturing and describing the constituents of a phenomenon.

In this dissertation, cloud manufacturing was revealed from different aspects: the evolution of manufacturing, a holistic view of cloud manufacturing, practical implementation examples, adaptation approaches, and strategic model. Cloud manufacturing establishes a series of standards to collaborate with other partners. With all of this guidance and these methodologies, companies can instantiate/duplicate already successful cases, and implement their own cloud manufacturing platform.

Secondly, to accommodate the development and support of cloud manufacturing, companies will need to update existing IT architectures and business operations to capitalize on this trend. This dissertation provides a CMSM to support practitioners in developing appropriate solutions.

Different companies intent to use different approaches and procedures to move into a cloud manufacturing environment. Therefore, a common platform is necessary to aggregate manufacturing resources/capabilities within a company, and also across different companies. In CMP, integration is provided as a service. This CMSM can provide a proactive decision-making paradigm, and it reduces the reaction time to a CMP.

6.3 Limitations

Case studies are both the strength and weakness of this research. It is possible to tailor the research design procedure to particular research requirements. Conversely, the cause studies resulted limitations to criticism.

Normally, case study research is not representative in general, but focused on carefully selected cases, and the study can then suggest a number of intriguing themes that deserve further discussion. Although the approach and framework proposed in this dissertation were applied in four industrial companies, it will be necessary to further evaluate the results and findings through qualitative research.

In this research, technical issues are not addressed in detail, because IT is in itself trivial, and the important thing to explore the applications and benefits. After all, enterprise collaboration and integration are more about strategic and organizational challenges, rather than an IT issue (Panetto & Molina 2008).

In this dissertation, the security issue has not been covered, because it is not the main focus. However, security is one of the primary issues and biggest concerns in most of the cloud-related research. Hence, more attention is needed.

Furthermore, the regulations and standards have not been addressed in this research. This is very important in the manufacturing industry. Therefore, in future cloud manufacturing research, cloud computing security and manufacturing regulations should be addressed and considered.

6.4 Future Research

In a cloud manufacturing environment, there are substantial challenges that must be overcome. The distributed resources need to be encapsulated in order for them to be shared over the internet. It is important to find out matching resources/capabilities in order to get all factories to join in the cloud manufacturing environment and share their value by sharing data with different companies (Helo & Szekely 2005).

In the cloud-based environment, privacy and security always are critical issues. Lack of appropriate security technology is the major barrier resisting the growth of any cloud-based implementations. As cloud computing is the enabling technology of cloud manufacturing, the security barrier has retarded its growth. By 2011 various technologies with wide acceptance began to catch the IT market. The emergence and usage of security technologies like AES 256 bit encryption and FIPS 140-2 make the cloud functionality of enterprises real (Lijohn & George 2014).

In order to overcome these challenges and to create a dedicated cloud manufacturing environment, it is importance to create an architecture to consider the measurement of quality of delivered service by monitoring performance and improving the SLA (service level agreements) over time (Xu 2013), and also make sure the selected services match the level of the customers' requirements. The measurement can be considered from the aspects of cost, schedule, quality, green environment, flexibility, and related SLA (covering the service levels and non-functional specifications). It is very worthwhile to provide a scientific answer to the metrics of cloud manufacturing performance.

Furthermore, all partners joining cloud manufacturing do so based on the QoS and also their own willingness. Several trust measurements were designed, such as by Li et al. (2014) and Wang & Xu (2013b). So trust and assessment are very important research themes that deserve further discussion.

Moreover, cloud manufacturing is particular to manufacturing industry, but the concept and logic can become a disruptive trend and also be implemented in other industry, such as the healthcare, education, retail, finance, and government sectors. However, the application and transformation of cloud manufacturing is not immediately obvious in other sectors. For instance, the needs of a health center would apparently be quite different from that of the manufacturing sector. Thus, it makes sense to tailor provision. Cloud manufacturing must conform to relevant industry standards, infrastructure needs, growth patterns and software functionality,

However, the findings obtained in this research also illuminate a number of concluding remarks that further need to be presented. This CMP and CMSM is an ongoing effort. More research can be put into CMSM. The next step is to study the alignment measurement in cloud manufacturing collaborative networks and find out what are the main enablers.

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Chapter 9

Cloud Manufacturing towards Sustainable Management

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ABSTRACT

Nowadays, most manufacturing companies have realized the importance of collaboration between dispersed factories, different suppliers, and distributed stakeholders. Cloud computing is an evolution of the Internet; it does not just change the technology, but also enables collaborative innovation. Cloud manufacturing (CM) is another form of networked manufacturing. It provides common and standard manufacturing services by cloud logic and principle. In this chapter, a new concept is suggested based on the fundamental theory and key technologies of CM. Cloud Future Factory, which is intended to manage a matrix-type organizational structure, focuses on improving communication in lean manufacturing. This case company has dispersed production lines and business departments. Therefore, it's very necessary to introduce an efficient and dynamic information integration platform. This chapter leads to a different way of thinking for using the cloud manufacturing concept in different formations. CM is not just suitable for small and medium sized enterprises, but also fits large size companies.

1. INTRODUCTION

The quality of our life has been improved by manufacturing industry. But it has become increasing difficult to ignore that industrial activities have caused negative environmental consequences. Waste and emissions of industrial manufacturing and usage of products intensify the problems of the global environment. Accordingly, this situation causes disadvantages for the traditional industries (Jovane, Westkämper & Williams 2008). It is widely recognized that environmental sustainable development is a priority for fundamental research (Bi & Wang 2013) because that environmental degradation becomes one of the serious problems and concerns for human today. Therefore, manufacturing is under intense pressure to manage sustainability.

Additionally, the levels of competition and uncertainty are very high in the current manu-

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facturing environment. The mounting demand for new products requires more worldwide production activities. This globalization tendency brings companies more and more opportunities with sharing knowledge and expertise in a collective manner. People and other related resources from all across the globe need to be connected instantaneously. These changes require manufacturing paradigm shift towards a more sustainable and agile business model. This evolvement must meet emerging dynamic needs from customers and maintain the sustainable in industrial development. Finding solutions to adopt these changes is very critical, because it requires a deep understanding of sustainability and a broad scope of engagement with all levels of the organisation and stakeholders.

Numerous factors, such as business strategies, organizational structure and technologies, have impacts on the implementation of a new manufacturing paradigm. The success of a manufacturing paradigm is the process of optimizing both hardware and software (Bi & Wang 2013). The emergence of the Internet and other advanced technologies has led to the development of collaboration networks in many different areas. This phenomenon has resulted in a power-shift from the hierarchical business models (Wu et al. 2013). The traditional business models cannot afford the flexibility and connectivity of today's business environment and sustain the innovation. Especially in manufacturing industry, companies have to be agile and reconfigurable so that their business structures or products can be adaptive in a dynamic environment.

Cloud computing is an attractive element of companies' competitive strategy now. Its appearance becomes one of the primary enablers for the manufacturing industry. Xu (2011) emphasizes that cloud computing is considered as a multidisciplinary research field. However, little work has been reported on investigating the potential of cloud computing in terms of product design and manufacturing (Wu et al. 2012).

As discussed by Xu (2011), the adoptions of cloud computing in the manufacturing industry can be mainly classified into two types: smart manufacturing and cloud manufacturing. Smart manufacturing means manufacturing with direct adoption of cloud computing technologies and enables better-integrated and more efficient processes. Cloud manufacturing means the manufacturing version of cloud computing, which very similar to networked manufacturing concept (Tai et al. 2012; Zhang & Zhong 2012; Li et al. 2011). Regardless which cloud adoption method is used in the company, the concept of cloud transforms the traditional manufacturing business model, and helps the company to align innovation with business strategy, and creates intelligent factory networks that encourage active collaboration (Xu 2011).

Columbus (2013) posted an article in Forbes and discussed using cloud computing to revolutionize manufacturing based on his visits with manufacturers. He pointed out 10 ways to utilize cloud computing such as implementing cloud-based business tools to mobility support the analysis and reporting, also deliver real-time order status and forecasts, and create multiple access entry points. These business tools can support different business purposes, such as customer management, marketing management, product management, vendor management, etc. However, there was a main central theme draw out attentions: collaboration. Using cloud-based platform can ensure collaboration in any phase of manufacturing and product management, which is strategy that many manufacturers are pursuing today. Zhou et al. (2011) emphasize that enterprise has become a node in the global inter-enterprise collaborative manufacturing network.

Collaboration is the key enabler to minimise cost, improve adaptability, responsiveness, robustness, and sustainability of manufacturing processes, especially in lean manufacturing. Value chains and cooperation between companies, especially SMEs, are increasingly flexible.

In this chapter, we introduce main prior research in cloud manufacturing and its associated characteristics. Since there are several definitions around this novel concept, it's very vita to review these definitions and propose a comprehensive definition embracing the competitive foundations of cloud and the key concepts of cloud manufacturing.

Our purpose is to design and develop a communication platform for cloud manufacturing activities, where it can provide execution, monitoring, planning, and optimization services. In order to make a change toward sustainability and globalization, new business strategies that are based on improving collaboration rather than its capital should be considered. We intend to answer the following practical questions in this chapter:

- What is cloud manufacturing?
- How is cloud manufacturing different from previous paradigm shifts?
- What new opportunities are derived from cloud manufacturing in large size companies?
- How does this new manufacturing paradigm achieve sustainability?

This paper attempts to address some of the basic requirements for achieving cloud manufacturing in a real case company, particular to large size company. Many manufacturing companies are already adopting a form of cloud computing in their existing business strategy and providing services to their suppliers, customers or employees. In this paper, we will present a case company that embraces the cloud manufacturing concept into its value chain, increases flexibility of its supply chain and centrally manages its dispersed factories. This new paradigm is Cloud Future Factory and it improves the ability to react faster on market needs and individual customer requirements.

A brief review of current literature is given to achieve our objective in this research in section 2 and it helps to create a knowledge base. In section 3, a new paradigm is proposed and the business benefits of this paradigm are discussed. Section 4 outlines future research endeavours and directions on cloud manufacturing, and it leads to potential benefits of sustainability. Finally in Section 5, conclusions are presented.

2. RESEARCH OVERVIEW

2.1 Related Concepts

In the manufacturing industry, many advanced business models and technologies have been developed to address different manufacturing challenges and to improve the manufacturing quality. Table 1 lists related concepts and definitions. These models are proposed and used widely, and they are capable of satisfying current manufacturing requirements on different aspects. According to the differences of these concepts' attributes and orientations, they can be classified into two different aspects: structure oriented and technology oriented. Structure oriented concepts mainly focus on the structure of business formation. On the other hands, technology oriented concepts primarily emphasize the importance of technology involvement. These technologies or models have played crucial roles in manufacturing related fields, and have made great contributions to the development of manufacturing informationalization (Tao et al. 2011b).

All the concepts have caught the attention of experts in both industry and academia. Although each of these manufacturing technologies or models has its own emphasis, they all have typical and common characteristics, such as network, resource sharing, and cooperative work. A lot of research has been carried out to compare and differentiate these concepts. Several issues are found existing in these concepts:

1. **Limited Number of Services:** Some physical manufacturing resources and manufactur-

Table 1. Related concepts and definitions

Concept	Main Attributes	Citation
Structure-Oriented		
Lean manufacturing	Refers to a business concept that emphasizes on minimizing the amount of time and resources used in the manufacturing processes and other activities of an enterprise with the goal of eliminating all forms of wastage.	Gunasekaran 1999
Agile Manufacturing	Emphasizes cooperative enterprises to adapt and respond quickly to rapidly changing markets driven by customer-based valuing of products and services.	Yusuf et al. 1999
Global manufacturing	Means that all manufacturing operations and activities are geographical spread across national boundaries.	Maskell 1991
Networked manufacturing	Includes the integration of distributed resources.	D'Amours et al. 1999
Virtual manufacturing	Integrates manufacturing resources and activities distributed in computer networks.	Iwata et al. 1997
Technology-Oriented		
Digital manufacturing	Incorporates technologies for the virtual representation of a physical manufacturing resources, such as of factories, buildings, machine systems equipment, labour staff and their skills, as well as for the closer integration of product and process development through modelling and simulation.	Chryssolouris et al. 2009
Computer-integrated manufacturing	Uses computers and integrate with Computer Aided Design and also other business operations and database, to control the entire production process and allows that the processes exchange information with each other and they are able to initiate actions.	Alavudeen & Venkateshwaran 2008
Manufacturing Gird	Uses for sharing and integrating resources in manufacturing processes and for the cooperating operation and management of the enterprises based on the grid and relative advanced computer and information technologies.	Fan et al. 2004

ing ability cannot be provided for users in the form of service (Tao et al. 2011b).

2. **Limitations of the Service Categories, Quality, and Quantity:** The services are autonomous in a wide range of manufacturing resources, complex types and different formats in multi granularity. The query services and access controlling are inadequate (Li et al. 2011). It's not easy to find out appropriate required service.
3. **Lack of Reliable Security Solutions and Technologies:** The integration of manufacturing IT systems to the overall supply chain management infrastructure is missing (Rauschecker & Stohr 2012). The coordination among the parties in a distributed network has been little and less effective in the reality.
4. **Lack of Centralized Operation Management of Services:** Moreover, due to the self-government of services, some resources are scarce and unstable.

At the same time, some recently emerged technologies need to be applied in various fields in order to adequately address the above mentioned bottlenecks in manufacturing. Tao et al. (2011b) summarize several technologies, such as service-oriented technologies (e.g., service-oriented architecture (SOA), service computing, web service, semantic web), internet of thing (IoT), advanced computing models and technologies (e.g., distributed computing, high performance computing (HPC), grid computing, and cloud computing), intelligent embedded system and technologies, and so forth.

In order to achieve seamless, stable and high quality transaction of manufacturing resource services, a new manufacturing business model should be proposed. Under this condition, combing the existing concepts and mentioned new technologies, a new service-oriented and networked manufacturing model, cloud manufacturing, appeared in 2009. The definition's system architecture and key technology for cloud manufacturing have been investigated in early works (Tao et al. 2011b).

According to Xu (2011), cloud manufacturing is considered as a new multidisciplinary domain that encompasses these existing concepts. Numerous studies have attempted to explain that cloud manufacturing has become a new mode of networked manufacturing (Xu 2011; Tao et al. 2011; Li et al. 2012). In contrast to the conventional networked manufacturing approach, the cloud manufacturing promises elasticity, flexibility and adaptability through the on-demand provisioning of manufacturing resources (Zhou et al. 2011). Zhang and Hu (2013) state that cloud manufacturing ensures the autonomy of scattered manufacturing resources to meet the requests of customers by the dynamic integration and the share of resources.

Figure 1 illustrates the scope of cloud manufacturing and its relations with existing concepts. Cloud manufacturing reflects existing concepts, but also extends current knowledge with both the dimension of the level of integration with other partners and the degree of ICT involved. As highlighted by D'Amours et al. (1999), the networking strategies are classified by different levels of shared information, such as on price and capacity. Therefore, in this scope scheme, the horizontal axis represents the level of ICT involved and the vertical axis.

2.2 Cloud Computing Concept and Application in Manufacturing

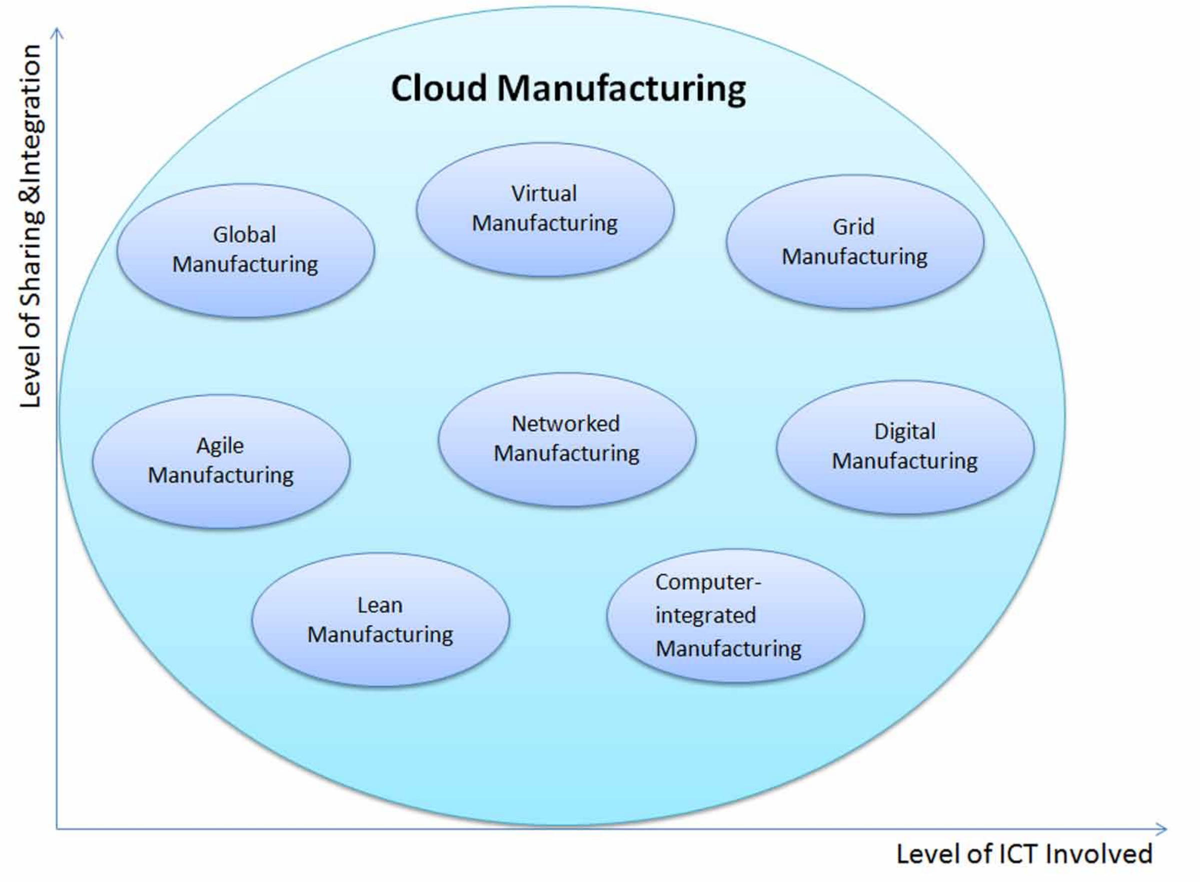
Cloud computing is treated as the evolution of the Internet. The concept of cloud is a combination of different technologies and resources, such as computing, networking, storage, and management solutions, etc. The National Institute of Standards and Technology (NIST) defined cloud computing as "a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction." (Mell & Grance 2009).

However, cloud computing is considered as a multidisciplinary research field. Cloud is not only an evolution of technology, but also an evolution of business model. In cloud, everything is treated as a service, therefore, the business model can also be offered as a service based on cloud logic.

Xu (2011) identifies two types of cloud computing adoptions in the manufacturing sector. The first type is the manufacturing with direct adoption of cloud computing technologies. The second type is cloud manufacturing, which means the manufacturing version of cloud computing. He provides a definition of 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.

Mezgár (2011) asserts that cloud computing is an important technology for networked enterprises as it offering high level collaboration possibilities. It enables a new generation of IT, and also manufacturing services. It makes the services available based on every demand. Cloud computing can realize dynamic resource sharing and on-demand resource provisioning by leveraging virtualization technologies at multiple levels (hardware, platform & application) (Zhou et al. 2011). Chen (2014) points out that "interoperability and scalability" are two essential characteristics of cloud. The manufacturers can respond to customers' requests and adjust their factories capacity.

Figure 1. Scope of cloud manufacturing



2.3 Comparison of Cloud Manufacturing Definitions

Cloud manufacturing concept owes a lot of previous paradigms of manufacturing models. At the moment, this concept is a vision and currently being refined to further its understanding. It is a hybrid construct of advanced technologies and any previous method of manufacturing, which provides a sharing and collaborative manufacturing environment with global competition in this industry. The advanced technologies can be cloud computing, the internet of things, semantic web, and information system integration, etc. (Luo et al. 2011).

Park and Jeong (2013) argue that cloud manufacturing is existing networked manufacturing, internet-based manufacturing or distributed manufacturing. These concepts mainly refer to integration of distributed resources for undertaking a single manufacturing task. The centralized operation management of the services, choice of different operation modes, and embedded access of manufacturing equipment and resources are missing in this regime. Therefore, it's difficult to guarantee a seamless, stable, and high quality transaction of manufacturing resources services.

The first serious discussions and analyses of cloud manufacturing emerged in 2010 with a research project funded by the National Natural Science Foundation of China. Li, Zhang and Chai (2010) propose the definition of intelligent cloud manufacturing as: "a service-oriented, knowledge-based smart manufacturing system with high efficiency and low energy consumption". Xu (2011) has recently developed a definition of cloud manufacturing by mirroring NIST's cloud computing definition: "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."

Zhou et al. (2011) labelled cloud manufacturing paradigm in five parts: resource cloud, manufacturing cloud, business cloud, infrastructure & public platform for cloud manufacturing and cloud users. This definition is very significant, because it reveals the essential potentiality offered by cloud manufacturing.

About the cloud manufacturing resources, they are not only virtual resources as in cloud computing, such as computing or storage, but also design, simulation, equipment, material, information, even manpower, etc. Most of the resources need to be operated manually by human (Hu et al. 2012). Tai et al. (2012) further explicate that cloud manufacturing resources are all kinds of service resources that service provider provides to consumer side.

Zeng (2012) proposes the same approach and points out that the services are dynamically delivered over networks from an abstracted set of resources. The resources are available on demand in somewhere of the cloud. Every manufacturing service has certain manufacturing functions and the unified access mechanism. The key idea is to represent the manufacturing service capabilities in an unambiguous, computer-understandable form based on ontology.

The cloud manufacturing resources' properties include the basic attribute resources, information resources, design resources, software resources, detection resource, etc. In this paper, the resource supply and demand intelligent matching process are intensely discussed. Li et al. (2011) emphasize that resource encapsulation of cloud manufacturing is the precondition of the realization of service-oriented cloud manufacturing mode. It is the important step of resources sharing.

In Zhang and Zhong (2012)'s work, they define manufacturing cloud service as web service. These services should be presented in cloud manufacturing platform and be searchable. However, Tai et al. (2012) argue in their work that the existing web service is hard to meet the requirements of Intelligent Cloud manufacturing services; the main problem is that web service uniform semantic description is lacking.

Cloud manufacturing is an integrated supporting environment. It's used both for resources sharing and integrating in an enterprise. All the virtual manufacturing resources are existing in virtual manufacturing resources pools, which shield the heterogeneousness and the regional distribution of resources by the way of virtualization (Fan et al. 2004). Wu et al. (2012) state that it is a type of parallel and distributed system consisting of a collection of inter-connected physical and virtualized service pools of design and manufacturing resources (e.g., parts, assemblies, CAD/CAM tools) as well as intelligent search capabilities for design and manufacturing solutions.

Wu and Yang (2010) address the concept of cloud manufacturing. The authors stressed on the integration and cooperation, which are two of the most important characteristics of cloud manufacturing. Moreover, cloud manufacturing provides a cooperative work environment through social networking and negotiation platform for both manufacturing enterprises and individuals, and it enables the cooperation of enterprise (Wu & Yang 2010; Wu et al. 2012).

In the work of Wu et al. (2012) and Ai et al. (2013), together these studies provide valuable insights that cloud manufacturing refers to a product realization model which covers the whole manufacturing lifecycle. The manufacturing lifecycle includes pre-manufacturing (argumentation, design, production and sales), manufacturing (product usage, management and maintenance), and post-manufacturing (dismantling, scrap and recycling) (Li, Zhang & Chai 2010). It's a rapid, secure, reliable product development process with minimum costs.

2.4 Characteristics of Cloud Manufacturing

Although each of the cloud manufacturing definitions has its own emphasis, apparently five common characteristics exist, namely: intelligent, distributed manufacturing, networked, resource sharing and collaborative work. Li, Zhang and Chai (2010) highlight the keys of cloud manufacturing are service-oriented, knowledge-based and energy efficient. Since cloud manufacturing is built up based on cloud computing concept, it follows the principle of X as a service. Therefore, it can be also named as manufacturing as a service (Wu & Yang 2010).

NIST's definition of Cloud computing (Mell & Grance 2009) states that the essential characteristics are: on-demand self-service, broad network access, resource pooling, rapid elasticity, measured service. These features are also detectable in cloud manufacturing. Wu et al. (2012) described the essential characteristics of cloud manufacturing based on this formation:

- **On-Demand Self-Service:** Manufactures which join in this cloud manufacturing platform can both release manufacturing resources and services, and also access a shared collection of on-demand manufacturing resources and services to form a networked manufacturing model, which is a temporary and reconfigurable production line according to their requirements (Wu et al. 2012; Wu et al. 2013; Tai et al. 2012).
- **Broad Network Access:** In order to ensure that various stakeholders (e.g., customers, designers, managers) can interact with each other and actively participate throughout the entire production process and achieve value co-creation, cloud manufacturing can provide users access to the resources and services through heterogeneous tools, e.g., mobile phones, tablets, laptops, and workstations (Wu et al. 2012).
- **Resource Pooling:** All the manufacturing resources and services are virtualized and made available to users through cloud manufacturing platform. Cloud manufacturing services are formed by identifying, virtualization and packaging process (Xu 2011; Wu et al. 2012). Cloud manufacturing enables convenient and on demand network access to such a shared pool of configurable manufacturing resources.
- **Rapid Elasticity:** This cloud manufacturing platform allows users to quickly scale up and down to respond quickly to changing requirements. It helps to better handle dynamic capacity planning under emergency situations incurred by unpredictable customer needs and reliability issues. For example, the cloud system allows the cloud service consumers to quickly search for and fully utilize resources, such as idle and/or redundant machines and hard tools, in another organization to scale up their manufacturing capacity (Wu et al. 2012).
- **Measured Service:** For manufacturers, there are too many services and resources in the business environment, only on-demand optimized resources are provisioned to their particular business processes. Therefore, the services and resources are monitored, controlled and reported to ensure the quality of cloud manufacturing services and resources (Tao et al. 2011).

2.5 Sustainability of Cloud Manufacturing

Sustainability is defined as the capacity of the present generation to fulfil its needs without compromising the ability of future generations to meet their own needs, so that the level of human consumption and activity can continue into the foreseeable future (Bi & Wang 2013; Wolfson, Tavor & Mark 2013).

In order to survive and to be successful in manufacturing industry with such market turbulence, manufacturers need to extend their vision, to cover sustainable value creation, new business models, and also flexible and agile business processes (Xu et al. 2012). Many new terminologies related to system sustainability, such as environmentally conscious manufacturing, sustainable manufacturing, green manufacturing, remanufacturing and sustainable productions, have been proposed (Bi & Wang 2013).

The most known concept is sustainable manufacturing. US Department of Commerce defined sustainable manufacturing as the creation of manufacturing products that use materials and processes that minimize negative environmental impacts, conserve energy and natural resources, are safe for employees, communities, and consumers and are economically sound (Bi & Wang 2013). Of course, it is not just manufacturing process or the resulting manufactured products. To describe a sustainable system, a multi-level approach on products, processes, enterprise and supply chain need to be considered (Bi & Wang 2013).

Besides, green manufacturing is another attractive concept. It has been used as an alternative of sustainable manufacturing. “Green” technologies are often understood as those capable of meeting product design requirements while minimizing environmental impact. However, minimizing impact is a necessary but not sufficient condition for a sustainability strategy.

Nevertheless, the limitations in the majority of the studies are the general discussions. Only a few new requirements are identified for next-generation manufacturing systems. More advanced systems and new concepts have not been systematically studied. Future research directions in this field are needed to address all the legacy problems (Bi & Wang 2013).

The core concept of cloud manufacturing is to revitalize social manufacturing resources, optimal allocation, improve the utilization rate of social resource, and reduce use cost of the social overall resource, in the trend of low carbon economy development (Tai et al. 2012). In addition to cost, time and quality concerns, the issues of sustainability is taken into consideration during process planning and optimization (Bi & Wang 2013).

Chen (2014) measured the SWOT of applying cloud manufacturing in semiconductor manufacturer. He draws our attention to cloud manufacturing and highlights this solution enhancing the sustainable development in this industry. Cloud manufacturing can serve as a vehicle towards better sustainability via a modular approach (Bi & Wang 2013). This modular approach means that modules with sophisticated technologies, such as for online tracking of resource utilization, multi-objective decision support for planning and simulation, and on-board manufacturing execution control, can be activated by a common cloud manufacturing platform to enhance responsiveness, adaptability, reliability, and optimality in achieving first-time-right processes, wherever they are needed (Bi & Wang 2013).

3. CLOUD FUTURE FACTORY PROPOSAL

3.1 Concept and Objectives

In this research paper, a new cloud manufacturing model is proposed based on review previous research. The approach in this work is named as Cloud Future Factory (CFF). This CFF concept is designed for a real case company from Finland, for the confidential reason, the company’s name is anonymous.

Our study is different from previous studies in terms of the type of organization. Although previous studies have been proposed cloud manufacturing, our study focuses on large size organization and its internal collaborations among various departments and factories.

Case company is a leading provider in machines and systems for sheet metal working. Its solutions include laser processing, punching, shearing, bending, automation, and so on. Case company's products are designed with the aim of assuring the success of customers, and also minimizing environmental impact, reducing energy consumption. This concept of sustainable manufacturing is the base of company's green objective.

Currently, this company employs around 1,500 people and operates in over 70 countries, up to 79 units (until 2012). Products are manufactured by Product Units. Case company's manufacturing facilities are divided into 4 groups: 2D & 3D laser technology (Product Unit 1); punching technology, combination machines and systems (Product Unit 2); bending technology (Product Unit 3) and other laser technologies (Product Unit 4), respectively dispersed in Italy, Finland, USA and China, from which they deliver machines and systems all over the world. Each product unit has independent R&D, logistics and manufacturing.

This case company targets to provide customers with the most comprehensive range of high performance, profitable and sustainable machines, and relevant services, and also to have a business model focused on actual customer's needs. In order to achieve this goal, case company is structured worldwide in matrix-type organization as shown in Figure 2. It acts as a single "virtual" company, although through a variety of legal entities and branch offices located in over 20 countries. Different Region Units are responsible for sales, installation, training and service of all case company's products for certain areas.

Product and Region Units are coordinated and supported at the divisional level by a lean central organization covering administration/finance, IT, HR, marketing, after sale coordination, R&D coordination, quality. Case company is an integrated global company. With this business and functional structure, this case company can flexibly and quickly respond to changes in markets and priorities.

Although this matrix organization structure provides many advantages to case company, one prominent feature is the internal complexity in information exchange. This is very typical phenomena in many international operation companies. Region Units are responsible for collecting customer requirement, and providing the customized design and prototype of the machines then sending to specified Product Units accordingly. For instance, if customer needs machines for the processing of three-dimensional parts, the working order will send to PU1. The transferring of information and production plan phase requires a significant amount of time.

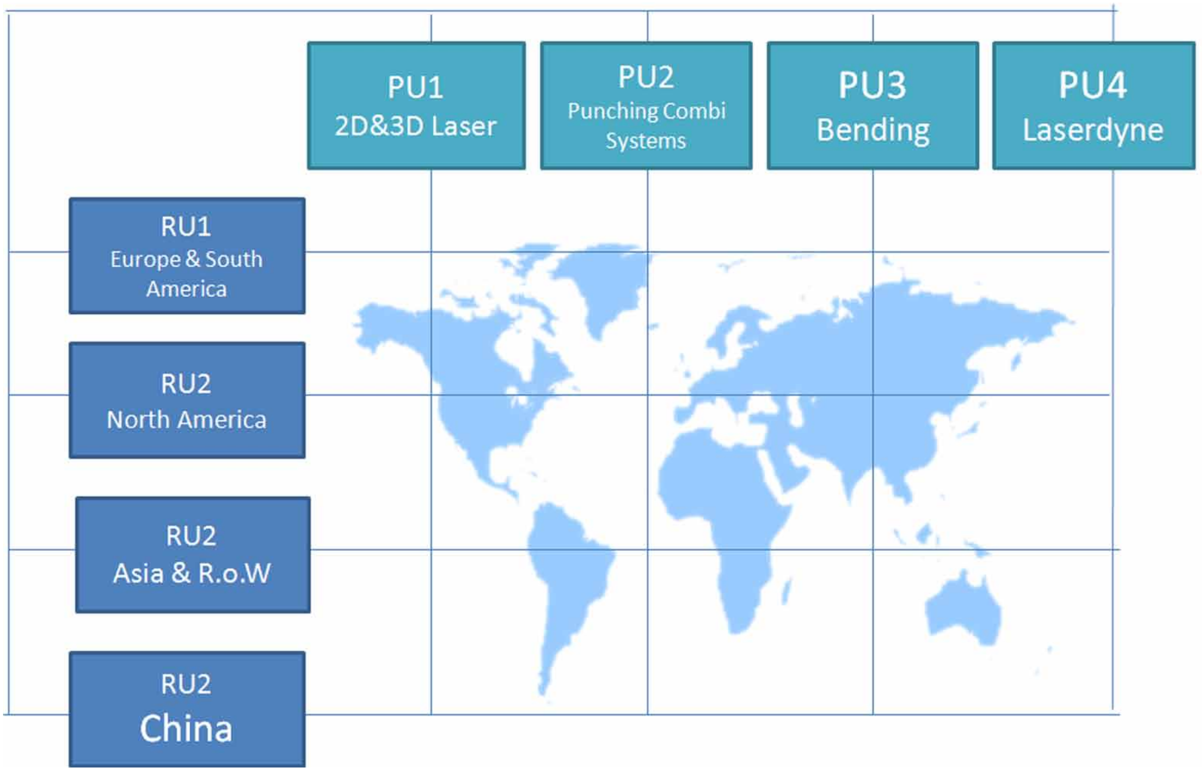
Due to this property of organization structure, case company needs an efficient way to manage its network of supply, manufacturing, sales and also various services, etc. Management of complexity is a very crucial issue for case company in a practical way. Integrated enterprise capabilities could grow by information sharing with all different units, various legal entities and branch offices.

The aim of CFF is to effectively organize all kinds of manufacturing information, resources and capabilities separated in different Product Units and Region Units all over the world, and virtually manage these assets and also be centralized in this CFF. Therefore, the project described here will set up and customize the cloud manufacturing infrastructure into case company.

3.2 Framework of Cloud Future Factory

The current manufacturing environment is highly competitive and uncertain. A manufacturing system has to be agile to adapt in a dynamic environment. Figure 3 illustrates the conceptual framework of Cloud Future Factory. Two main directions state the matrix-type relationships

Figure 2. Matrix organization structure with 4 Product Units (PU) and 4 Region Units (RU)



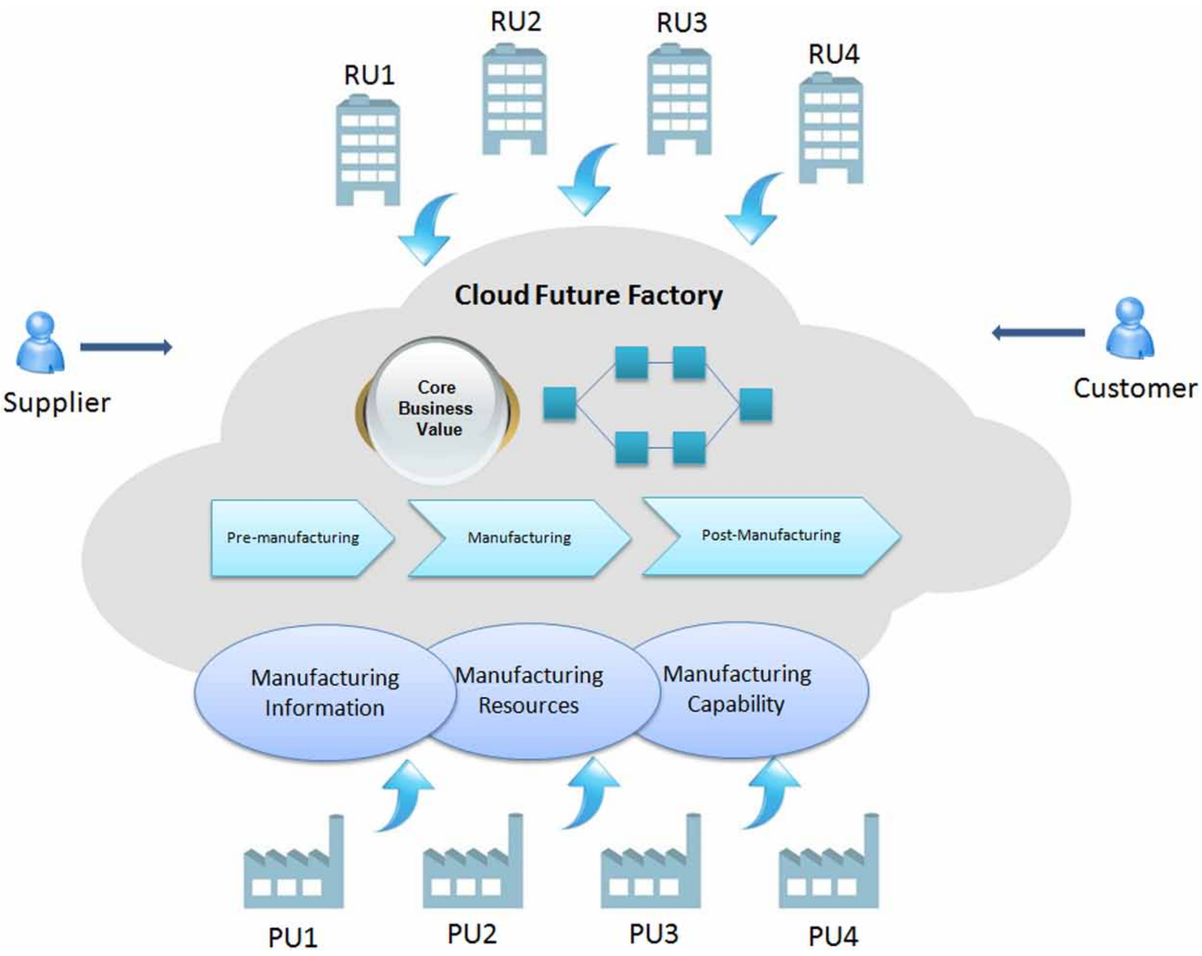
among Product Units and Region Units. All the Product Units publish their product manufacturing information, resources and capabilities into the cloud manufacturing platform, in the meanwhile, all Region Units are able to publish sales, customer orders, etc. into this platform with customized design.

Communication is one of the most vita factors in lean manufacturing. In most companies, the goal of implementing "lean manufacturing" is to eliminate waste to increase productivity. But in this CFF framework, it emphasizes the seamless collaboration and real-time communication. Prompt and accurate communication of manufacturing information, resources, and capabilities is very critical in an effective lean manufacturing environment. By using this CFF concept, it can centrally manage the shared information, resources and capabilities, and achieve competitive and sustainable.

This conceptual framework covers the whole machines and software manufacturing process. Strictly speaking, it refers to the whole manufacturing process, from pre-manufacturing, manufacturing to post-manufacturing. All the activities in this CFF are to achieve the core business value which is also the business objectives of this case company:

- Effective communication: reducing the time consuming during communication;
- Reducing cost of manufacturing: manufacturing line optimization;
- Align supply with the demand in real-time;
- Improving elasticity of system: dynamic production planning;
- Expanding scope of services: more partners, namely suppliers and customers, involved in this manufacturing process.

Figure 3. Conceptual framework of Cloud Future Factory



3.3 Lifecycle of Cloud Manufacturing

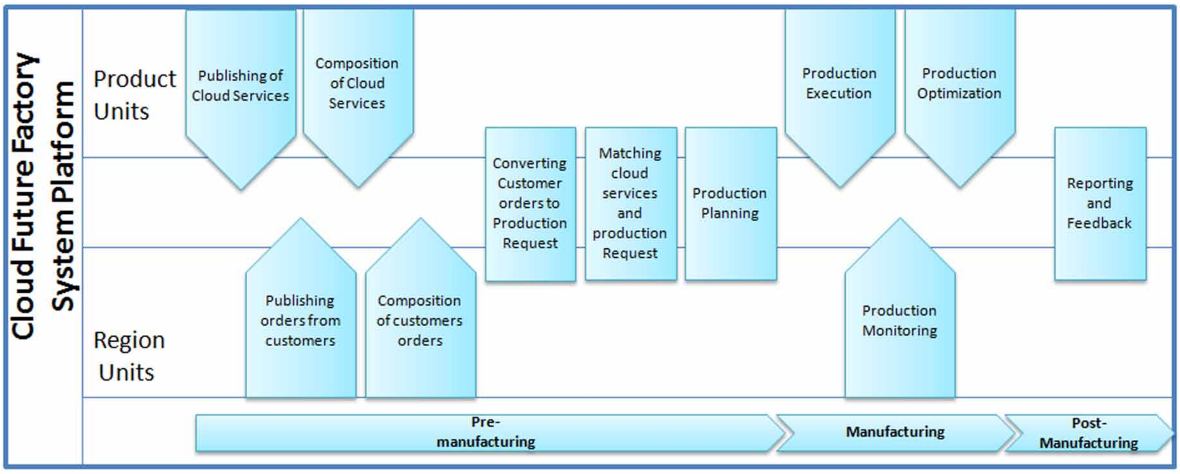
This CFF includes the areas covering products lifecycle management, modelling, design and optimization, and also inter-organizational relation management in cloud computing. In this particular research, case company is addressed to encourage international cooperation under the cloud manufacturing model.

Manufacturing is a process of transformation of input to output and value adding (Jovane, Westkämper & Williams 2008). It is of fundamental interest to optimize the benefits of each manufacturing process in its perspective life cycle. In order to achieve the costs reducing and the elasticity increasing, it is necessary to increase the efficiency of the communications and change the traditional ways of customer-oriented towards a manufacturing lifecycle paradigm.

Figure 4 demonstrates the functionalities provided by the cloud future factory system platform, and all the functionalities are classified by the manufacturing lifecycle. It makes full use of the group advantages to achieve integration and coordination by sharing cloud services.

- **Publishing of Cloud Services:** The manufacturing information, resources, and capabilities are encapsulated into cloud services. All the cloud services are accurately

Figure 4. Functionality provided by the CFFSP according to the manufacturing lifecycle



described, according to the domain ontologies and attributes, and then publish them to the cloud service pool (service registry).

- **Publishing Orders from Customers:** Region Units need to analyze the customer's needs, generating customer orders and configuring the products by orders. In the meanwhile, they need to provide customers with product information and communicate with customers.
- **Composition of Cloud Services:** It combines several cloud services according to the production needs to provide more compelling new services. The manufacturing resources, capabilities, and information are sharing in the cloud service pool.
- **Composition of Customer Orders:** All the customer orders from different region units are combined based on the products and the product units.
- **Converting Customer Orders to Production Request Description:** The production request is converted from one customer order or multiple customer orders with the same requests. The production request includes products requested by the customers and schedule of manufacture. It also records the location and special requirements.
- **Matching Cloud Services and Production Orders:** Matching the production request description and the cloud service description, then selecting the best cloud services composition.
- **Production Planning:** It determines the production paths and locating the required resources and capabilities.
- **Production Execution:** Once the product units get the production requests and production planning, they can carry out the manufacturing work.
- **Production Monitoring:** It's necessary to monitor their execution during runtime. The monitoring information is not only gathered and collected from the legacy systems but also managed centrally. So the production status are available for all units.
- **Production Optimization:** The production process need to be optimized throughout the entire lifetime.
- **Reporting and Feedback:** The production process will be evaluated and reported. Feedbacks from customers are collected. All knowledge and information are stored

in an information repository for cloud service.

This integrated cloud manufacturing services built on lifecycle thinking, in order to increase information sharing and communications. For instance, when the manufacturing schedule changes, machines are down, or any production quality or inventory issues occur, these information need to be communicated as soon as possible to solve the problems, to improve the performance, and to manage the process.

3.4 Cloud Future Factory System Platform Architecture

To demonstrate the tool of CFF, a Cloud Future Factory System Platform (CFFSP) is under developing. CFFSP is designed as an Information and Communication technology (ICT) tool. It can be used as a concrete tool of manufacturing management system to fulfil the concept of cloud manufacturing in reality, and to realize the integration within manufacturing processes in an increasingly globalized industrial context. Factories involved can share and circulate their manufacturing resources and capabilities while they can also request various manufacturing services on-demand for the whole lifecycle of manufacturing.

Figure 5 shows a function view of CFFSP. The proposed architecture of the CFFSP is a hierarchical structure. It consists of the following three layers: CFFSP business management layer, Technology support layer and Manufacturing layer.

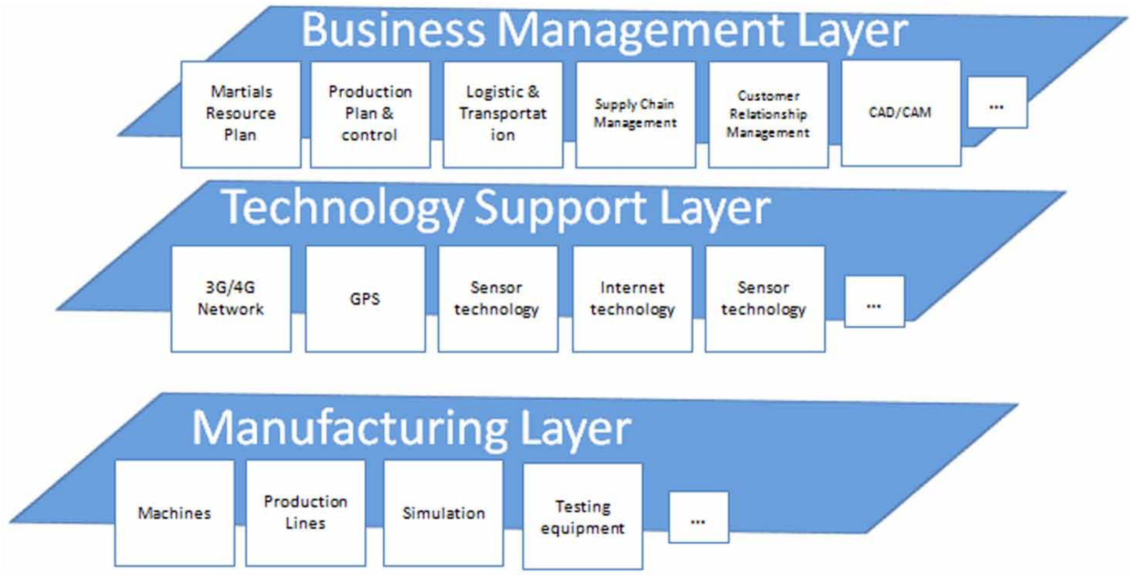
- **CFFSP Business Management Layer:** Provides the business operation and business logic definitions which oriented to the business requirements of the CFFSP consumers (Region Units). All manufacturing applications are provided to users depending on various requirements.
- **Technology Support Layer:** Similar to Infrastructure as a service (IaaS) layer, which establishes a basic operational support environment.
- **Manufacturing Layer:** Provides the manufacturing resources and capabilities involved in the entire manufacturing lifecycle. It enables CFFSP services provider (Product Units) to unload their services. Each of the resources and capabilities is encapsulated as a service, and then it can be requested on demand by CFFSP.

Most manufacturing companies use various systems to determine product manufacturing and the production planning process. CFFSP is used herein to translate all the customer orders into production request descriptions. The CFFSP is a cloud based system for distributed (multi-site) production planning and control system. The key features of the system include:

- Production scheduling is done continuously, not daily, etc.
- Alternative possibilities are processed beforehand.
- Actual processing times are fed to production plan and control system real-time.
- Machine or work phase specific error data could be input directly to production plan and control system.
- Alternative schedules are adjusted based on feedback and situations.
- Possible integration to wider supply chain.

CFFSP can support a dynamic manufacturing process with a closed-loop pre-emptive production planning and control. The objectives are to develop a concept of real-time multi-level optimization production scheduling system and test it at the sheet metal processing line.

Figure 5. The architecture of Cloud Future Factory System Platform



4. FUTURE WORK

In order to continue the work described and to achieve further results, this project will be extended to include more business activities. As mentioned early, each Product Unit has its own R&D. Therefore, it is very crucial to combine various dispersed R&Ds. It will support the product innovation and production process innovation. Furthermore, this cloud manufacturing will play a significant role in floor shop management as well. It will integrate with Manufacturing Execution Systems (MES), and create ideal conditions for high-quality and efficient manufacturing, increasing reliability and global product traceability.

Future work will concern more about the technologies needed to support the cloud manufacturing. Cloud computing technologies can be used to realize the integration between different business applications and enable the collaborations. However, security issues of this cloud manufacturing infrastructure should be considered as well. Besides, more research efforts should put on how to publish and compose the cloud services because current techniques are limited. Cloud service composition and optimal selection is one of the key issues for implementing a cloud manufacturing (Xiang et al. 2013).

Handhold devices, i.e. Smart phones and tablets, with internet access are very convenient to access and respond to real-time communication. They are essences for cloud computing. They will be used to improve the experience of communication. Real-time reporting and comprehensive monitoring of shop floor operations, resources, and capabilities are very imperative in new lean processes.

5. CONCLUSION

Cloud computing is not a new concept anymore, and it is already embodied in practices from many aspects. But to realize the full potential of cloud computing will depend on the technology deployment, the application implementation, database integration and different cloud applications integration (Zhang & Xue 2012). Many manufacturing companies are using cloud concept to their business model, namely, cloud manufacturing.

This concept may not be radically different from existing manufacturing paradigms, such as networked manufacturing, but it brings a new way to think the agility.

Current structure of the industry and the considerable amount of international trade requires a strategy that takes these conditions into account in advancing sustainable production and consumption. Cloud manufacturing aims at a new industrial revolution. Cloud manufacturing is a solution for trade-offs among the interests and sustainability. It emphasizes the collaboration between different stakeholders and process innovation. It allows the possibility of value co-creation patterns.

This paper has examined the role of cloud manufacturing in a large size company. This Cloud Future Factory (CFF) represents an example of cloud manufacturing. The CFF roads to high value added lean manufacturing, involving the stakeholders from all factories and business units. It was proposed to manage all dispersed factories and their sales centers in a case company, which is a matrix-type organizational structure.

The major works undertaken in this paper include a comprehensive literature review (to highlight the possibilities and potentials of cloud manufacturing) and a technology review (to find out a set of cloud technologies used in implementing such platform).

This chapter attempts to offer a system platform that not only coordinates the production and sales across many physical locations, but also allows the limitations and capabilities of the supply chain to be explicitly available during the production processes. CFF acts as a strategic platform to pursue sustainable manufacturing. Besides, the purpose of Cloud Future Factory System Platform (CFFSP) is to construct a flexible and effective management platform and provide users a concrete ICT tool. This approach of CFFSP, however, demands more technology design and concerns.

In most previous studies, cloud manufacturing is considered as a particular business model for small and medium sized enterprise. For the large company, usually have a lot of established business processes employed and running, which requires sophisticated monitoring and control structures. Thus, the necessary degree of flexibility required to quickly adapt to changing requires and changing environments is missing. Therefore, we adapt this cloud manufacturing concept to fit a large company. The competition shifts from reducing costs to high-added value.

The evidence from this study suggests that cloud manufacturing is ideal for SMEs to collaborate with other companies while maintaining their core competencies, but also it is suitable for large size companies. Large size companies can achieve the lean manufacturing with the focus on better communication.

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KEY TERMS AND DEFINITIONS

Architecture: Providing the overall view of the cloud manufacturing platform.

Cloud Computing: Not only a technological innovation but also a business evolution.

Cloud Future Factory: A novel concept proposed in this research to manage the seamless collaboration and real-time communication for matrix-type organization in the form of cloud manufacturing.

Cloud Manufacturing: An integrated collaborative working environment to support distributed factories sharing their resources and interoperating with each other.

Lean Manufacturing: To eliminate waste to increase productivity.

Lifecycle: Means the process and possible functionalities of the cloud manufacturing platform.

Matrix-Type Organization: The organizational structure with a variety of legal entities and branch offices located in different countries but acting as a single “virtual” company.

Sustainability: Refers to the capability of fulfilling current needs without compromising the future generations’ environment. In this context, sustainability of cloud manufacturing means that all the factories maintain the collaborative relationship based on mutual complements in resources and capabilities.

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Virtual factory system design and implementation: integrated sustainable manufacturing

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ABSTRACT

Manufacturing is the backbone of the European economy, but it is challenged by globalisation and technological evolution. Among the potential problems existing in current European industry are that the manufacturers are mostly small and medium-sized enterprises (SMEs), and it is difficult for them to take quick actions and relocate resources flexibly based on turbulent requirements. Therefore, it is critical to move towards sustainable development in terms of business models and business practices. In order to respond to these challenges, disruptive changes are needed to maintain the competitive advantage. In this paper, a new way to achieve collaboration among distributed SMEs is introduced, namely the Virtual Factory. Our purpose is to promote an innovative value-added manufacturing in sustainable development. This paper describes how an integrated information system can be designed and implemented to support collaboration among distributed SME manufacturing.

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Virtual factory; distributed manufacturing; supply chain; information system; sustainability

1. Introduction

Under international pressure and globalised market competition, organisations are facing the challenges of increasing their competitiveness while ensuring high-quality products and services. Organisations must dedicate much effort towards quick responses to business requests and opportunities in an efficient and sustainable way. An important factor that organisations need to consider is dealing with constant changes (Azevedo & Almeida, 2011). These changes vary from several aspects, such as customers' requirements, the market environment, business approaches, etc. Organisations have to develop their ability to adapt and reconfigure themselves, in the meanwhile cope with a more and more complex business environment. However, in order to achieve sustainability, it is essential to create a collaborative environment for different organisations. Work collaboratively brings enormous benefits to organisations (Rabelo & Gusmeroli, 2007), such as offering conditions to reduce expenses, increasing capacity, broadening markets and improving themselves with knowledge acquired in business (Drissen-Silva & Rabelo, 2009; Rabelo & Gusmeroli, 2007).

The Virtual Enterprise (VE) is a concept describing the collaboration of multiple independent companies. It is seen as a dynamic, temporary cluster of autonomous companies that collaborate with each other to take a given opportunity or to deal with a particular need, offering services abroad as it is a single organisation. This operation is achieved by a coordinated sharing of skills, resources, information and knowledge, and also a sharing of risks, cost and benefits. Mostly the activities are supported by computer networks and strongly correlated with IT use (Drissen-Silva & Rabelo, 2009; Song & Nagi, 1997; Zhao, Cheung, & Young, 1999).

In recent years, several research projects (e.g. Modular Plant Architecture (MPA), a configurable virtual reality system for Multi-purpose Industrial Manufacturing Applications and Digital Factory for Human-Oriented Production System) studied the opportunity to apply new digital and virtual technologies in the manufacturing industry (Sacco, Redaelli, Cândea, & Georgescu, 2009). By reviewing the directions of ongoing research and the market environment characteristics, it can be concluded that modern factories have to be modular, scalable, flexible, open, agile and knowledge based in order to quickly adapt to the continuously changing market demands, technology options and regulations (Sacco et al., 2009). Use of the VE concept is becoming prevalent in many manufacturing enterprises (Fujii, Karihara, & Morita, 2000). They increasingly rely on Information Communication Technology (ICT) and leverage their information systems (IS) to react to the demands of the market more efficiently (Gunasekaran & Ngai, 2004). Recently, the advent of Internet technologies have opened up even more opportunities and business has evolved different forms (Goel, Schmidt, & Gilbert, 2009).

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However, the current approaches still do not meet the demands of industry and fail to provide all the required functionalities. Especially in European countries, most companies are small and medium enterprises (SMEs) and usually they do not have the empowerment to accomplish their business goals, so it is critical for them to constantly change to interoperate with their surrounding ecosystem. In order to make a change towards sustainability, new economic development strategies should be considered. Manufacturers need to engage in new thinking, about how the technologies and practices meet the new challenges (Park & Jeong 2013).

An answer to the problems and requirements highlighted so far can be given by the development of the new Virtual Factory Framework (VFF), which can be defined as 'an integrated virtual environment supporting the design and management of all the factory entities, ranging from the single product to the network of companies, along all the phases of the factory lifecycle' (Azevedo, Almeida, Bastos, & Piedade, 2010). This paper presents the topics and goals of a new research project titled 'ADaptive Virtual ENTerprise manufacTURing Environment (ADVENTURE)', and it highlights the answers that contributes towards the previously described requirements. This project has been developed by academic research institutes, industry and software development companies. The present approaches to supporting planning and optimisation of factories have shown limitations and an inability to address the increasing market competitiveness and need for responsiveness. Most of these research projects focus primarily on the business side in general and on aspects like partner finding and factory building processes. However, no proven tools or technologies exist in the market that would provide the creation of VF applying end-to-end integrated ICT. There is an urgent need for new approaches that address these current market challenges. This paper describes an integrated scenario and shows a possible real use for solving the production needs of SMEs.

Our solution provides a full spectrum of the VF environment and the related requirements and technologies. An IS infrastructure was designed for supporting VF in manufacturing processes and facilitating information exchange between factories beyond the boundaries of the individual enterprises involved. The three-layer infrastructure paradigm provides both brokers and partner factories with an easily deployable and configurable, distributed, scalable, on-demand VF platform. This VF platform is not a replacement of partner enterprises' existing systems, but it provides a communication channel among all the distributed systems and supports collaboration in moving towards a sustainable manufacturing environment.

2. Research context review

Since the main purpose of this paper is to propose a new approach for integrated manufacturing systems, it is important to clearly understand the previous research and initiatives that have supported and stimulated this research. The fundamental concept used in this research is VE. Therefore, we will start from a definition of VE, and then step forward into the manufacturing industry.

2.1. Definition of virtual enterprise

The notion of VE has been around over the past decade and a number of mainly empirical activities have been going on in this area. The term itself has undergone several versions or modifications. There have been many discussions and debates on how to define it, but still a precise definition of the concept and an agreement on the used terminology is lacking (Camarinha-Matos & Afsarmanesh, 2005). Many research efforts have been concentrated on realising some of the features of VE, even without recognising or labelling them as such. Khoshafian (2002) highlights that VE has emerged from the organisational paradigms of Virtual Corporation, Virtual Organisation, Virtual Community, Supply Chain and e-business, and more recently, Extended Enterprise. Nevertheless, VE is different from these pervious paradigms.

In practice, many geographically dispersed enterprises often feature this type of business collaboration. Each enterprise can publish, discover and share its respective manufacturing services while focusing on its own core business (Zhang, Zhang, Cai, & Wu, 2012). This cooperation in the form of VE can achieve a particular business requirement and obtain more opportunity to compete favourably in the rapidly changing global market (Browne & Zhang, 1999; Helaakoski, Iskanius, & Peltomaa, 2007). Katzy and Obozinski (1999) authored one of the most cited papers, which introduce the concept of VE as follows: 'the virtual enterprise is based on the ability to create temporary co-operations and to realise the value of a short business opportunity that the partners cannot (or can, but only to a lesser extent) capture on their own'. Andrade et al. (2015) connect the VE format with the concept 'Holon', which refers to autonomous organisations which act as a whole but which are not self-sufficient.

Furthermore, VE provides a new solution for unpredicted opportunities (Katzy & Obozinski, 1999). Easley (2007) concludes that three primary factors comprise the driving force behind VE, and they are an increasing focus on core competencies, an increasing need for partnering due to the levels of complexity in the lifecycle engineering of some product areas, and a need for more agile systems as the result of market forces. Romero, Rabelo, Hincapie, and Molina (2009) define the needs and requirements from quality, time and cost aspects. These requirements are also the criteria to consider regarding effective collaboration relationships among different partners. The key elements of VE are 'cooperating' and 'networking'. The VE temporarily acts as a single organisation without forming any new legal entity (Camarinha-Matos & Afsarmanesh, 2005). New network- and web-based technologies allow the using and sharing of knowledge worldwide, which eases collaboration between different business areas and also among geographically distributed partners and stakeholders (Jufer, Politze, Bathelt, & Kunz, 2012).

This form of cooperation especially benefits SMEs which can join skills and resources to gain competitive advantage. Some distinguishing and essential characteristics are obvious in VE:

- Customer-based: All the participating partners appear as one single enterprise to the customers (Goel et al., 2009; Larsen & McInerney, 2002) and they have the ability to fulfil customers' unexpected requirements together (Jufer et al., 2012).
- Organisational structure: The VE itself owns no inventoried resources, assets, plants, factories or warehouse. These are owned by its participating companies. It is a network to tie independent enterprises together (Camarinha-Matos & Afsarmanesh, 2005; Goel et al., 2009; Larsen & McInerney, 2002).
- Geographical dispersion: In order to capture a new opportunity quickly and respond to customer requirements flexibly, cooperation between distributed sites is necessary (Huang, Gao, & Chen, 2011; Jägers, Jansen, & Steenbakkers, 1998; Katzy & Obozinski, 1999; Larsen & McInerney, 2002; Wang, Wong, & Wang, 2014). Because the communication between participants is taken care of by ICT, the work location is no longer important.
- Based on core competencies: Most companies have both higher and lower quality competencies. In VE, several companies can pool their talents and resources and then each enterprise can contribute their high-quality competencies (Jägers et al., 1998; Larsen, & McInerney, 2002).
- Lifetime: It is of a temporal nature and is dissolved as soon as the business opportunity is passed (Goel et al., 2009; Larsen & McInerney, 2002; Zhang et al., 2012; Wu, Zhu, & Zhou, 2014). A VE is something unique, which means that the way a problem was solved in a given previous VE is not necessarily valid for another VE (Drissen-Silva, & Rabelo, 2009).
- Partner equality: Each partner in this collaborative effort has equal responsibility for the process of VE, and all companies need to play their own roles, contribute to the improvement of the end product and form a link, regardless of location and functionality (Jägers et al., 1998).
- Changing participants: According to the specific business opportunities and objectives, VEs could be composed of different partners even if the objectives are the same. Each activity can be performed by different companies which have the same competencies (Jägers et al., 1998; Wang et al., 2014).

2.2. Product management and Virtual Enterprise lifecycle

Product lifecycle (PLC) refers to the time period from product design, manufacturing, to being available in the market and maturity, until it declines. The PLC approach is essential to achieve sustainability by expanding the focus from the production site to the entire factory (Azevedo et al., 2010). Four generally considered perspectives are identified, i.e. marketing, product management, manufacturing and computer systems/data management. Due to the fast changing markets and appearance of new technologies, the PLC is becoming shorter but also more complex. The product per se has also evolved from physical product to the notion of the extended product, which has additional services to make it more competitive and attractive (Romero et al., 2009). Therefore, changes in product management are frequently and continuously implemented at all levels of the factory.

Although major ICT players already offer comprehensive product lifecycle management (PLM) supporting most of the processes, they do not offer all the required functionalities and they lack interoperability. Moreover, SMEs cannot afford the present expensive PLM software (Hints et al., 2011). The VE business model is a promising approach to tackling issues in PLM and reacting to changes in product management and adapting to opportunities (Katzy & Schuh, 1998). It facilitates the sharing of resources, manufacturing information and knowledge, while harmonising and integrating all the factory entities, from a single product to networks of companies, along all the phases of their lifecycles (Azevedo et al., 2010; Terkaj & Urgo, 2012). Several previous studies have reported on the lifecycle of VE based on its characteristics. They put emphasis on different perspectives, but the essences are similar. Katzy and Obozinski (1999) refer to a lifecycle-based framework for designing VE. The value system lifecycle gives a framework for all concurrent engineering activities in designing VE. It includes the pre-phase, configuration phase, design phase and subsequent operation. Reid, Liles, Rogers, and Johnson (1996) also propose VE lifecycle as a new and innovative strategy for becoming competitive in this dynamic manufacturing environment. (1) A VE is conceived when customers' needs are recognised. (2) The VE is created when relationships are established. It brings together the requisite competencies. (3) The VE competes when the 'product' is offered in the marketplace. (4) After competing, the enterprise is configured as assets and competencies are acquired and the requisite processes and infrastructure are developed to accomplish the objectives of the enterprise. (5) The VE then conducts operations to produce, deliver and support the 'product' and to maximise stakeholder value. (6) It concludes operations when the objectives of the enterprise are satisfied, by terminating the relationships.

Rabelo and Gusmeroli (2007) report on the requirements of constructing collaborative networked organisations (CNO), and they define diverse phases of a virtual organisation lifecycle into creation, execution and dissolution. Drissen-Silva and Rabelo (2009) used four phases classification: creation, which is for VE planning and partners' selection; operation, which comprises the execution and monitoring of the planned activities; the evolution phase comprising the handling of problems detected in the operation phases; and the dissolution phase comprising all issues associated with the VE ending. Cong, Zhang, Liu, and Huang (2010) divide the lifecycle of service-based VE into four phases, namely recognition, formation, operation and termination. The recognition phase includes goal and opportunity recognition, etc. After making a decision on partners in the formation phase, the VE is established and the operation mode is designed. In the operation phase, the main activities include design, marketing, financial management, manufacturing and distribution. When VE has realised all its goals, then comes the termination phase, and the operation is terminated, the assets liquidated and alliance disbanded. Jufer et al. (2012) point out three essential activities in the context of factory planning and management: monitoring, optimisation and (re-design). It is very important to define the activities of VE in the manufacturing context, and these activities can address more concrete functional requirements.

2.3. *Information system for Virtual Enterprise*

Numerous studies have attempted to build models for VE information systems to enable their evaluation in manufacturing industry (Ader, 2001; Cong et al., 2010; Goel et al., 2009; Park & Favrel, 1999; Yoo & Kim, 2002). Innovative information systems (IS) in VE play a critical role and enabling factor in extending the enterprise scope beyond the traditional organisational boundaries (Romero et al., 2009). Advances in modern technologies, such as the Internet, workflow management systems, etc., have made it possible for IS to enable enterprises to cooperate with each other (Zhang & Shi, 2003). VE structure is IS-centred, and it is further interpreted such that its core competence is in supporting different organisations working together. However, as Ader (2001) foresaw, it would take a long time to generate the full effect of VE. Due to the heterogeneous and autonomous nature of the involved organisations and the dynamic nature of a VE formation, the lack of a sophisticated coordination mechanism is problematic (Zhang et al., 2012). There are many challenges related to technology when implementing IS to support VE. The structure of VE has to face different technical constraints (Martinez et al., 2001). In order to support VEs' activities, several ICT-related issues should be handled. The ICT infrastructure should be transparent in order to provide reliable communication (Rabelo & Gusmeroli, 2007).

VE facilitates cross-enterprise collaboration but it is not easy to realise this business formation. Considering the activities in the lifecycle of VE, the search for and selection of partners is a very important and challenging process in the lifecycle of a VE (Camarinha-Matos & Afsarmanesh, 2001; Cunha & Putnik, 2006). Sarkis, Talluri, and Gunasekaran (2007) state that in order to be competitive and agile, organisations must adapt themselves and select their strategic partnerships and alliances. Choosing the right partners for the right job is the most fundamental and also the most difficult decision. Different companies fit together in terms of mutual trust, organisational culture, business processes and their ICT systems, etc. It is difficult to accomplish a search for suitable partners who hold the needed resources and/or competencies and will also fit with the other partners. It bears the risk that the allocated partners will not fit together. Camarinha-Matos and Afsarmanesh (2001) suggest that the VE partners' search and selection activity can be achieved by the application of multi-agent systems and market-oriented negotiation mechanisms. However, it is difficult to guarantee coordination between independent agents unless common rules are adopted (Camarinha-Matos & Afsarmanesh, 2001).

In order to perform the search and selection, it is important to ensure that the information is available when needed. Real-time access is a major advantage of the Internet and Intranet technologies and is a primary reason for the existence of VE. However, the issue is that in reality many manufacturers are missing appropriate real-time information about manufacturing and there is often a lack of control. Another challenge in search and selection activities is the effecting of information exchange among application systems (Athanasiadis, 2007; Neaga, Harding, & Lin, 2007). The problem here is missing interoperability between the business partners' IT systems as well as the fact that some information might not be automatically generated and provided (Athanasiadis, 2007). With the development of ICT, there are a number of standards and methods that have been proposed for the various aspects of integration and exchange (Khoshafian, 2002; Terkaj & Urgo, 2012). However, current technical standards still do not provide complete support in the VE environment.

In this temporary organisation of VE, quality of services (QoS) is the key point to ensure all participating enterprises have a good cooperation (Wu, Zhu, & Zhou, 2014). It is very important to consider information about the partners and their performance when searching and selecting appropriate partners (Huang et al., 2011; Wu, Zhu, & Zhou, 2014). In order to measure the performance of a manufacturing organisation, usually dashboard is implemented. It is not new but has been widely adopted by businesses. Dashboard is a valuable method for companies to exchange information among different parties. This management of information supports the measurement of the performance of employees in an organisation with respect to problem solving, work integration and customer service (Doll & Torkzadeh, 1998).

In order to monitor the partners' performance, certain criteria need to be defined in this dashboard. QoS criteria include domain-independent ones such as response time, price, reliability and domain-dependent ones like precision and refresh frequency for an exchange rate inquiry service (Wu, Zhu, & Zhou, 2014).

It appears to be a growing trend for supply chain partners to collaborate in a VE formation (Wang et al., 2014). As Gunasekaran and Ngai (2004) point out, integration of the supply chain's activities and processes before development and implementation of the IS in supply chain management is needed. Song and Nagi (1997) analyse the requirements of agile IS development. They emphasise that even in global integration, it is imperative to maintain the autonomy and heterogeneity of geographical distributed partners. However, since the partners are totally autonomous, decisions cannot be imposed by a single company (Drissen-Silva & Rabelo, 2009). Therefore, to support collaboration among all partners and obtain maximum benefits from VE in terms of manufacturing industry, the IS must possess functionalities which provide both high integration and significant autonomy. These are very difficult to balance.

Overall, these studies presented above provide valuable insights into IS design and also drive the requirements and development for the next generation of VE in terms of challenges that imply (1) the selection of proper manufacturing enterprises; (2) rapid integration of the manufacturing processes; (3) dynamic reconfiguration of the system; (4) adapting to changes introduced by various factors such as the joining and dropping of partners, and market and context changes; (5) keeping the factory's autonomy for easy partnership maintenance.

3. Empirical study

Industrial manufacturing is a typical application area of the VE concept, which is also our focus in this paper. In the current turbulent global economic environment, the manufacturing processes can hardly be accomplished by only one manufacturer, and need multiple manufacturers. Manufacturers must be viewed in the context of their contribution to the total value chain (Helaakoski et al., 2007). It is very important for manufacturers to focus on their core competences and join in the efforts with others, in order to fulfil the requirements of new products (Camarinha-Matos & Afsarmanesh, 2006). Therefore, we label this particular VE as Virtual Factory (VF). More specifically, VF is dynamic, *ad hoc* and temporary, and exists only for the lifetime of a specific business opportunity in the manufacturing field. Each manufacturer in VF is an independent operation agency, but the management of VF is logically concentrated and physically distributed (Chen, Huang, & Ji, 2008).

VFF can be defined as 'An integrated collaborative virtual environment aimed at facilitating the sharing of resources, manufacturing information and knowledge, while supporting the design and management of all the factory entities, from a single product to networks of companies, along all the phases of the their lifecycles' (Terkaj & Urgo, 2012). The VF paradigm can assist in achieving business process innovation by addressing various key issues (Sacco et al., 2009):

- reduction of production times and material waste through the analysis of virtual mock-ups of new products;
- development of a knowledge repository, where people can find any kind of stored material (designs or documents) in different versions;
- improvement of workers' efficiency and safety through training and learning on virtual production systems;
- creation of a collaboration network among people concurrently working on the same project in different places.

3.1. ADVENTURE project

It is critical to promote European SMEs to be collaborative through sharing costing resources and valuable knowledge and expertise. This collaborative environment supports SMEs to achieve more bargaining power with the larger companies in general. ADVENTURE is a research project sponsored under the Europeans Commission's 7th Framework programme as well as by the project members (www.fp7-adventure.eu). This project aims to foster and strengthen the primacy of future European manufacturing by creation of the next generation of VF.

The goal of this project is to generate a framework that provides the tools to combine factories in a 'plug & play' way to manufacture a particular product with customers' unique requirements. The aim of this project is to lay the foundations for future applications in this research area. The desired outcomes are major time and cost savings for manufacturing companies, while increasing performance in the design, management, evaluation and reconfiguration of new or existing facilities. ADVENTURE aims at simplifying the establishment, management, adaptation and monitoring of dynamic manufacturing processes in VFs. A new solution will be designed to enable VFs and all related enterprises to collaborate beyond existing operational boundaries and exchange performance information across factories. Various technologies from the field of Ubiquitous Computing and 'the Internet of Things', e.g. wireless sensors, are a necessary requirement. They will be adopted in order to support the monitoring and governance of processes, i.e. to give information about the current status of manufacturing and delivery.

From the above description of the complex processes in the PLC, it clearly indicates that it is not an easy task to effectively manage processes with all the related information and collaborative tasks in the PLC. All these require effective and efficient collaboration among all the processes in the PLC. Effectively managing the PLC and related business process can reduce time-to-market, shorten the time-to-volume and enhance tune-to-profit (Ming & Lu, 2003). However, currently available enterprise application systems are unable to meet such requirements for effective collaboration in the management of the PLC. Therefore, a new business model called collaborative product services and the corresponding architecture need to be developed for collaboration in PLC management.

3.2. *Virtual factory reference model*

We consider each VF as a collection of service oriented business processes to manage a specific PLC and deal with all the issues related to this PLC. The lifecycle of VF is ended when the PLC is dissolved. In order to support the VF business model, a VF platform needs to be established in which the manufacturing services are registered, searched for and used. In this way, the infrastructure is capable of managing and supplying those services that are provided by manufacturers and requested by service consumers in order to run the production networks within a VF platform (including the secure exchange of data between all parties, joint specification management, product configuration infrastructure, etc.).

A new reference model (Figure 1) is created based on two principles: 'integration' and 'autonomy', to better address and meet the requirements of VF. This solution helps VF and the cooperating manufacturing enterprises move beyond existing operational limitations by providing concrete tools and approaches for leveraging the information exchange between enterprises. The centralised control enterprise is named manufacturing broker and is responsible for collecting customer orders, designing the process model and describing the manufacturing process and then assigning appropriate manufacturing enterprises (in this scenario, they are called partner factories) to accomplish the manufacturing processes. Therefore, the clients in this VF platform comprise two parts: brokers who propose the VF and partner factories which perform the manufacturing process. From this reference model, all the factories must manage their own business while integrated in this platform and share their own resources and capabilities.

In order to fulfil orders in a short time and avoid bottlenecks, control over the whole manufacturing process is carried out in a form of virtual factory. The brokers benefit from this platform as follows:

- Brokers can provide a (semantic) description of companies, their production facilities and products.
- Brokers can design a process to produce specific products and describe the constraints, e.g. regarding environmental and ethical questions, lead time and costs.
- Brokers can assign different partner factories to each process step. This platform can suggest the best fit partner factory for each step in order to optimise the manufacturing process.
- Brokers can simulate a well-designed process and then execute the process.
- Information about the current status of the manufacturing process is given in real-time. Furthermore, information from different ICT systems of the partner factories is also integrated into process monitoring.
- When unforeseen events happen and change the outcome of the manufacturing process (e.g. delay and cost increase), an automatic adaption of the process will take place.

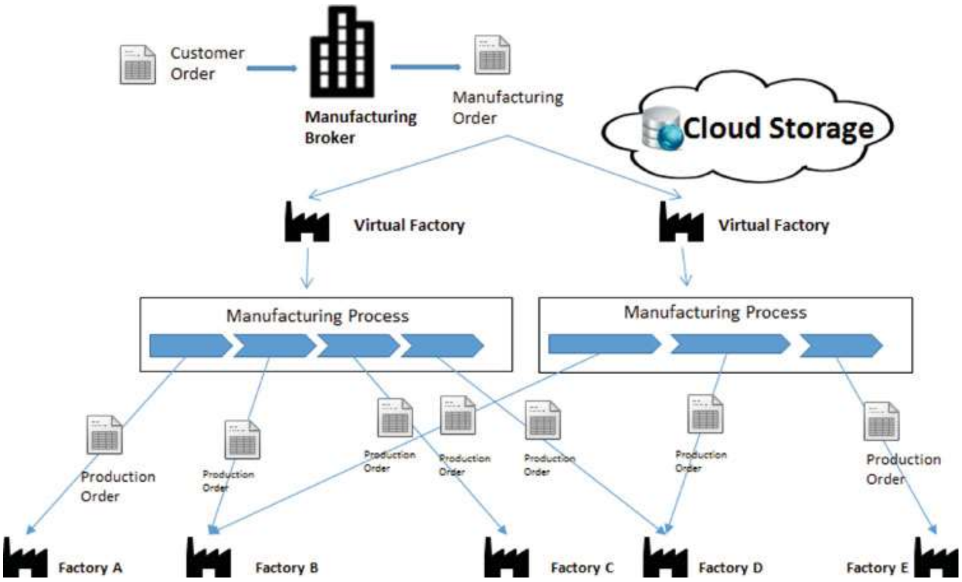


Figure 1. Reference model of Virtual Factory.

Comparing with previous research, the relationship among brokers and factory partners is perceived differently. The relationship is not simply non-hierarchical. In this paper, the relationships are considered in two aspects: business logic and information flow. From the business logic perspective, it is a non-hierarchical relationship because all the entities in this VF platform are autonomous. On the other hand, the information flow appears as hierarchical architecture because the brokers are situated at the upstream of information flow.

3.3. *Operational lifecycle*

The methodology for operating a VF is structured in four phases and these can be grouped into two stages: pre-phase and execution. This is shown in Figure 2.

In the first phase, the enterprises need to analyse their own business and technology, then understand the specific requirements of creating VF and adapting to the VF platform environment. By performing this provision, the enterprise becomes a member of the VF platform. The enterprise needs to provide information about its profile, including its capabilities and products. This enterprise is mainly responsible for the VF creation and relevant actions. It plays a broker role between customer and production in the acquisition of new products. This pre-phase will only be performed once for each enterprise. At this phase, essential processes are designed from scratch and updated according to need.

In the execution phase, predefined processes are adapted as ready-made with the objective of running the VF successfully. At this phase, already designed and validated processes are adapted during VF run time. There will be several instances of VFs, so that SEARCH, PLUG and PLAY will be performed multiple times, but only once for each VF. In this case, the whole lifecycle can be divided into two stages as defined previously, namely 'pre-phase' and 'execution'.

The second stage starts with the SEARCH phase. The broker analyses preliminary business opportunities, designs products with the required components, tools and facilities, and then searches for suitable partners. Based on the customers' requirements and specific needs, the broker designs a process-based VF with several

Figure 2. Virtual Factory operational lifecycle.

steps, and assigns different partners to each step according to the partners' capabilities. In the PLUG phase, the broker can simulate the designed VF and optimise the business flow processes. Once the broker is satisfied with the simulation result, the VF can be executed in reality. Each partner can download the product and process design into their real factory and start production activities. In the PLAY phase, the whole execution process will be monitored. At the same time, process forecasting will be performed automatically and notification sent to the broker when potential risk occurs. After all activities are accomplished and all parties of the VF are satisfied, the process ends with dissolution. When a new business opportunity is detected, the broker can establish an entirely new VF or restart a VF based on historic cooperation. The SEARCH phase is launched again.

In this VF operational lifecycle, major time and costs savings can be achieved when dynamic complex behaviour over the entire lifecycle factory is simulated. Both brokers and partners have their own business and production lifecycles, but they are also integrated in the supply chain as a signal VF. They both participate and contribute to this VF platform, but the broker has more responsibilities on the VF side and all the partners acting move on the real factory side. This VF platform is designed to enable the desired harmonisation and factory planning and performance monitoring between the VF and real factory.

3.4. Three-layer platform architecture

A new architecture is designed to implement all the required functionalities. This layered architecture can provide a better understanding of VF from both the software engineering and knowledge engineering perspectives. The three-tier architecture model is the fundamental framework for VE information systems. Bergamaschi, Gionata, Guerra, and Vincini (2003) and Chen et al. (2008) propose three-tier model architecture to implement the VE platform. However, traditional three-tier architecture is suitable mostly for applications with a predictable number of users, following a small number of usage patterns and a reduced number of load spikes (Petcu, Macariu, Panica, & Crăciun, 2013). In other words, this architecture runs into problems with the need for high scalability and elasticity in modern web applications such as for VF implementation. Furthermore, traditional web applications use relational databases for their data tier. This database system is difficult to scale or to replace in case of failure and any change in the database schema requires some downtime. Also, performing queries on these databases is slow (Petcu et al., 2013). To solve these issues in three-tier architecture and benefit from the cloud, we provide a more advanced architectural style. In this paper, the three-tier architecture needs to be modified with two additional services components. The architecture is presented in Figure 3.

- User interface layer: This layer retains the same functionalities as traditional presentation layer to interact with users. The user interface layer provides the required Graphical User Interface – called 'Dashboard' – for the VF partners. This layer primarily includes process visualisation and configuration that is supported by the process designer and message exchange and information management with defined user role. This user interface can be customised based on the users' different needs and users can use any devices with a web browser to access this VF platform. The user interfaces for brokers and partner factories are different.
- Process management layer: This layer consists of business rules. In the process management layer. various processes-related requirements such as process execution, adaptation, forecasting and simulation, monitoring and optimisation are performed actively. It is responsible for implementing the manufacturing process. It contains six distributed components: process design, process simulation, process optimisation, process execution, process monitoring and process adaptation. Although these components are designed separately, they interact with each other. The interplay of these components is used to manage the manufacturing process in order to fulfil customer orders. These components are mainly used by brokers, but when signing the partner factories to the manufacturing process, the system will send notification to the partner factories. Although the partner factories do not actively interact with these components, they are an important part of the manufacturing process.
- Data management layer: In the data management layer, all data which is needed across component and factory borders is collected and stored in a cloud-based data storage system and is responsible for data exchange and data search between VF partners. The data layer contains cloud storage. This cloud storage serves as central data storage. It allows the business layer to pass by different types of data (binary, semi-structured, structured and semantic) and will ensure high scalability for data storage processes. Within this cloud storage, scalability and reliability both have a higher priority than speed. Because there are many different types of data in a VF platform, the cloud storage should support all of them through different cloud providers.

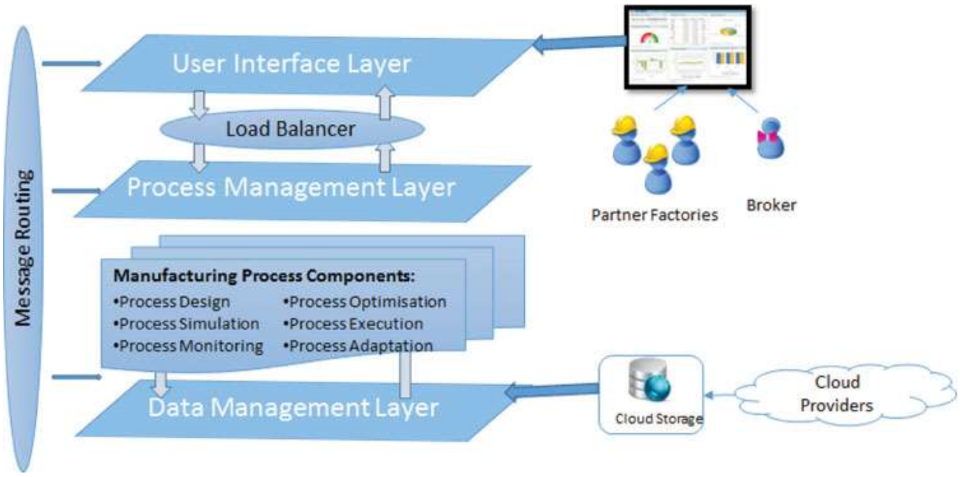


Figure 3. Overview of Virtual Factory multi-layer architecture.

- Load balancer service: This service distributes user requests to different components in the business layer in order to avoid overload and minimise response time. It is a fundamental requirement to build dynamic cloud architecture. This scalable and open platform can ensure access to services according to the load of the physical network in a centralised manner.
- Message routing service: This service is needed to connect the different tiers and to manage the communications between each layer. This service provides valuable information and ensures scalability.

3.5. Conceptual approach justification

The purpose of VF is to define how the access to the complementary skills between organisations and the different types of knowledge exchange in a network will influence the network value. In this chapter, we will explain how the proposed conceptual approach handles issues and challenges.

In order to manage all the manufacturers, different instruments are introduced to realise the VF and to ensure the performance of VF. First of all, the contracts and relevant agreements are designed in the JION and SEARCH phases. They are used to define the rights and duties of each partner and the type of penalties to be applied in case of breach of the agreed conditions. Risk management plan will be made accordingly as well. This document includes the identification of risks, its impact estimation, and the definition of migration strategies for each risk and the plan of action that determine when the expected migration is to occur.

In this VF, all parties work together to solve problems. Therefore, all partners' complete information is included in the cloud data storage. In order to ensure the data exchange performance, when in PLUG and PLAY phase, only relevant and value-added information is exchanged in an accurate, timely and credible manner.

The product is designed based on customer order or market need. The broker provides a description of the product specifications. In the PLAY phase, value analysis will be used to manage the product development process. It is important to set up standard criteria for evaluation purpose.

The real-time monitoring provides a live view of the ongoing processes. Brokers may decide to undertake flow adjustments and efficient decision-making process in order to improve the design processes performances. The process analytics provides the key performance indicators (KPIs) relating to the design processes.

Moreover, in order to ensure product quality, a set of quality management practices should be conducted, such as supplier certification, inspection, statistical process control, continuous quality improvement programmes and competitive benchmarking.

Once the customer needs have been fulfilled and the VF comes to dissolution in the PLAY phase, it is vital to create knowledge database about VF experience. This knowledge database includes document on the assessment of the collaboration established by each partner, and also a final report on the evaluation of the manufacturing network.

4. Virtual factory system design and implementation

4.1. Data modelling

As mentioned previously, VF data model development aims at formalising the concepts of VF lifecycle along with both broker's business process in VF and partner

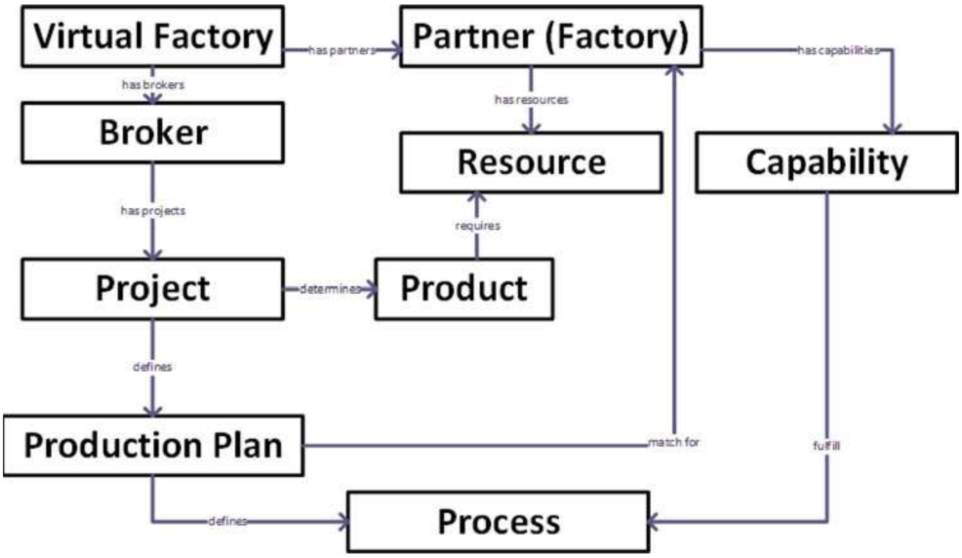


Figure 4. Top-level classes of Virtual Factory.

factories' production process in the real factory. It must be holistic, but with enough flexibility, extendibility and scalability.

This data model will be considered as a shared meta-language providing a common definition of all information that will be governed by VF brokers and all partners and also be used and updated by the decoupled functional modules. The top-level class diagram (Figure 4) is composed of all the abstract classes and their relationships. It enables the realisation of VF operation in the VF platform. These base classes include VFs, enterprises with different roles (brokers and partners) and different resources and capabilities, projects with specific business opportunities, product design and production plan, including suggested partners who have the capability to fulfil the predefined process. These abstract classes can be used to model a wide range of VF information systems while taking into consideration both VF and real factories aspects.

4.2. Cloud data storage

As mentioned in Section 3.4, the bottom layer, namely data management layer, is designed to centrally manage all data, information and transactions. Cloud-based storage is applied to support this VF platform. It allows manufacturers to share information about production/products over the cloud platform. The data layer supports several types of data: for instance, semi-structured data storage such as XML or JSON data, structured data used internally by different components in the business layer, semantic data for semantic company descriptions, and also binary data, which comprises documents such as specifications. Therefore, different cloud storage is needed for different types of data.

This cloud storage will be based on the concept of buckets, which are specific isolated storage spaces managing data for different data type. These buckets can be thought of as independent databases to store and retrieve different types of data in different databases. Thereby, the data types decide their databases and how they store the data.

Within this solution, a set of four different bucket types for semi-structured, structured, semantic and binary data will be implemented. Designing in this way can ensure flexibility. If other bucket types are needed, such as a SQL bucket, they can be added easily. The cloud storage will support a basic set of CRUD (create, read, update, delete) operations for all bucket types in a suitable data format (e.g. OData for structured data).

In order to realise this integrated cloud storage, it is necessary to identify adequate technologies to store structured, semi-structured, binary and semantic data. One unique feature of the business model in cloud is that different services are provided by multiple operators. Therefore, different cloud storage providers will be selected to provide different types of cloud storage. For instance, Amazon's Simple Storage Service (S3) provides basic unstructured remote storage, while Microsoft's SQL Server Data Services is used to support more structured data (Chappell, 2008). For managing these data types, a lot of proven technologies exist. In this paper, well-tested and high-performance technologies are selected (Table 1):

Based on the selection of technology on different types of bucket, cloud storage can be decomposed into

Table 1. Description of different bucket types and the technologies selection.

Bucket types	Type of data	Requirements	Selected technology
Structured	Typical application data	Table based structure on top of relational databases	MySQL
Semi-structured	Typical data in a document-oriented way without a fixed data schema	As 'NoSQL' storage	MangoDB
Binary	A document-centric storage for binary data (e.g. Store videos, PDFs, etc.)	Queries will be based on the document name or ID, e.g. by requesting the content of the document 'company description.pdf'	Amazon S3
Semantic data bucket type	Storage of semantic information, e.g. for managing semantic factory descriptions	Queries will be based on a semantic query language such as SparQL	Sesame

a detailed structure. Figure 5 illustrates the structure of cloud storage.

- Message routing: It is used to realise communication and message exchange within the information system via queues in the cloud. It receives messages from other components in the business layer to this data layer.
- Cloud storage facade: This is the message interface and virtual controller of the cloud storage. It manages the buckets, interprets the messages and executes the commands sent in the message. Additionally, it checks whether the data has to be transformed and if the needed access rights are granted. To achieve this it uses query translator and access control.
- Query translator: It is used to convert the data from the messaging format into the specific database query format and back.
- Access control: It is used to check if components in the business layer are authenticated to access a specific bucket. It also checks whether the users have the rights to access specific binary data. Access control list will be stored in semi-structured data storage.
- Buckets: Buckets are independent data storages that can be created and used by components. Depending on the types, they are realised as own database instances, separate tables or keys, with a specific prefix. Each component can create its own separate bucket, so the cloud storage has to manage several buckets of each type, as can be seen in the example in Figure 5, where two binary buckets exist in binary data storage.

4.3. Dashboard for sustainable metrics

In order to evaluate manufacturing performance, it is important to keep constantly monitoring, reporting and improving the manufacturing performance. Community expectations will drive consumer choices towards more sustainable products. Therefore, it is very important to measure the VF performance. In this paper, we used Dashboard as a tool to measure the factory performance.

All the processes needed to run the VF will be visualised through a 'Dashboard' component. This dashboard facilitates the visualisation of the real-time status of the running processes. This visualisation process ensures the users are able to monitor and manage the VF's overall operational processes. Each of the processes within the VF is designed and validated individually, and then interfaced with other processes to execute as a complete VF.

Users directly interact with the dashboard component through required registration and login process that confirms the access through protocol and data security, and this refers to the 'JOIN' phase in the whole VF lifecycle. In this case, the users can be representatives from the participating companies of the VF and can be in the form of broker or partners, depending on the type of users and their predefined roles within the VF.

This dashboard user interface mainly fulfils three functionalities for VF production: process management, process monitoring and process performance metrics.

- Process management: When integrated with the collaborative process, dashboard enables displaying of the status of the work in process to different partners. So VF partners have opportunities to manage their own factory process in real time and to coordinate the required actions with other partners in the process. Moreover, optimisation of the manufacturing process with the most suitable partners is the most fundamental and important decision. Therefore, management of the partner's capabilities, descriptions and resources is important in this VF platform.
- Process monitoring: It refers to the day to day evaluation of KPIs. High-quality data about the VF process is graphically represented on the dashboard. Process monitoring activities, for instance, real-time simulation and forecasting, will help the VF broker make instant business decisions. Real-time

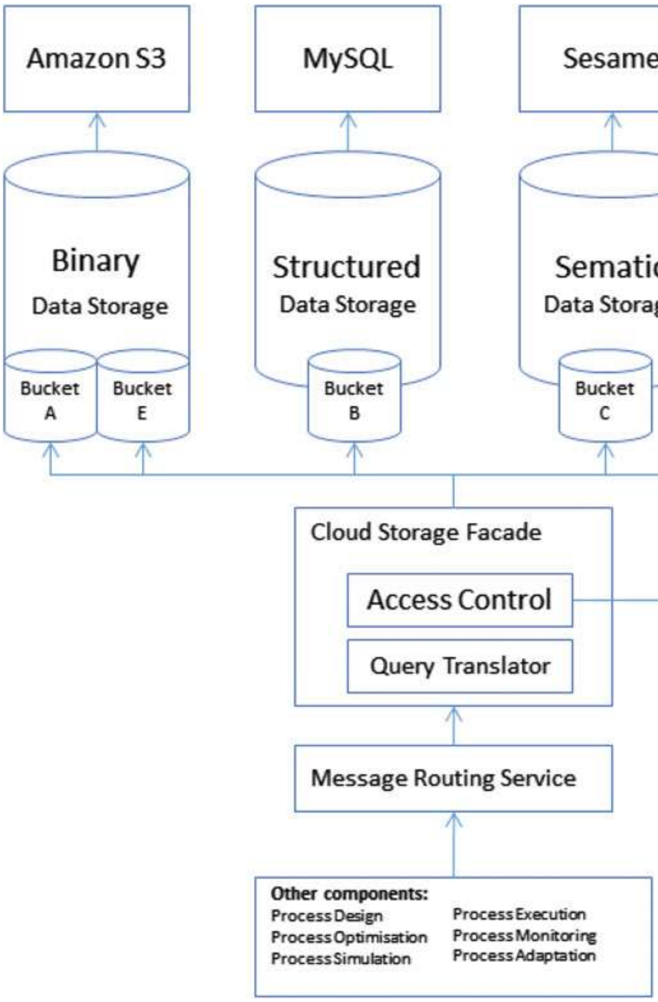


Figure 5. Cloud storage structure.

notifications and alerts are also helpful for the VF partners to initiative immediate corrective actions. Monitoring and communication between each user can be considered as the major concern and functionality.

- Process performance metrics: A sustainable manufacturing strategy requires metrics for decision-making at all levels of an enterprise. Dashboard acts as a diagnostic tool to provide brokers with a quick overview of a VF's performance. We develop this integrated dashboard to display all the required functionality to users in order to realise VF.

5. Platform operation and evaluation

5.1. Dashboard prototype and use case

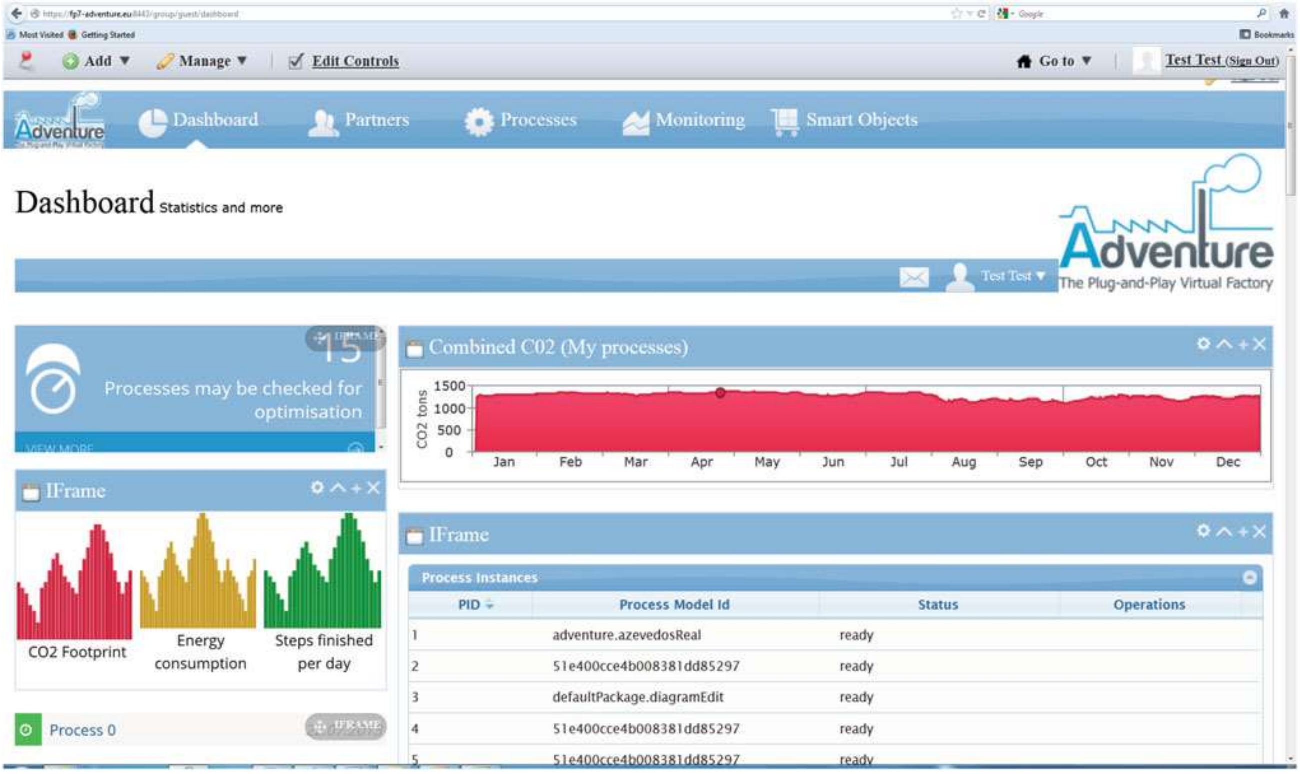
To demonstrate the feasibility of the proposed approach for VF, a Liferay-portal-based VF platform prototype is implemented. This Liferay-based dashboard provides improved business agility and flexible SOA architecture permits various implementations in different languages to work together.

Figure 6 displays a sample of dashboard. The high-level performance measurement indicators of each of the VF processes and shown exclusively. This high-level information of all the VF-related process such as overall status, order status, stock level, process and notifications are presented in order to monitor them.

Figure 7 shows the detailed status information of each process related to monitor the VF. The VF partners that are directly included in each of the processes can be visualised through this dashboard user interface.

These dashboard examples present an initial idea of how various information monitoring related to the VF operational process contributes to the overall performance measures of the collaborative VF. This also presents how to develop up-to-date communication infrastructure.

The collaborative manufacturing process will be optimised by enabling the integration of factory selection, forecasting, monitoring and collaboration

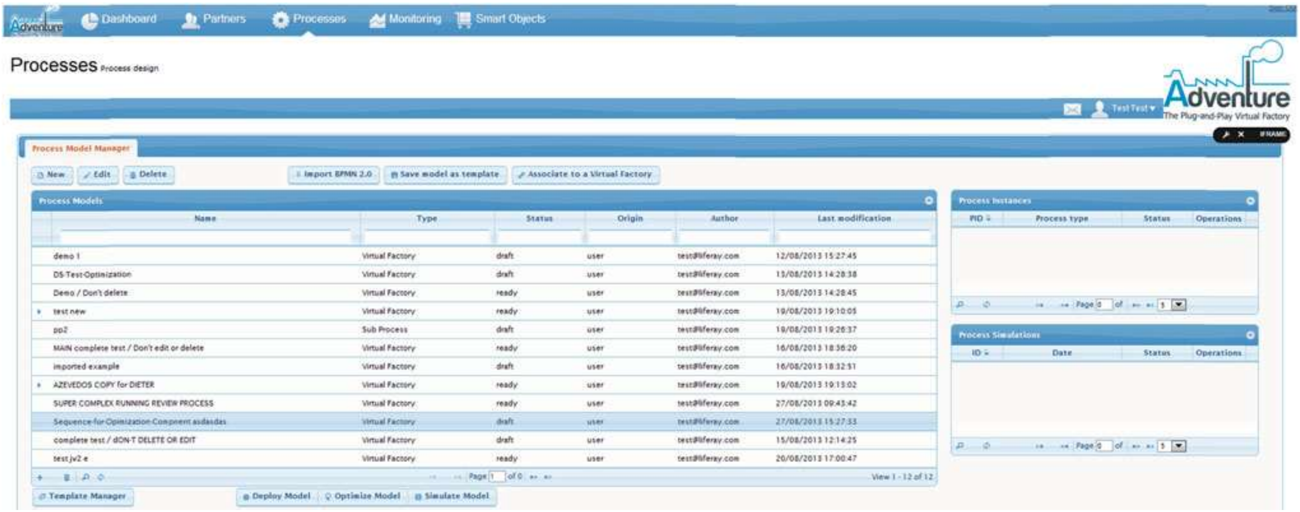


PID	Process Model Id	Status	Operations
1	adventure.azevedosReal	ready	
2	51e400cce4b008381dd85297	ready	
3	defaultPackage.diagramEdit	ready	
4	51e400cce4b008381dd85297	ready	
5	51e400cce4b008381dd85297	ready	

Figure 6. Snapshot of dashboard.

during runtime. We implement a use case to describe major activities undertaken to utilise the platform in reality.

Company A is a global company which offers a wide range of products for the cork industry. It registers as a broker in this VF platform in order to manage its customer orders. Once Company A receives an order/request through its web portal, asking for a completely new cork production machine, the order/request will load into the VF platform and be available in the dashboard. Company A can choose and use an appropriate process template with certain tasks and workflow (without any partners). Then Company A can adapt this process template according to customer's requirements to meet the new machine requirements. Once the production process is well designed, partners can be searched for and selected based on some options and criteria (some constraints are pre-defined). In the search process, several factories



Name	Type	Status	Origin	Author	Last modification
demo 1	Virtual Factory	draft	user	test@liferay.com	12/08/2013 15:27:45
DS-Test-Optimization	Virtual Factory	draft	user	test@liferay.com	13/08/2013 14:28:38
Demo / Don't delete	Virtual Factory	ready	user	test@liferay.com	13/08/2013 14:28:45
test new	Virtual Factory	ready	user	test@liferay.com	19/08/2013 19:10:05
pp2	Sub Process	draft	user	test@liferay.com	19/08/2013 19:26:37
MAIN complete test / Don't edit or delete	Virtual Factory	ready	user	test@liferay.com	16/08/2013 18:36:20
imported example	Virtual Factory	draft	user	test@liferay.com	16/08/2013 18:32:51
AZEVEDOS COPY for DIETER	Virtual Factory	ready	user	test@liferay.com	19/08/2013 19:13:02
SUPER COMPLEX RUNNING REVIEW PROCESS	Virtual Factory	ready	user	test@liferay.com	27/08/2013 09:43:42
Sequence-for-Optimization-Component asdasdas	Virtual Factory	draft	user	test@liferay.com	27/08/2013 15:27:33
complete test / dON-T DELETE OR EDIT	Virtual Factory	draft	user	test@liferay.com	15/08/2013 12:14:25
test jv2 e	Virtual Factory	ready	user	test@liferay.com	20/08/2013 17:00:47

Figure 7. Process detail information on dashboard.

which qualify are found, but only suitable factories are selected as partners. The production process is saved in the process management and a simulation is executed in order to verify the results: total price, delivery days, etc. Once Company A is satisfied with the result, the process is ready to start. Process execution starts executing the adaptive workflow involving gateway services and putting the orders in the different systems from Company A's ERP to the ERP of partner 1 (for instance, laser supplier) and partner 2 (for instance, controlling system supplier). Company A can always monitor the status of the process execution using the dashboard. In case of an urgent issue arising, such as the laser producer having a major breakdown and not being able to produce the laser system anymore, an alert is displayed in the dashboard. Company A can stop the process instance in the process management, then search for suitable partners to replace the position and so fulfil the task.

5.2. Evaluation

For business in practice, there still is no standard approach for companies to develop their VF systems, as they often have unique and proprietary operational strategies and practices. Therefore, the VF infrastructure presented in this study has significant implications for SMEs in structuring an effective collaboration network.

Cloud-based solutions are increasingly used in managing geographically distributed companies. Our cloud storage enables data synchronisation and manufacturing process coordination between the dual systems. We present a typical example of using cloud storage platform to create an opportunity to providing a consistent integrated data management solution. In turn, SME factories benefit from virtualised, secure, reliable and elastic cloud services to scale the performance and operation of the network for peak usage periods. Based on suggestions from previous research, we use different hosted data storages for different types of data to avoid storage vendor lock-in (Abu-Libdeh, Princehous, & Weatherspoon, 2010).

However, the challenge of using cloud storage is that when the number of users increases, the performance and data transfer rates become key issues. Moreover, cloud storage is not an ideal choice for transactional data which is write-intensive (Abadi, 2009) as it requires frequent read and write accessed data.

Further, dashboard when used for visualisation purposes in business processes can be used by different users such as front-line workers to process monitoring inventory management, performance monitoring and measurements, etc. It incorporates various functional features that help to improve process cognition and interpretation. Dashboard has evolved from the purpose of monitoring and management of business performance in today's dynamic market environment. Its visualisation functionality offers an interactive representation of process abstract and scenario analysis. The challenges and open issues of dashboard are which parameters should be monitored and how to interpret the monitored information (Chituc & Restivo, 2009).

The application of the dashboard user interface can be successfully extended towards the area of monitoring and management of the virtual factory, which is defined as a collaborative platform for similar size and capacity companies. This collaborative platform demands continuous process visualisation as offered by the dashboard component. This component ensures real-time process visibility as part of its functionality, which can also be used as a technique to monitor and measure the performance metrics of VF.

6. Conclusions

In order to respond to all of the demands imposed by the market and to follow the tendencies, companies need to shorten their products' lifecycle, and reduce the time to market. They should not only consider how to fulfil the customers' requirements, but also anticipate the actions of competitors and take over the market leader's position. However, companies need to be more adaptive, agile and flexible in their business processes and increase the efficiency of all their resources and capabilities in accordance with more sustainable and more ecological manufacturing.

The challenges and opportunities in striving for sustainability are significant and will require committed leadership and strategic solutions. ADVENTURE is an EU project which is committed to create more opportunities for the European manufacturing industry, especially SMEs, and provide solutions for the sustainable VF. There are many challenges as well as opportunities that arise from the growing pressure to find sustainable ways of conducting a collaborative business model among distributed SMEs. A sustainable VF business formation turns to the paradigm of harmony and full integration with the PLC. New technologies and VF practices are suggested as primary solutions in meeting the challenges.

The goal of ADVENTURE is to dynamically combine various manufacturing resources and capabilities from distributed partner factories in such a way that the broker can gather and aggregate all the necessary resources and capabilities to fulfil certain customers' requirements, and act as one VF. The customers will not be aware of the physical location or nature of the infrastructure providing the service. This VF provides not only a reference model and approaches, but also a sustainable business model.

The most obvious finding to emerge from this study is that we defined two principles for utilising the virtual factory: integration and autonomy. All the partner factories are autonomous; however, they run all of their operations (related to current VF) on the VF platform and act as an integrated entity. Integration of the different partners within the manufacturing process provides a more comprehensive picture of both the supply and demand in real time. This business model will put all the SMEs in a better position for making effective business decisions. Therefore, we designed a three-layer architecture information system (IS) and implemented it with cloud-based data storage. In our IS solution, the partner factories share information about their resources and capabilities with brokers and all other partners who registered in the VF platform in order to ensure other brokers can search for and find suitable partner factories, and then enable virtual collaborations in the form of virtual factories to fulfil customers' various requirements. All the information related to each particular virtual factory, such as production orders, product design, working schedule, etc. will be sent to all partner factories. The two-way integration between the parent factories' system and the virtual factories' IS allows it to send real-time operation information back to complete the communication. Therefore, the brokers can simultaneously monitor different partner factories, detect any unexpected situations in real-time and take effective actions. This effective combination of integration and autonomy enable real-time and intelligent trade-offs in manufacturing planning and control.

There are several limitations to this research. The main limitation of the study relates to the unavailability of a real case example, which will be done after completing this ongoing research. Another limitation might be that the research is not implemented in a real-life case company yet, which is necessary to generalise any research theme or hypothesis. The prototype version of the web-enabled dashboard user interface highlighted in this research is the other limitation which needs to be fine-tuned further to produce maturity and reliability. Nevertheless, this research shows some pathways to investigate the performance measures of networked business through a process visualisation component dashboard. It is believed and hoped that the presented approach will be helpful to monitor and manage the performance metrics of the collaborative business domain that will ultimately bring benefits to the collaborative partners in the longer term. Future research can focus on the development of identifying specific metrics for performance assessment and selecting appropriate advanced technologies which may support actual implementation of such platform.

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A Holistic Analysis of Cloud Based Big Data Mining

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ABSTRACT This paper presents a holistic analysis of the main challenges of exploring big data that has recently emerged especially due to the application of new digital technology such as social networking systems, electronic business applications among others. These applications are generated huge amounts of data that require the adaptation of the existing data mining approaches and systems. The paper describes the background of big data and cloud computing based on the latest approaches in these areas. The opportunities provided by cloud computing paradigm to enable the development of big data mining applications, business intelligence and analytics are dealt with. The main contribution of this paper is a theoretical definition of the possibilities of using cloud computing for the deployment of business intelligence applications using big data mining and analytics.

Keywords: big data mining, cloud computing, software-as-a-service, data/information-as -a service, analytics-as-a service

Introduction

We live in an era of big data that has embedded a huge potential and increased information complexity, risks and insecurity as well as information overload and irrelevance. Also business intelligence and analytics are important in dealing with data driven problems and solutions in the contemporary society and economy. Analysts, computer scientists, economists, mathematicians, political scientists, sociologists, and other scholars are clamouring for access to the massive quantities of data in order to extract meaningful information and knowledge. Very large data sets are generated by and about organisations, people, and their collaboration and interactions in the digital business ecosystems. For example, the connected devices such as smartphones, RFID readers, webcams, and sensor networks add a huge number of autonomous data sources. Scholars argue about the potential benefits, limitations, and risks of accessing and analysing huge amounts of data such as financial data, genetic sequences, social media interactions, medical records, phone/email logs, government records, and other digital traces generated by people and organisations.

With the development of internet communication and collaboration, data is playing a central and crucial role. Currently data intensive applications are developed and used. Also applications such as the Google+, Twitter, LinkedIn and Facebook are generating massive of data. Generally, data intensive applications including eBay, Amazon store and process data in a cloud environment.

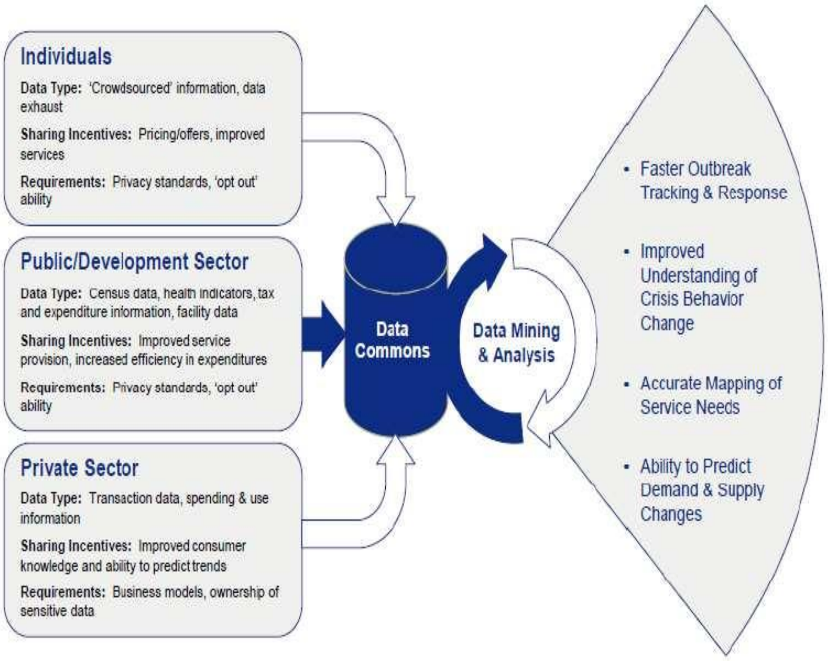

Figure 1: Complex Data Infrastructure/Ecosystem (source: World Economic Forum, 2012)

Big data could be beneficial to resolve critical issues providing the potential of new insights for the advancements of medical especially cancer research, global security, logistics and transportation solutions, identification and predicting terrorism activities, and dealing with socio-economic and environmental issues. The logistics sector is ideally placed to benefit from the technological and methodological advancements of big data. Logistics providers manage a massive flow of goods and that create massive data sets. Millions of shipments every day, of different origins and destinations, size, weight, content, and locations are tracked across global delivery networks (e.g. DHL, UPS) However this present and past data tracking is not fully exploited in order to deliver business value. Most likely there is huge untapped potential for improving operational efficiency and customer experience, and creating useful new business models based on the exploration of big data.

Big data is defined as a complex data infrastructure and new powerful data technologies and management approaches are needed. These solutions are directed to improve the decision making processes and forecasting through application of advanced data exploratory techniques, data mining, predictive analytics and knowledge discovery as presented in figure 1.

The main key characteristics that define big data are volume, velocity, variety and value. Veracity could be also considered an additional characteristic. The related big data models are presented in figure 2.

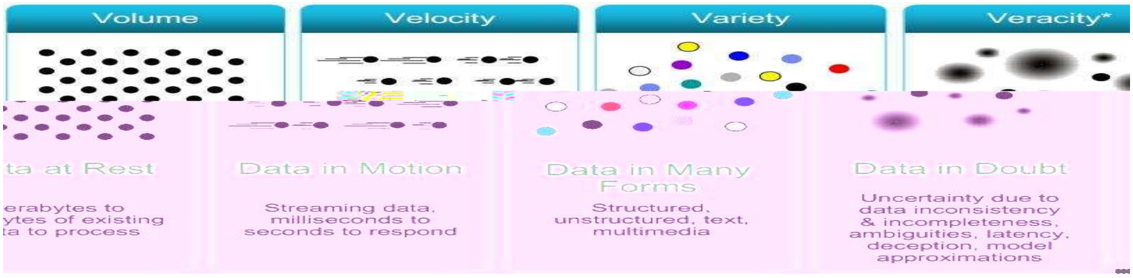

Figure 2: Big Data Characteristics based on the source: McKinsey Global Institute, 2011

On the other hand because of the characteristics of the cloud, this is an enabler of big data acquisition, and associated software processing tools/strategies. Based on Gartner's estimation, 50% of data will be stored on the cloud by 2016 (Schouten, 2012). However in the reality, cloud has not been widely used for data analytics especially in practical applications.

The availability of cloud based solutions has dramatically lowered the cost of storage, amplified by the use of commodity hardware even on a "pay as-you-go" basis that is directed to effectively and timely processing large data sets. The big data could be analysed "as -a -service". Google BigQuery[1] is an example of providing real-time insights about massive data sets in a cloud based platform.

In cloud computing, data and software applications are defined, developed and implemented as services. These services have defined a multi-layered infrastructure and are described as follows (Grace, 2010; Mell and Grance, 2009):

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[1] https://cloud.google.com/products/big-query

1. *Software as a Service* (SaaS): applications are hosted and delivered online via a web browser offering traditional desktop functionality
2. *Platform as a Service* (PaaS): the cloud provides the software platform for systems (as opposed to just software)
3. *Infrastructure as a Service* (IaaS): a set of virtual computing resources, such as storage and computing capacity, are hosted in the cloud; customers deploy and run only their own applications for obtaining the needed services.

On the other hand it is recognised the tension between big data strategies, and solutions versus information security and data privacy requirements. The big data might enable the violation of the privacy and information security breaches and by consequence decreasing the trust in data defined as a service in the cloud. Big data stored and processed in the cloud could lack a centralized control and ownership.

According to McKinsey Global Institute (2011), big data is seen as "the next frontier for innovation, competition and productivity" and as such the related applications will contribute to economic growth. The positive impacts of big data provide a huge potential for organisations. In order to achieve these aspirations several issues should be analysed and discussed in the context of complex systems and using systems approaches such as holistic thinking and system dynamics.

Therefore major issues are emerging and this work-in-progress attempts to discuss a few key aspects directed to the development and adopting data mining techniques and strategies for cloud based big data applications.

Background and Research Approach

Demirkan and Delen (2013) have defined some research directions including dealing with affordable analytics for big data in the cloud. This means using open-source, free-of-charge data/text mining algorithms and associated commercial tools (e.g. R, RapidMiner, Weka, Gate, etc.) New approaches need to provide solutions for moving these tools to the cloud and produce efficient and affordable applications for discovering knowledge and patterns from very large/big data sets directed to support business intelligence and decision support systems applications.

The principles of data/information- as- a- service, data/information-security-as-a-service, and analytics- as- a- service are explained in the context of using service oriented architecture.

However the cloud platforms are not completely following service oriented thinking and even more there is a debate that cloud computing is different of service oriented architectures, and grid computing.

The main motivation of adopting cloud computing for analytics applied for large (big) data sets are based on the accessibility of cloud solutions outside the a web based organisation communication secured with firewalls. Cloud based business analytics are also cost effective, easy to set up and test. The results are easy to be shared outside the organisations. Greg Sheldon, CIO of Elite Brands said "The biggest benefit, is to be able to access huge amounts of information from anywhere you have web access, specifically on an iPad. This is beneficial to our field sales team when information is needed on the fly." (Fields, 2013:2)

The main research questions are related but not limited to the following aspects:

1. In the context of cloud based big data how analytics (e.g. data mining), information and knowledge management disciplines and strategies will evolve?
2. What should be the techniques, strategies and practices to increase the benefits and minimise the information risks ?
3. How to deal with the growing number of security breaches and cyber security risks and increase organisational awareness, business agility and resilience?
4. How to adapt the existing legislation such as data protection law, regulations and standards? Moreover, the ethics issues will be considered.

Efforts and Challenges of Big Data Mining and Discovery

Considering big data a collection of complex and large data sets that are difficult to process and mine for patterns and knowledge using traditional database management tools or data processing and mining systems a briefing of the existing efforts and challenges is provided in this paragraph. While presently the term big data literally concerns about data volumes, Wu et al. (2013) have introduced HACE theorem that described the key characteristics of the big data as (1) huge based on heterogeneous and diverse data sources, (2) autonomous with distributed and decentralized control, and (3) complex and evolving in data and knowledge associations. Generally, business intelligence applications are using analytics that are grounded mostly in data mining and statistical methods and techniques. These strategies are usually based on the mature commercial software systems of RDBMS, data warehousing, OLAP, and BPM. Since the late 1980s, various data mining algorithms have been developed mainly within the artificial intelligence, and database communities. In the IEEE 2006 International Conference on Data Mining (ICDM), the 10 most influential data mining algorithms were identified based on expert nominations, citation counts, and a community survey (Chen et al, 2012). In ranked order, these techniques are as follows C4.5, k-means, SVM (support vector machine), Apriori, EM (expectation maximization), PageRank, AdaBoost, kNN (k-nearest neighbors), Naïve Bayes, and CART (Wu et al, 2007). These algorithms are for classification, clustering, regression, association rules, and network analysis. Most of these well known data mining algorithms have been implemented and deployed in commercial and open source data mining systems (Witten et al. 2011). Chen at al. (2012) have compared data base management systems and analytics as well as ETL with using MapReduce and Hadoop. Hadoop was originally a (distributed) file system approach applying the MapReduce framework that is a software approach introduced by Google in 2004 to support distributed computing on large/big data sets. Recently, Hadoop has been developed and used as a complex ecosystem that includes a wider range of software systems, such as HBase (a distributed table store), Zookeeper (a reliable coordination service), and the Pig and Hive high-level languages that compile down MapReduce components (Rabkin and Katz, 2013). Therefore in the recent conceptual approaches Hadoop is primarily considered an ecosystem or an infrastructure or a framework and not just the file system alongside MapReduce components.

The big data and cloud computing frameworks include the Google MapReduce, Hadoop Reduce, Twister, Hadoop++, Haloop, and Spark etc. which are used to process big data and run computational tasks. The cloud databases are used to store massive structured and semi-structured data generated from different types of applications. The most important cloud databases include the BigTable, Hbase, and HadoopDB. In order to implement an efficient big data mining and analysis framework, the data warehouse processing is also important. The most important data warehouse processing technologies include the Pig, and Hive.

Strambei (2012) has suggested a different conceptual interpretation of the OLAP technology considering the emergence of web services, cloud computing and big data. One of the most important consequences could be widely open access to web analytical technologies. The related approach has evaluated the OLAP Web Services viability in the context of the cloud based architectures.

There are also a few reported practical applications of big data mining in the cloud. Patel et al. (2012) have explored a practical solution to big data problem using the Hadoop data cluster, Hadoop Distributed File System alongside Map Reduce framework using big data prototype application and scenarios. The outcomes obtained from various experiments indicate promising results to address big data implementation problems.

The challenges for moving beyond existing data mining and knowledge discovery techniques (NESSI, 2012, Witten et al, 2011) are as follows:

1. a solid scientific foundation to support the selection of a suitable analytical method and a software design solution
2. new efficiency and scalable algorithms and machine learning techniques
3. the motivation of using cloud architecture for big data solutions and how to achieve the best performance of implementing data analytics using cloud platform (e.g. big data as- a-service)
4. dealing with data protection and privacy in the context of exploratory or predictive analysis of big data
5. software platforms and architectures alongside adequate knowledge and development skills to be able to implement them
6. ability to understand not only the data structures (and the usability for a given processing method), but also the information and business value that is extracted from big data.

Concluding Remarks

The emergence of big data movement has energized the data mining, knowledge discovery in data bases and associated software development communities, and it has introduced complex, interesting questions for researchers and practitioners. As organisations continue to increase the amount and values of collected data formalizing the process of big data analysis and analytics becomes overwhelming. In this paper, we discuss some existing approaches and have analysed the main issues of big data mining, knowledge, and patterns discovery in the data driven cloud computing environment. This research will be progressed providing theoretical and practical approaches that will be tested through the development of case studies for the application of big data particularly in collaborative logistics.

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16

Cloud-based Data Storage for Data Management in the Virtual Factory

Yuqiuge Hao, Ahm Shamsuzzoha and Petri Helo

16.1 Introduction

In today's global markets, Small and Medium-sized Enterprises (SMEs) in Europe are facing competitors not only from neighbors, but also competitors from non-European countries with higher production and lower labor costs. There is a need for a highly flexible business relationship between manufacturing companies. Therefore, the former hierarchical networks and supply chains are being replaced by collaboration among dispersed companies. This dynamic collaboration includes activities such as designing, manufacturing and delivering more complex products (Cunha et al., 2011). For these SMEs, they can concentrate on their core competencies while adapting themselves to participate in agile enterprise formations following the Virtual Enterprise (VE) paradigm (Browne and Zhang, 1999).

Even though the concept of VE has already existed for decades, there is a lack of efficient IT tools and methods to support its inherent functionalities. Consequently, a need arose for a holistic approach to handle the complexity of VE businesses (Goel et al., 2009). Manufacturing companies must be able to make the best use of possible ICTs, as they positively affect VEs' productivities. Although many researchers proposed different ICT approaches to establish VEs, the problem is they are mostly inflexible regarding changing circumstances and general conditions. Thus, it is very necessary to find a new technology solution to improve VE activities. New ICT technologies are a prerequisite for the concept of VE.

Cloud computing is a new and overloaded IT term. More and more businesses are taking advantage of it. The flexibility of cloud computing makes it easier for companies to scale their services according to user demands. This new operation and business model allow companies to pay for the resources they effectively use (Rimal et al., 2011).

Despite the trumpeted business and technical advantages of cloud computing, many potential cloud users have yet to join the cloud, and in most cases they only put their less sensitive data in the cloud (Fujii et al., 2000).

Data storage provided by cloud model is named as Storage as a Service (SaaS) (Hwang et al., 2011), which means the storage is delivered on demand. There are several different types of cloud storage services. The major differences are how clients use the data storage and how users access the data storage (Fredriksson and Augustsson, 2011). Lack of control in the cloud is a major concern (Fujii et al., 2000), and another unresolved issue is the lack of standardization. Therefore once cloud users upload their data to the data center, the data is locked in (Rimal et al., 2011).

However, it is good to face new challenges, and linking virtual enterprise and cloud computing is an important one. The question is how can the concepts of cloud computing be deployed and integrated in the business environment to support VE? In order to address this problem, a new strategy for cloud-based Virtual Factory Information System (VFIS) design is proposed in this research. The objectives are particularly aimed at enabling SMEs to participate in the VF. There exists much need for a mechanism to manage and control information flow among collaborating manufactories. The VFIS design aims at setting up a process-based collaboration network, and leveraging the information exchange between different manufactories. It also aims to work toward implementing a data-sharing environment based on cloud storage in which the data and information of a complex production processes is stored. There is not yet a global standard specification and general architecture for cloud computing and cloud storage. This chapter will analyze the requirements of cloud storage for the VF in practice, and propose an architecture of cloud storage.

Section 16.2 describes related work about the virtual factory and cloud storage; Section 16.3 describes how to utilize cloud storage in VFIS; Section 16.4 illustrates how to implement this cloud storage by an example. Section 16.5 will summarize the chapter.

16.2 Related work

16.2.1 The Virtual Factory and Information System (VFIS)

With continued growth and development in global business, many geographically dispersed enterprises have collaborated to increase their market share and benefits together with other enterprises. Virtual Enterprise (VE) becomes a solution for small and medium-sized enterprises (SMEs) to compete and survive in this volatile environment (Fujii et al., 2000). VE is defined as a temporary alliance of independent enterprises that come together to share skills and core resources in order to achieve a particular business requirement and access more business opportunity (Goel et al., 2009; Browne and Zhang, 1999; Helaakoski et al., 2007).

The domain of advanced manufacturing is a typical application area for the VE concept. In this chapter, we concentrate on the VE in manufacturing industry. Nowadays, manufacturing processes can be hardly accomplished by a single manufacturer, but require multiple manufacturers. Many products are no longer produced in isolated facilities. Manufacturers must be viewed in the context of their contribution to the total value chain (Helaakoski et al., 2007). It is very important for individual manufacturers to focus on their core competences and join efforts with others, in order to fulfill new product requirements (Camarinha-Matos and Afsarmanesh, 2006). Therefore, we label this particular virtual enterprise as the Virtual Factory (VF).

More specifically, VF is dynamic, ad hoc and temporary, and exists only for the lifetime of a specific business opportunity in manufacturing. Each manufacturer in VF is an independent operation agency, but the management of VF is logically concentrated and physical distributed (Chen et al., 2008). VF is attracting more and more attention from both academic and industrial communities.

A different kind of general hierarchy organization concept, this Virtual Factory is a non-hierarchical network (Martinez et al., 2001). Although there is a centralized control enterprise in VF that has a temporary leading role in VF, all the partner factories are in an equal position. In this non-hierarchical collaboration, the central enterprise launches a project and leads the network. It collects customers' requirements and orders, then designs an appropriate manufacturing process. Different manufacturers contribute to the manufacturing process accordingly. However, the core of VF is the same as general VE in sharing resource and expertise for mutual benefits.

Naturally, the complexity of multiple parties and non-hierarchical networks makes the manufacturing process liable to unexpected events (Cunha et al., 2011). With the purpose of handling complexity, the form of VF is highly reliant on information systems. Advances in modern technologies, such as the Internet and workflow management system, have made an information system possible that enables enterprises to cooperate with each other much more easily (Zhang and Shi, 2004).

Martinez et al. (2011) highlight in their research that VE structures are information system-centered, and that the main objective of a VE structure is to link different organizations to help them work together in a collaborative and reactive manner. The core competence that has to be developed is an information system working with different organizations. However, flexible and dynamic information integration among multiple firms in a virtual enterprise remains unaddressed (Song and Nagi, 1997). There are many challenges when implementing information systems to support VE. The challenges are considered from two aspects: business and technology (Goel et al., 2009). The structure of VE has to face different technical constraints (Martinez et al., 2001). For instance, (1) it is difficult to select proper manufacturing enterprises; (2) it is difficult to rapidly integrate within the manufacturing processes; (3) there are changes introduced by various factors such as joining and dropping of partners, market and context changes (Goel et al., 2009).

16.2.2 Data management in the VFIS

One issue in realizing virtual enterprises is products and processes information/ data exchange among different application systems in this virtual activities environment (Yoo and Kim, 2002). VE requires that manufacturing be information-intensive and communication-extensive (Martinez et al., 2001). ICT support systems have to allow enterprises to share information, by guaranteeing data-consistency and establishing synchronized and collaborative processes (Bergamaschi et al., 2005). When different actors are working together at the same time (synchronous collaborative work), real-time communication becomes a key issue (Martinez et al., 2001). However, information/ data exchange between different software tools is a common problem for all information systems. Efficient data management is the most critical issue to obtain the necessary agility and improved competitiveness of virtual enterprises (Yoo and Kim, 2002). In manufacturing, the multifaceted nature of design information makes communications particularly difficult. In order to support the activities of the virtual factory, the Virtual Factory Information System (VFIS) has been designed.

16.2.2.1 VFIS architecture

VE collaborative network is often supported by information technology elements at different levels such as computer networks, business process and workflow management systems and service-oriented architectures. The three-tier architecture model is the fundamental framework for VFIS. The business logic layer consists of business rules, such as business algorithms and governmental regulations, and data access rules, such as keeping the data structures consistent within either specific or multiple databases. This layer is separated from the data layer. The data layer consists of database servers and provides actual data access (Microsoft, 2012). The information/ data is stored and retrieved. This tier keeps data neutral and independent from application servers or business logic. Giving data its own tier also improves scalability and performance.

Berganaschi et al. (2005) propose a three-tier model architecture to implement the VFIS. The client tier makes available a web user interface on which information is collected and presented in a customized way. The data tier manages the interactions with the data provided by the enterprise information systems. The business logic tier combines the capabilities of two separated modules, the Project Collaboration Portal and the Integration Framework. The Project Collaboration Portal supports the business logic for monitoring, execution and planning of a project. The Integration Framework collects the data required by the implemented business process from heterogeneous and distributed data sources.

Similar research work has been done by Chen et al. (2008). Virtual enterprise workflow management system architecture is proposed in the same manner as by Bergamaschi et al. (2005), with a three-tier structure: a data services layer, a business logic layer and a presentation layer. In the data services layer, focus is on the completion of data storage, access, and ensuring data consistency and integrity. A database connection mechanism was designed that allows users to easily amend the connection string to ensure the right connection between the virtual enterprise workflow management system and the database. The business logic layer is the core value in system architecture, its attention focused on the system design related to business demand, such as the formulation of business rules and the implementation of business processes; it also means that it is related to the system logic of the field. The presentation layer is used to display the user interface.

Because the traditional three-tier architecture is suitable mostly for applications with a predictable number of users, following a small number of usage patterns and a reduced number of load spikes (Petcu et al., 2013). In other words, this architecture runs into problems with the need for high scalability and elasticity of modern web applications such as for virtual factory implementation. Furthermore, traditional web applications use relational databases for their data tier. This database system is difficult to scale or to replace in case of failure, and any change in the database schema requires some downtime. Also, performing queries on these databases is slow (Petcu et al., 2012). Therefore, in this chapter, this three-tier with two additional services components architecture needs to be modified. It is presented as Figure 16.1.

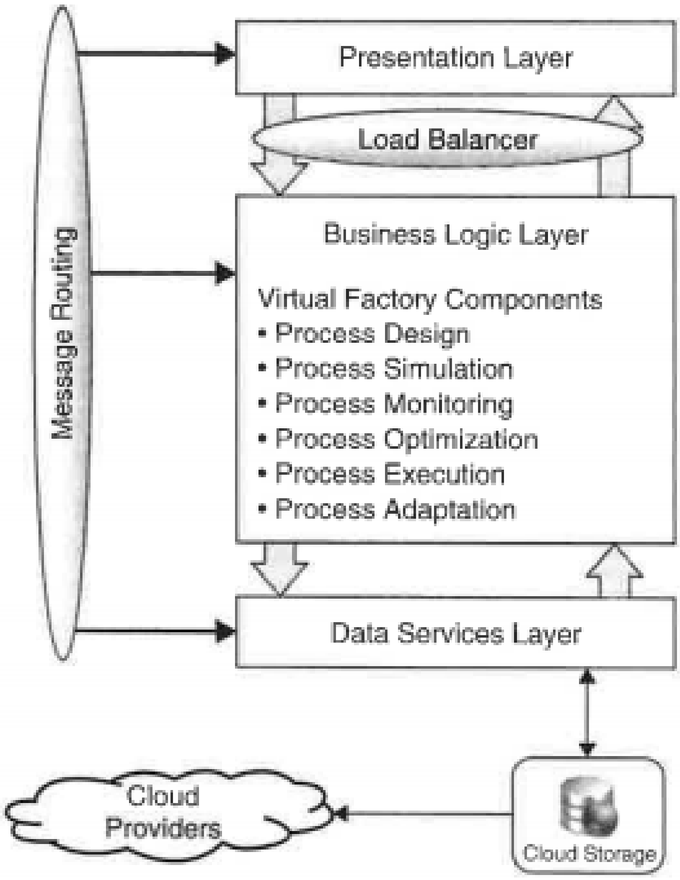

Figure 16.1 Cloud-based VFIS architecture

- Presentation Layer: This layer retains the same functionalities as the traditional presentation layer to interact with users. This user interface can be customized based on users' different needs, and users can use any devices with the web browser to access the VFIS. The user interfaces for brokers and partner factories are different.
- Business Logic Layer: This layer is responsible for implementing the business processes specific to the application use cases. It contains six distributed components: Process Design, Process Simulation, Process Optimization, Process Execution, Process Monitoring and Process Adaptation. Although these components are designed separately, they interact with each other. The interplay of these components is used to manage the manufacturing process in order to fulfill customer orders. These components are mainly used by brokers, but when signing the partner factories to the manufacturing process, the system will send notification to the partner factories. Although the partner factories do not actively interact with these components, they are an important part of the manufacturing process.
- Data Services Layer: This data services layer provides data storage and data access. It allows the business logic layer to pass by different types of data and will ensure high scalability for data storage processes. It ensures the connection with cloud storage. This cloud storage serves as central data storage. Within this cloud storage, scalability and reliability both have a higher priority than speed. Because there are many different types of data in VFIS, the cloud storage should support all of them by different cloud providers.
- Load Balancer Service: This service distributes user requests to different components in the business layer in order to avoid overload and minimize response time.
- Message Routing Service: This service is needed to connect the different tiers and manage the communications between each tier. This service routes valuable information and ensures scalability.

In this chapter, we mainly focus on the data services layer. Therefore, the following subsections will illustrate data management in VFIS.

16.2.2.2 VFIS data management in cloud storage

Although the core of the virtual enterprise environment is information exchange, it is a very difficult task given the dispersed of information resource. There is a desire to enable seamless data sharing in VE (Song and Nagi, 1997). In order to manage the virtual factory, the entire supply chain should be considered. Each party needs partnership information to make correct decisions. Even the simplest manufacturing process involves data from upstream suppliers and downstream customers. It is always a problem to construct a seamless communication platform and integrate the data to support manufacturing process.

Yoo and Kim (2002) claim that there are two types of data that enterprises need to properly manage: business data (financial management, cost center management, HR management, etc.) and product data (for instance, CAD and CAM). In the Virtual Factory environment, process data is another important type of data. In the process, data about the partners and their capabilities needs to flow from one enterprise department to another openly, efficiently and automatically. In contrast, the receiving enterprise will feed back its information (Wu, 2009).

The cloud computing model possesses the capability to dynamically provide computation and storage, and increasingly data-intensive applications are being attracted by clouds (Cao et al., 2011; Huo et al., 2011). The cloud storage system was developed based on technologies such as the broadband network, Web 2.0, storage virtualization, storage networks, application storage integrated with servers and storage devices, cluster technology, grid computing, distributed file systems, content delivery networks, peer-to-peer, data compression, data encryption, etc. (Zeng et al., 2009). Cloud storage can provide high scalability, availability, fault tolerance, security and cost-effective data services for those applications (Huo et al., 2011). Due to the complexity of manufacturing data, cloud-based solutions are an ideal choice.

Cloud storage providers supply storage capacities and data storage services through the Internet to clients; meanwhile, clients do not need to know the details and mechanisms (Zeng et al., 2009) and users can quickly add information to the cloud (Huo et al., 2011). Compared to traditional on-premises data center storage, this cloud storage is delivered at extremely low process and extending capabilities.

The increasing popularity of cloud storage is also an issue. There exist many cloud storage architecture schemes from different service platforms. These are usually complex and incompatible (Zeng et al., 2009). Consequently, several data storage concerns can arise. If users have a single provider, they would not be able to tolerate any failure by the provider. Replicating data to multiple providers allows users to tolerate failure, but it becomes very expensive to switch storage providers (Abu-Libdeh et al., 2010).

16.3 Cloud storage in the virtual factory

To overcome the issues and concerns of cloud storage, we must develop a security model that promotes the virtual factory. This model could enable data sharing among different partners in this virtual factory, and it provides an innovative way to manage data by multiple providers. Cloud-based data storage plays a very important role in implementing this VFIS.

16.3.1 The virtual factory working environment

The working environment for a virtual factory is proposed in Figure 16.2. This solution will help the VF and related manufacturing enterprises move

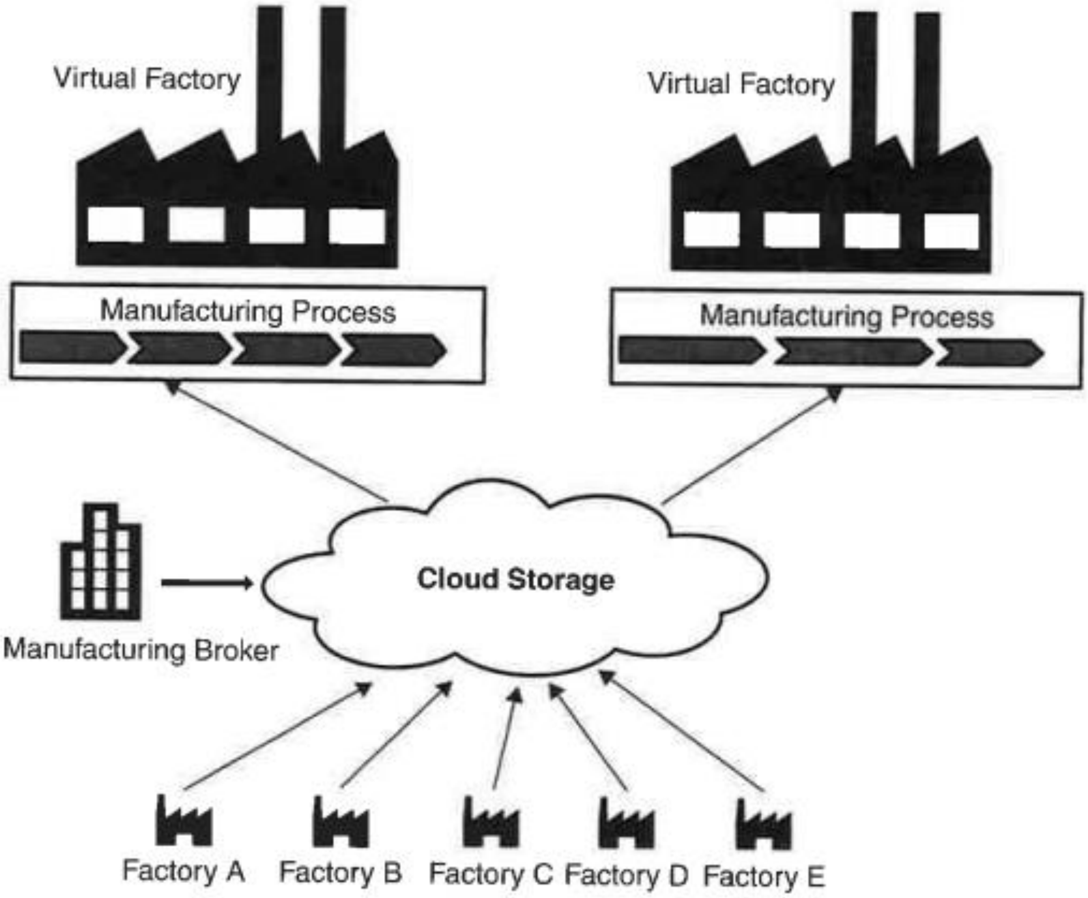

Figure 16.2 A cloud-based VFIS working environment

beyond existing operational limitations by providing a concrete platform to leverage the information exchange between partner factories. The centralized control enterprise is named as the manufacturing broker. It is responsible to collect customer orders, design a process model, describe the manufacturing process and then assign appropriate manufacturing enterprises (in this scenario, they are called partner factories) to accomplish the manufacturing processes. The factory illustrated at the top of Figure 16.2 is a VF. This virtual factory is not a legal entity. All the dynamic cross-organizational manufacturing processes are designed by the manufacturing broker, and each production step (task) is accomplished by a set of real partner factories at the bottom.

In cloud storage, it is capable of both storing information and manipulating data. The clients in this cloud storage system are two parties: partner factories and brokers who propose the VF.

In order to satisfy orders in a short time and avoid bottlenecks while controlling the whole manufacturing process carried out by a VF, the brokers and partner factories must execute the following activities in order to create a VF together:

- Brokers provide the (semantic) description of their companies, production facilities and products requirements.
- Brokers get customer orders and design a manufacturing process to produce specific products and describe the constraints, for example, regarding environmental and ethical questions, lead time, costs.
- Brokers assign different partner factories to each production step.
- Brokers simulate a well-designed process and execute the process. Partner factories get production orders, then start producing.
- Information about the current status of the manufacturing process in real factories is given back to brokers in real time. Furthermore, information from different ICT systems of the partner factories is also integrated into process monitoring.
- After the entire individual production step is finished, the brokers get the final products and deliver to customer. Every party satisfies the result and the virtual factory terminates.

Based on this scenario, the proposed solution must be able to fulfill all functionalities. At the same time, the cloud storage must support all the information and generated in the entire virtual factory, as well as the relevant operations for all types of data.

16.3.2 Cloud storage selection criteria support the virtual factory

In this chapter, we classify data into four different data types: structured data, semi-structured data, binary data and semantic data. There are increasing numbers of cloud computing and cloud storage providers to support these different data types, such as IBM, Google, Microsoft, Amazon, etc. In order to realize this cloud storage, adequate technologies to store this data must be identified.

In the cloud computing environment, there is a unique feature of the business model that one service can be provided by multiple operators (Hwang et al., 2011). Therefore, different cloud storage providers will be selected to manage different types of data. Namely, this cloud storage is built up by the combination of different cloud storage providers. Table 16.1 illustrates the different data and requirements analysis.

In order to select cloud storage providers, we define the selection criteria:

- Scalability: Since a large number of brokers and partner factories are needed and must be managed at the same time, this cloud storage is necessary to store the increasing amount of data in an efficient way.
    - ACID compliant: ACID stands for Atomicity, Consistency, Isolation and Durability. These properties guarantee that a transaction is processed reliably by a database.

Table 16.1 Description of different data types in the Virtual Factory

Data Type	Descriptions	Requirements	Possible technologies
Structured	This will be used to store typical application data such as settings or administration data and will provide a table-based structure on top of relational databases	Structured data will represent data that is manageable in tables and rows, which are typical to relational databases. As such, this cloud storage will reuse a relational database technology as a base for its data management.	Potential base technologies range from MySQL to Postgres
Semi-structured	This is used to data in a document-oriented way without a fixed data schema, such as XML or JSON data which is used internally. In the virtual factory, for instance, this might be company profiles, service descriptions, manufacturing process relevant data, etc.	It executes semi-structured (for example, for NoSQL databases) queries and returns the results to Cloud Storage Façade	It may be realized by technologies such as CouchDB or Apache Cassandra
Binary	Binary files are used for storing document-centric data such as specifications or even multimedia files; in this case, it could be store promotion videos, PDFs, images, configuration files of application, etc.	Queries will be based on the document name or ID, for example, by requesting the content of the document "company description. pdf"	For this data type, technology is needed that offers an easy-to-use and scalable storage, such as Amazon S3 or (distributed) file systems
Semantic	Storage of semantic information, for example, for managing semantic company descriptions, partner profiles, description of process models and relevant service descriptions	For semantic data, the cloud storage will use a RDF query language such as SparQL	Possible base technologies include Jena or Sesame

  - Atomicity means that in case of multiple related operations either all will be executed or none. If an error occurs for one of these operations, all operations in this transaction will be rolled back.
  - Consistency means that it has to be guaranteed that after an operation all the data in the database is correct, if the data was correct before it.
  - Isolation defines how changes will be executed in case of multiple operations. This prevents operations from working with outdated data and from overriding actual and correct data.
  - Durability guarantees that the data will be stored permanently after a successful transaction.
- Redundant Data Storage: Data redundancy means that the same data is unnecessarily stored several times in the database. In relational database systems it means, for example, a field that is repeated in two or more tables. The aim is to reduce or even eliminate data redundancy, unless it is created for backup or replications, which are intended. For the selection this criterion will be ignored, because the data redundancy is not dependent on the used technology, but on the defined data schema.
- CRUD Operations: CRUD stands for Create, Read, Update and Delete and forms the base operation of a database management system.
- Backup: Backups of the data can be created and stored in other backup storage.
- Replications: Replication means the storage of the same data at several data storages and the synchronization between them.
- Relations/References: Relations or references reduce the redundant data, because data can be stored once and referenced afterwards with, for example, a foreign key relationship.
- Transactions: Transaction is defined as a sequence of database operations that belong together and can be considered as a logical unit. In execution they guarantee the consistency of the database in case of errors.
- Costs for Data Storage: From an economic point of view the costs for data storage should be included in the selection decision.
- Version Control (Binary Storage): Version control stores older versions of documents and binary files and provides the possibility to restore them.
- Large File Support (Binary Storage): The virtual factory might need to exchange documents, like specifications, with many images and definitions, for example, to describe the parts that they need. Hence, the binary data storage should support the storing of large files in an efficient way.
- Tagging (Binary Storage): Tagging provides the possibility to name binary files, which simplifies the data search.
- Key/Value Storage (Semi-Structured Storage): Key/value storage serves for storing simple data without large structures in a very efficient way.
- Schema-less (Semi-Structured Storage): Databases that work schema less are more flexible to add new data properties.

- SparQL support (Semantic Storage): In order to create semantic queries, the semantic storage should support SparQL, which is the quasi-standard language for semantic requests.

16.3.3 Cloud storage structure

This cloud storage will be based on the concept of buckets, which are specific isolated storage spaces managing data for different data types. These buckets can be thought of as independent databases to store and retrieve different types of data in different databases. Thereby, the data types decide their databases and how they store the data. Within this solution, a set of four different bucket types for (semi-)structured, binary and semantic data will be implemented. Designing in this way can ensure flexibility. If other bucket types are needed, such as a SQL bucket, they can be added easily. The cloud storage will support a basic set of CRUD (create, read, update, delete) operations for all bucket types in a suitable data format. Additionally some buckets will provide an advanced set of queries in a suitable data format, such as for example OData for (semi-)structured data or SparQL for semantic data.

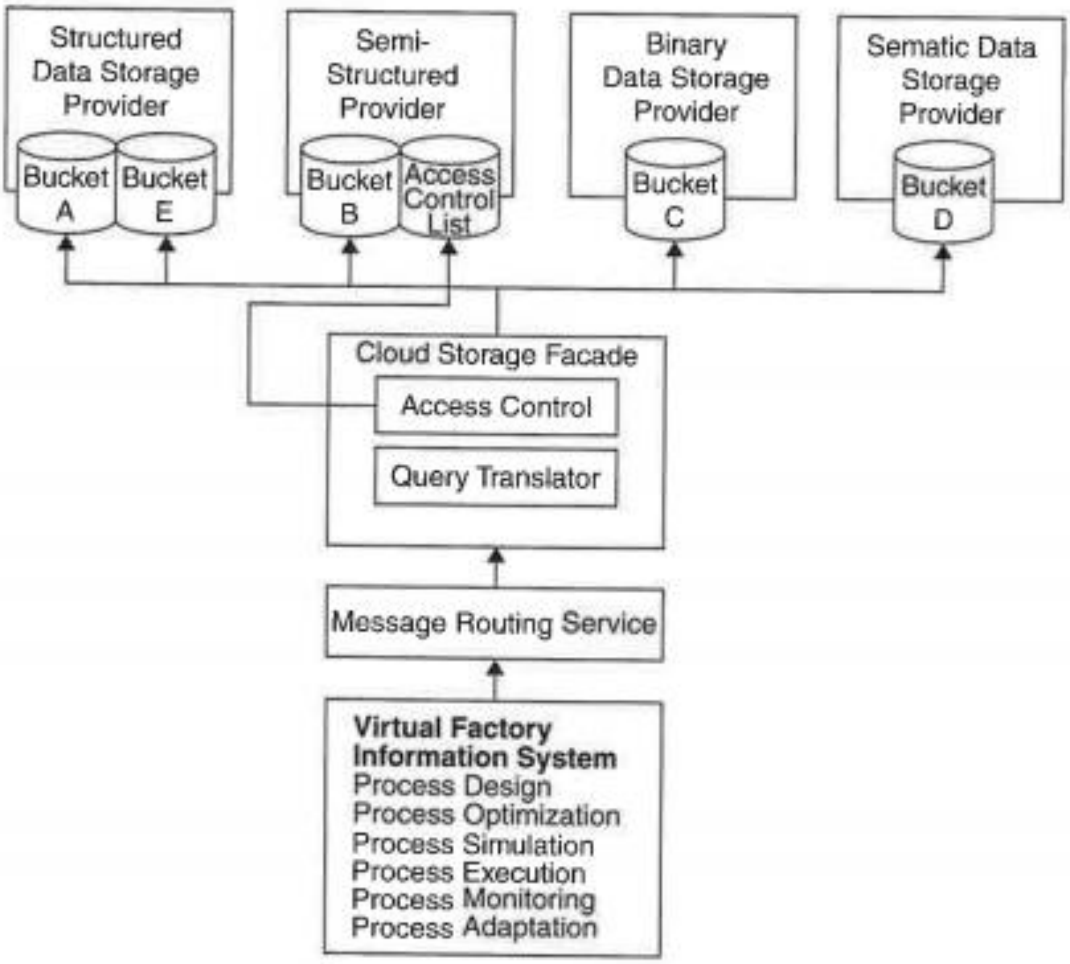

Figure 16.3 Cloud storage structure

Bucket names reside in the cloud storage and every name must be unique across the entire cloud storage namespace. All data, information or activities are managed in the buckets, and each can create an own separate bucket. Therefore, the cloud storage has to manage several buckets of each type, as it can be seen in Figure 16.3, where two structured buckets exist.

Figure 16.3 illustrates the structure of cloud storage. It contains five main components: Cloud Storage Providers, Buckets, Cloud Storage Façade, Message Routing Service and Virtual Factory functionalities.

- Virtual Factory Components: This contains all the functionalities in VFIS for brokers and partner factories to establish a virtual factory and execute the manufacturing process. The functionalities include process design, process optimization, process simulation, process execution, process monitoring and process adaptation.
- Message Routing: This is used to realize the communication within the virtual factory, for instance, pass data from process design to process optimization, and the reverse. An event handler will be triggered, if a message will be received, and Cloud Storage Façade will start to handle the message.
- Cloud Storage Façade: This is the message interface of cloud storage. It manages the buckets, interprets the messages and executes the commands sent in the message. Additionally, it checks whether the data has to be transformed and if the needed access rights are granted. To achieve this it uses Query Translator and the Access Control.
    - Query Translator: This is used to convert the data from the messaging format into the specific database query format and back.
    - Access Control: This is used to determine if functionalities in the virtual factory are authenticated to access a specific bucket. It also checks user credentials to access specific binary data. Access Control List will be stored in Semi-Structured Data Storage. To make it reachable for other functionalities it is necessary to set adequate rights.
- Buckets: Buckets are the basic containers that hold all the data. Every data that generated by virtual factory functionalities must be contained in a bucket. Depending on type they are realized as own database, separate tables or keys with a specific prefix.

16.4 Cloud storage implementation

Based on the selection criteria and the cloud storage structure designed in above paragraphs, we implemented a program to achieve cloud storage.

16.4.1 Technology decision on cloud storage

Suitable cloud providers are selected for each type of bucket. The selection criteria were defined in the previous section.

- Structured Data: MySQL database was selected to store structured data, because it is very stable, well-tested and Open Source. Additionally, it has good performance and scalability. It can be also used with the OData Format. In addition, by using MySQL it is possible to migrate data easily between different cloud providers and local systems with minimal migration effort. This ensures high data portability, which enables high flexibility in future development and avoids vendor lock-in.
- Semi-structured Data: MongoDB was selected as the semi-structured data storage, because it is very stable and has good performance. It is Open Source and uses the GNU Affero General Public License4, a non-infecting license. It is available for Windows, Linux, OS X and Solaris, and drivers exist for many programming languages. The number of drivers continues to grow, as the community develops new ones for further programming languages. It can be run on an own server, an own private cloud or on Microsoft Azure as a public cloud. The database supports replications by itself, so that synchronization is still integrated.
- Semantic Data: Sesame was selected to store semantic data, because it is a de facto standard to store RDF. It works with several RDMS and is platform-independent. It has a better performance then Jena for larger amounts of data and a better stability then BrightstarDB. It is Open Source and uses LGPL, a non-infecting license.
- Binary Data: Amazon S3 was selected as binary storage, because it offers a good interoperability with standardized interfaces like REST or SOAP. It offers high availability and scalability. The account on services is by a pay-as-you-use manner and thus there are no upfront costs for the initial hardware purchase required. Further, it is a broadly established solution for binary data storage, is well documented and enjoys a large community.

16.4.2 CreateBucket

As described above, in this model, each data object is created, retrieved, updated and deleted as a separate resource.

This is an example when a component, for instance Process Design, in business layer sends a message to the data layer to create a binary bucket. Message Routing Service records an event that a message has been received. Cloud Storage Façade checks this message, which kind of bucket has to be created. A Binary bucket will be created in Amazon S3 and returns a BucketID. Then Cloud Storage Façade sets the needed write and read rights for the component that has sent the message and it returns the BucketID to it. For instance, the Process Optimization component has the right to access Process Design buckets with read and write access. But some other components only have read-only access. Also, Process Design and Process Execution can share a bucket to store the process models (see Figure 16.4).

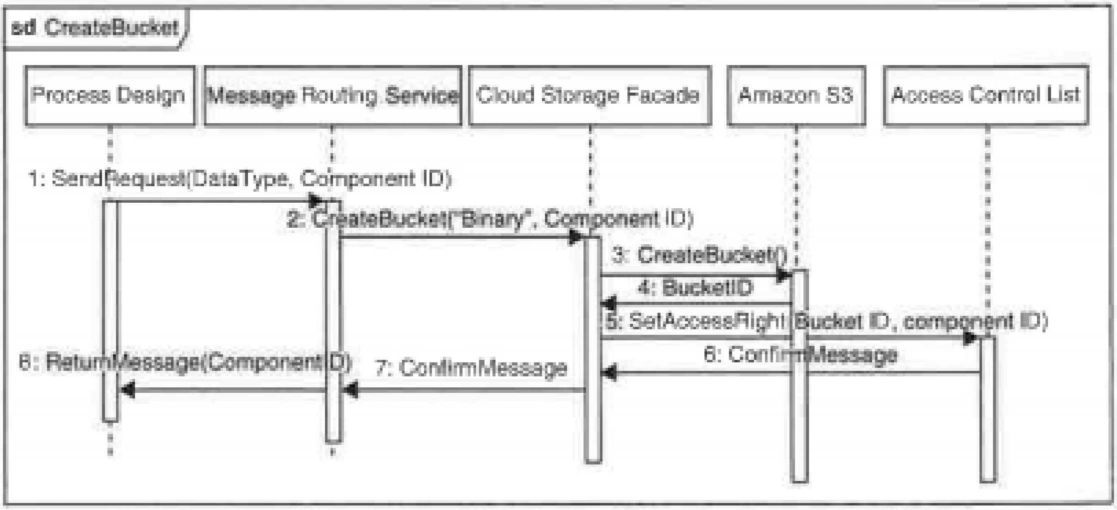

Figure 16.4 Sequence diagram for bucket creation

This method will create a new bucket for an application for managing data:

public String CreateBucket(String bucketType, String componentID, Boolean publicRead, Boolean publicWrite)

Parameters

bucketType: Type of the bucket that should be created.
values="Structured," "SemiStructured," "Binary," "Semantic"
componentID: Identifier of the component that wants to create the bucket It will be provided by the Message Routing component.
publicRead: Flag, for public read access. Default: false
publicWrite: Flag, for public write access. Default: false

Return Value

The bucket identifier

Remarks

The access rights for the component will be set automatically by the Cloud Storage component in the ACL.

Request Message Example:

```
<?xml version="1.0">
<tns:cloudRequest
xmlns:tns=
"http://example.
com/CloudStorage.xsd"
```

Response Message Example:

```
<?xml version="1.0">
<tns:cloudResponse
xmlns:tns=
"http://example.
com/CloudStorage.xsd"
```

```
xmlns:xsi="http://
www.w3.org/2001/
XMLSchema-instance"
xsi:schemaLocation="http://
example.com/CloudStorage.xsd
CloudStorage.xsd ">
<tns:createBucket>
<tns:bucketType> Binary
</tns:bucketType>
<tns:publicRead>false
</tns:publicRead>
<tns:publicWrite>false
</tns:publicWrite>
</tns:createBucket>
</tns:cloudRequest>
```

```
xmlns:xsi="http://
www.w3.org/2001/
XMLSchema-instance"
xsi:schemaLocation="http://
example.com/CloudStorage.xsd
CloudStorage.xsd ">
<tns:createBucket>
<tns:success>true
   </tns:success>
<tns:bucketId>BUCKET1234
   </tns:bucketId>
</tns:createBucket>

</tns:cloudResponse>
```

16.4.3 GetAccessRights

Each component can request the stored user rights in the ACL. To get the list it is needed to transmit the ComponentID of the user. This sends the corresponding message with the component or user identifier. Cloud Storage Façade gets the rights from the ACL and sends them back (see Figure 16.5).

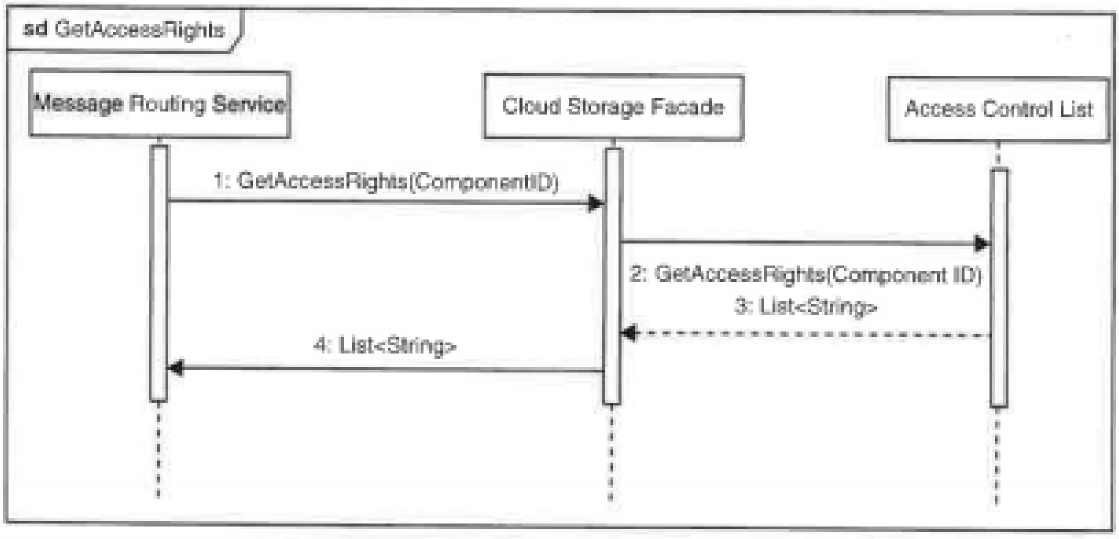

Figure 16.5 GetAccessRights

This method will return a list of access rights for a specific bucket or user:

public List<String> GetAccessRights(String identifier)

Parameters
identifier: Identifier of the component or user, whose access rights should be provided

Return Value
List with access rights, if no rights are exist an empty list will be returned

Request Message Example:

```
<?xml version="1.0">
<tns:cloudRequest
xmlns:tns=
"http://example.com/CloudStorage.xsd"
xmlns:xsi="http://www.
w3.org/2001/XMLSchema-instance"
xsi:schemaLocation="http://example.
com/CloudStorage.xsd CloudStorage.
xsd ">
<tns:getAccessRights>
<tns:subjectId>ID1234
</tns:subjectId>
</tns:getAccessRights>

</tns:cloudRequest>
```

Response Message Example:

```
<?xml version="1.0">
<tns:cloudResponse
xmlns:tns=
"http://example.com/CloudStorage.xsd"
xmlns:xsi="http://www.
w3.org/2001/XMLSchema-instance"
xsi:schemaLocation="http://example.
com/CloudStorage.xsd CloudStorage.
xsd ">
<tns:getAccessRights>
<tns:success>true</tns:success>

<tns:subjectId>ID1234</tns:subjectId>

<tns:privileges>
<tns:name>Dashboard:createUsers
</tns:name>
<tns:name>Designer:createProzesses
</tns:name>
</tns:privileges>
</tns:getAccessRights>
</tns:cloudResponse>
```

16.5 Conclusions

This chapter describes a solution to design information system for virtual manufacturing enterprises. The manufacturers use this VFIS to support mission-critical manufacturing processes and provide a wide range of information and insight to help management make better decisions.

This solution applies cloud storage to support a Virtual Factory Information System data layer. Cloud computing is changing the way to do business in many industries. However, this chapter mainly focuses on cloud storage implementation. With earlier adoption of cloud storage to access/manage data enterprise can stay ahead, and it is crucial to the SMEs' existence. This flexible and dynamic control of data allows manufacturers to share information about production/products over the cloud platform. The cloud storage component should support several types of data storage, like semi-structured data storage (for example, for XML or JSON data) and structured data used internally by different components in the business layer, as well as the semantic data necessary for semantic company descriptions and also data storage for binary files, which is used for storing documents such as specifications.

This cloud storage approach provides several advantages:

1. The products and process data can be retrieved and reused easily since the location of required information is readily identified even in a distributed product database.
2. It promotes an easy discovery of complex product data. This is particularly useful when the product data are created and used in many different domains, using different terminology or sometimes domains using different terminology, or sometimes in different languages.
3. Consistent product data can be shared from the beginning of the product lifecycle to the end of it.
4. Since the system is a web-based one, any user connected to the Internet can have ready access to the services. Overall, these advantages together provide a foundation for logical integration of distributed product databases for virtual enterprises.

However, it is difficult to guarantee the performance of multiple cloud storage providers serving the same data layer. It is important to consider how to benchmark cloud services, along with networking performance and storage performance. Moreover, the selected technologies only cover the basis for storage and a part of the data transmission. The whole logic around it has to be implemented separately. For instance, bucket creation and management for each database type must be considered.

To sum up, this information system solution achieves an end-to-end integration both in terms of business hierarchy and in terms of systems hierarchy, as it involves almost all parties that participate in the manufacturing process.

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Cloud manufacturing system for sheet metal processing

Abstract

Cloud computing is changing the way industries and enterprises run their businesses. Cloud manufacturing is emerging as an approach to transform the traditional manufacturing business model, while helping the manufacturer to align production efficiency with its business strategy, and creating intelligent factory networks that enable collaboration across the whole enterprise. Many production planning and control problems are essentially optimization problems, where the objective is to develop a plan that meets the demand at minimum cost or maximum profit. Because the underlying optimization problem will vary in the different business and operation phases, it is important to think about optimization in a dynamic mechanism and in a number of interlinked sub-problems at the same time. Cloud manufacturing has the potential to offer decision support as a service and medium of communication in production planning and control. To solve these problems and produce collaboration across the supply chain, this paper provides an overview of the state of the art in cloud manufacturing and presents a model of cloud-based production planning and production system for sheet metal processing.

Keywords: cloud manufacturing, production control, supply chain, sheet metal.

1 Introduction

Changes in the global economy, fierce competition and the rapid development of internet technology are continually stimulating new models of manufacturing that may be appropriate for a particular business. These characteristics require soft hierarchical approaches to operate manufacturing systems (Frayret et al., 2004). The characteristics of this new era of manufacturing industry are agile, networked, sustainable and digitalized processes with temporary collaborations across supply chains. At the same time, the trend towards more geographically distributed manufacturing, coverage of the enterprise chain, and inter-enterprise collaborative business follow an evolution trajectory that leads to the enterprise manufacturing model (Zhou et al., 2011). A number of similar paradigms have emerged in parallel with the intention of solving the challenges of distributed resources, such as holonic manufacturing, agent-based intelligent manufacturing, reconfigurable manufacturing, distributed manufacturing, dispersed network manufacturing, and virtual enterprises (Bi et al., 2014; Ford et al., 2012). They all have played a critical role in the development of manufacturing industries, although each definition has its own emphasis. However, there are still many barriers to efficient manufacturing systems and current systems cannot meet the demand for enhanced quality requirements (Ning et al., 2011; Zhang et al., 2014). Fortunately, a more comprehensive and profound solution, i.e. cloud manufacturing, has emerged and has been widely applied in various fields.

Cloud manufacturing is a new type of smart manufacturing system that focuses on service-orientation and knowledge-bases. It aims to provide high efficiency and low energy consumption for manufacturers (Li et al., 2010). During the innovation process in manufacturing industry, the development of ICT (information and communication technology) always plays a crucial role in improving production efficiency and takes full advantage of manufacturing resources (Jiang et al., 2013).

In a cloud manufacturing system, state-of-the-art technologies such as digitalized manufacturing, cloud computing, the Internet of Things (IoT), semantic web, and high-performance computing are integrated. By extending and shifting existing manufacturing and service systems, manufacturing resources and capabilities are virtualized and provided as manufacturing services based on demand. This is achieved by the coordination of local information (e.g. machine loading and performance) and global information (e.g. demand from a market). There are similar forms of coordination in agent-based manufacturing systems (Sikora and Shaw, 1997; Parunak et al., 1997; Frayret et al., 2004). A cloud manufacturing system is a scalable service platform to support cross-enterprise operation and multi-agent collaborative interaction (Zhang et al., 2014). Compared with traditional agent-based manufacturing systems, cloud manufacturing not only improves information and resource sharing, but also aims to improve machine utilization and enable rapid capacity scalability. Moreover, the virtualized resources and capabilities are efficiently shared among different enterprises by unified and centralized intelligent management and operations. Cloud manufacturing supports the whole manufacturing lifecycle with the goal of high quality, flexible and on-demand services at low prices through a networked system (Li et al., 2010).

The motivation of this paper is to outline a cloud manufacturing system for sheet metal processing and to address the challenges and issues that original equipment manufacturers (OEMs) have in production planning and control. The purpose of this paper is to present a cloud-based production planning and control concept for sheet metal manufacturing. This study was conducted in the form of a case study. Twelve domain experts from one company, which is a specialist in sheet metal fabrication machines, were interviewed about their perspective on possible ways to achieve cloud manufacturing by implementing cloud-based production planning and control system. The results of the interview were analyzed, and several requirements were suggested. Based on this case study, a model of cloud-based production planning and control system is proposed. Cloud computing technology and physical information fusion technology may benefit manufacturing enterprises.

The remainder of the paper is organized as follows. Section 2 elaborates the relevant studies that were reviewed. Section 3 studies the functional requirements for cloud manufacturing. Section 4 presents the conceptual model and architectural considerations. Section 5 then concludes the paper.

2 Literature Review

2.1 Cloud Manufacturing

Cloud computing is the next step in the evolution of the Internet and it is the trend of pay-as-you-go utility computing, elasticity, virtualization, grid computing, distributed computing, content outsourcing and Web 2.0 (Xu, 2012). Cloud computing is not a new technical term but a convergence of several existing technologies, such as computing, networking, storage, and powerful management tools (Cisco, 2012). It is considered as a multidisciplinary research field and it enables a new generation of IT and business management. Cloud computing simultaneously provides a paradigm shift of IT (information technology) and business infrastructure (Xu, 2012).

Manufacturing companies need a new platform to fulfill their need for an increasingly IT reliant, globalized, distributed and agile business model. Multinational companies are looking for a solution to dynamically add both tangible and intangible resources for a particular project, while improving plant floor visibility and achieving more efficient processes without having to make incremental investment in their IT resources (Giriraj and Muthu, 2013). Cloud computing infrastructure not only provides the power of virtualization, automation and collaboration to the whole manufacturing supply chain and networked enterprises, but also brings significant financial advantages. While services are becoming inherent characteristics of products, manufacturing industry is gradually transforming from a traditional product-oriented type to a service-oriented one (Huang et al., 2013; Luo et al., 2011). Cloud computing represents a breakthrough concept to achieve the transformation from production-oriented to service-oriented manufacturing (Xu, 2012; Cheng et al., 2010; Tao et al., 2011), where everything is provided as services: argumentation as a service, design as a service, fabrication as a service, experiment as a service, simulation as a service, management as a service, operation as a service, and so on (Ma et al., 2010).

It is very interesting that many researchers 'borrow' the concept of cloud computing to give rise to 'cloud manufacturing' (CM), which is a manufacturing approach to cloud computing. There are valid reasons and perhaps requirements for manufacturing business to develop towards digitalization and embrace cloud computing (Li et al., 2010; Xu, 2012). It is believed that cloud computing can play a critical role in establishing linkages between MRP (manufacturing resources planning), ERP (enterprise resource planning) and CRM (customer relationship management) (Xu, 2012). The concept of cloud manufacturing has borrowed some central ideas from earlier work, which should be acknowledged. A standardized framework for co-operation between entities is one of them. Information and resource sharing mechanism in the network has been introduced already in the early 80's by Smith (1980) in the ContractNet system. Shaw (1988) introduced dynamic scheduling for cellular manufacturing systems for networked system. Agent based systems in manufacturing have also introduced rules and negotiations in order to adjust toward requested capacity (Monostori et al 2006). The problems have always been there and the approaches proposed in earlier literature have remained mostly in academic context. The general availability and emergence of cloud technology is able to deliver this type of features for wider audiences. Standardized information models, real-time or close to real-time interfaces between entities and possibility to utilized centralized decision making or local rules are all possible implications.

When cloud manufacturing is discussed, what comes to mind first is the existing networked manufacturing concept, sometimes called internet-based manufacturing or distributed manufacturing, manufacturing grid, virtual manufacturing, and agile manufacturing (Ford et al., 2012; Xu, 2012). All these concepts have common origins, which can be traced back to the 1990s, when the agent based framework for manufacturing systems was proposed to integrate distributed machines and to manage heterogeneous components in a homogeneous fashion (Sikora and Shaw, 1997; Parunak et al., 1997). The distributed manufacturing systems concept was designed to allow optimum decision making on distributed resource usage (Tharumarajah, 2001); virtual manufacturing was designed to realize the actual manufacture process by computer (Zhang et al., 2014); and agile manufacturing appeared in response to changing demand (Wang and Lin, 2009). However, today's networked manufacturing mainly refers to an integration of distributed resources for undertaking a single manufacturing task (Xu, 2012). A resource pool or resource sharing mechanism was proposed in previous coordination formats (Frayet et al., 2004). However, what is lacking in these types of manufacturing regimes are the centralized operation management of the services, choice of different operation modes, and embedded access to manufacturing equipment and resources, without which a seamless, stable, and high quality transaction of manufacturing resource services cannot be guaranteed (Xu, 2012). In the manufacturing system, "control" and "communication (coordination)" are identified to solve distribution problems (Caridi and Cavalieri, 2004; Frayret et al., 2004). The evolution of manufacturing systems needs to be considered from these two dimensions. At present, cloud manufacturing has become a new mode of multi-agent networked manufacturing, and it is evolving significantly in both control and communication approaches.

Cloud manufacturing contains two important principles: ‘integration of distributed resources’ and ‘distribution of integrated resources’. Xu (2012) defined cloud manufacturing by mirroring The National Institute of Standards and Technology (NIST)’s definition of cloud computing 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.’

Li et al. (2010) introduced the definition of cloud manufacturing to perform larger scale collaborative manufacturing in a research project funded by the National Natural Science Foundation of China. Based on this definition, many cloud manufacturing related studies have been launched, such as Zhang et al. (2014), who further described the key issues for the construction of cloud manufacturing, and Li et al. (2011; 2012) who discussed cloud manufacturing and resource encapsulation technology.

ManuCloud is a project in the European Union (EU)’s Seventh Framework Programme (FP7) which is targeted at developing a marketplace for virtualized manufacturing services, supporting on-demand manufacturing scenarios, and achieving the next level of integration of manufacturing networks based on the dynamic interconnection of multiple factories (Yip et al., 2011). It provides users with the ability to utilize the manufacturing capabilities of configurable, virtualized production networks, based on cloud-enabled, federated factories, supported by a set of software-as-a-service applications (Meier et al., 2010).

Manufacturers and their subcontractors develop a close collaborative relationship to improve the coordination of their mutual activities and enhance innovative performance. Trust and contracts have been viewed as two important mechanisms to safeguard business opportunity and maintain a cooperative relationship (Wang et al., 2011). In a cloud manufacturing environment, during the product development process the collaborating agents have to exchange product information, so they should have mutual understanding of that exchange information, and most importantly, they need to trust each other both in communication and information contents in order to improve the quality of their relations (Fatahi Valilai and Houshmand, 2014; Ripamonti and Peraboni, 2010).

Yousif (2014) presents an example showing that in a cloud based collaborative environment, the parties need to go through the authorization process every time before establishing a relationship. Such collaborative environment allows distributed manufacturing to realize competitive advantages by using their existing resources for collaborating with each other. This method can also satisfy the risk control requirements. Similarly in cloud manufacturing, in order to build a trusting environment, it is necessary to embed an authentication and authorization mechanism, a trust evaluation and measurement mechanism, and reliability analysis features into the cloud manufacturing platform (He and Xu, 2015).

However, many issues about cloud manufacturing are still confusing and more attention should be paid to advance progress in this field (Chandrasekaran et al., 2013). The present work is a step forward in applying cloud computing concepts to the optimization of production planning.

2.2 Production Planning and Control

The development of cloud manufacturing needs to be synchronized with the development of enterprise manufacturing systems and manufacturing environment (Ma et al., 2013). It should support the overall management of processes, products, resources and information.

Production planning and control (PPC) is very critical for manufacturing execution. It includes tasks of job or task scheduling, inventory planning, loading production, process selection and planning, facility location, estimating quantity and costs of production, capacity planning, line planning, follow-up, and execution. In the context of cloud a manufacturing environment, PPC is even more difficult and complex. There are two main considerations:

(1) Temporality of delivery configuration - The cloud manufacturing mode is driven by the uncertainty of customer orders. When a customer order is received, participants in CM should quickly form a virtual enterprise based on the cloud service, and with the delivery of the product or service the virtual enterprise is dissolved. This feature of CM distinguishes it from traditional PPC (Ning et al., 2011). In order to respond to dynamic requests, the PPC must embed attributes adaptively so as to provide a reconfigurable interaction model (Caridi and Cavalieri, 2004).

(2) Networked manufacturing - A single process includes multiple participants (i.e. cloud services providers and users), distributed resources, and decentralized management. Therefore, multiple process plans should be defined for each supplier, and each sub-process plan needs to determine alternative operations and alternative machines (Um et al., 2014). Due to the different status (i.e., system configuration and customer demands) of each supplier, the quantifications and requirements are different (Caridi and Cavalieri, 2004). In order to monitor the distributed manufacturing processes and guarantee the quality of final delivered services, a set of Services Agreement Level (SLA) need to be defined in advance.

When discussing the PPC in CM environment, the topics consist of production planning, process management, and also supply chain optimization. The optimization of the supply chain includes every link in procurement, marketing, logistics, planning, and scheduling. The optimization involves collaborative project management and resource distribution and scheduling to improve resource utilization and efficiency.

2.3 Optimization in Cloud Manufacturing

Cloud manufacturing approach can offer centralized optimization service for the production units. With the dynamic changing of manufacturing resource services, the quality of resource services and the requirements of enterprise users, there are many uncertain factors influencing the dynamic optimization of resource services, which make the manufacturing task impossible to be completed efficiently and with high-quality. Various optimization tasks can be conducted to solve dynamic problems by centralized cloud manufacturing services.

Production process optimization is one of the most widely investigated topics in the field of manufacturing (Chandrasekaran et al., 2013). Formally, the process of optimization in manufacturing engineering consists of the following processes: (i) defining variables, constraints, and objective function(s), (ii) solving the constrained problem of general mathematical form by using various types of algorithms and methods, and (iii) simulating the optimization algorithm and then deploying the algorithm in practical systems for application (Tao et al., 2015). Different types of optimization can be employed due to the different nature of the formulated manufacturing problems.

Tao et al. (2015) provide a comprehensive analysis of all kinds of manufacturing optimization problems and their general methods. It is shown that optimization can be applied almost everywhere. Currently, most existing studies focus on the optimization objectives in areas such as management of manufacturing process, design and analysis of product/element, and system management and control. The optimization problems include both single-objective and multi-objective ones (Tao et al., 2015). Multi-objective optimization refers to the optimization problem crossing different disciplines, and it is always very complicated. It includes different variables and parameters to solve one single optimization problem. However, the methods of onsite decision or multi-step optimization in collaborative manufacturing are inevitably not thorough enough. Therefore, multi-disciplinary optimization becomes a significant challenge and it is the most recent trend in the development of advanced manufacturing systems.

The dynamic changing of manufacturing requirements produces many uncertain factors. The adoption of cloud can bring a lot of benefits to manufacturing companies. In terms of cloud manufacturing, the optimizations can be discussed from two aspects: cloud resource optimization and manufacturing resource optimization. Cloud resources refer to technical infrastructure and on the other hand manufacturing resources mean the physical resources in manufacturing. Tharumarajah (2001) describes resource allocation problems as the embodiment of the choice of resources, performance, and constraints. Both types of optimizations in cloud manufacturing are discussed based on this principle.

The first utilization of cloud computing resources was their use in optimizing manufacturing resources (Laili et al., 2012). In cloud computing, there are different kinds of computing resources, such as cloud storage (Rimal et al., 2011) and transaction process (Zeng et al., 2009), and these resources can be virtualized and then applied to optimize the schedule of using these resources. Cloud systems can automatically control and optimize resource use by leveraging a metering capability at some level of abstraction that is appropriate to the type of service (e.g., storage, processing, bandwidth, and active user accounts) at the physical layer in computing. Resource usage can be monitored, controlled, and reported, providing transparency for both the provider and consumer of the utilized service (Mell and Grance, 2009).

The second type of optimization is the use of the cloud concept to obtain on-demand cloud resources to optimize the business processes. Cloud-based solutions enable better-integrated and more efficient business processes to improve the efficiency of operation. In cloud manufacturing, it is not only about providing computing resources, but also controlling a variety of other manufacturing resources and abilities directly for collaboration and sharing (Laili et al., 2012) through the whole manufacturing lifecycle. Therefore, the core focus of cloud manufacturing is to optimally use dispersed manufacturing resources in the prevailing trend to attain a low-carbon footprint in economic development (Ning et al., 2011).

In the cloud manufacturing research area, the most discussed issue is resource (service) optimization. Manufacturing resources refer to resources that are required during the product development life cycle (Xu, 2012). These manufacturing resources may take two forms: manufacturing physical resources and manufacturing capabilities. Manufacturing physical resources can exist in hardware or software form. The former includes equipment, computers, servers, raw materials, etc. The latter includes, for example, simulation software, analysis tools, 'know-how', data, standards, and employees. Some manufacturing capabilities are intangible and dynamic resources 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 (Xu, 2012). Therefore, the optimization problems in cloud manufacturing are optimizing the manufacturing resources, and matching these resources with specific capabilities.

In cloud manufacturing, the optimization process consists of some key elements: the users submit a computing (manufacturing) resource request, the cloud manufacturing system platform analyzes the mission, divides it into subtasks in accordance with the requirements from users, executes scheduling algorithms for mapping these requirements to available resources, allocates resources optimally, and sends a final solution back to the users (Laili et al., 2012). Compared with traditional manufacturing paradigms, the optimization complexity is increasing in cloud manufacturing because the requirements of supply chains are dynamic and the parameters changing as a manufacturing process proceeds.

3 Functional requirements for sheet metal processing

Companies operating in sheet metal forming (SMF) are at the beginning stage of manufacturing for a broad spectrum of industries including automotive, aerospace, energy, domestic appliances, electric cabinets, elevator, and escalators. Production steps consist of units such as punching, shearing, laser cutting and sheet metal handling systems. SMF industries, in comparison with other discrete part manufacturing industries, are typically highly automated and flexible in production diversities.

3.1 Decision problems

Sheet metal processing has some special characteristics in terms of production planning and control. Many of the decisions are completed several times a day and analytic techniques such as mathematical optimization in nesting are widely used.

Traditionally, optimization tools have been used to solve the sheet nesting problem. For example, Nehal et al. (2012) proposed a genetic algorithm based system. Huang et al. (2009) presented optimal layout and path planning for flame cutting of sheet metal. Optimization has also been used in the sheet metal forming process (Gantar et al. 2002, Liu and Yang 2008, Wang et al. 2008, Wang and Xie 2005). However, there is still limited capability in shop floor applications of optimization methods, due to the complexity and volatility of different processes, and also because of the non-availability of required information (Chandrasekaran et al., 2013).

Managing tools and setups is also a typical complex problem in sheet-metal production. Giannakakis and Vosniakos (2008) introduced an expert system for making this decision. Marvizadeh and Choobineh (2013) introduced a similar process for punch presses. Akturka et al. (2007) and Daskin et al. (1990) have also introduced analytical approaches in the same domain.

The scheduling of production has been also studied. Some specific features could be non-identical machines and tools. Gurel and Akturk (2007) have considered the job allocation problem in non-identical parallel machines. Hirvikorpi et al. (2008) introduced a scheduling system considering wearing tools and stochastic lifetimes. In CM environment, the decision making process for PPC is broken into different levels when the manufacturing become more and more distributed. As an effective solution, cloud computing infrastructure can be used to develop reliable predictive models and carry out the optimization in a cloud (Chandrasekaran et al., 2013).

3.2 Business Requirements

The motivation of this research is to demonstrate the realization of a cloud manufacturing environment which can transfer cloud-based solutions to the manufacturing domain, and make sure that manufacturers can benefit technically, and also conceptually. The goal is to combine various manufacturing resources and capabilities dynamically in such a way that customers can access them as if they were in a single facility. However, production planning and control and their optimization are the main focus of this research.

To have a better understanding of cloud-based production planning and control and its opportunities the requirements for a CM system were collected from SMF solution provider. Twelve related domain experts were interviewed twice during a specific time period. In the first round experts in different disciplines of the company were required to provide their technical opinions about the optimizations. After presentation of their points, face-to-face interviews were conducted and the requirements of each discipline were analyzed. Table 1 summarizes the key requirements which were used to develop a prototype CM environment. The main requested linkages included factory level control with connections to both steel sheet suppliers and customers placing orders for the production. The real-time visibility was requested within production line (RQ1) and in the supply chain to see the planned and actual progress of each work (RQ4). From a process view, the main connections were to design CAM (computer-aided manufacturing) activities. Design of a product is a main driver for task durations, tools and setups – for this reason CAM software packages need to be communicate directly with cloud based system (RQ2).

A common set of key performance indicators (KPIs) was requested for the entire supply chain (RQ3) as machines are providing this information for the production planning needs.

The primary requested functionality (RQ5) was to have an optimization based production planning system to combine line-level capacity, raw material usage, and various machine related setups. However, this system should be parameterized for different needs.

Status information for each work and events in different parts of the production process are centrally stored in the cloud system. This information should be available for change management and rescheduling considerations (RQ6). Planned and actual production plans should be compared as typically in low volume production, the predicted processing times may vary from actual and manual parts of the process such as tool changes, material feeding and operator confirmations may take more time than planned. In order to improve the understanding of variability, actual processing times were requested to be stored for learning and development purposes (RQ7).

Table 1. Requirements collected for cloud-based product planning and control.

ID	Requirement	Priority

RQ1	Overall line level production planning and control combining all machines and phases	1
RQ2	CAM and dynamic nesting connected to PPC	2
RQ3	Real-time key performance indicators	2
RQ4	Access for customers and suppliers to see work and material tracking information	2
RQ5	Dynamic multi-objective optimization for scheduling	1
RQ6	Event management for re-planning of the supply chain	3
RQ7	Actual processing times feedback for production planning	3

3.3 Functional Requirements

Based on the business requirements, more specific functional requirements are defined and developed. Figure 1 shows a general reference model of CM for SMF industries. This architecture was based on the pertinent articles that were reviewed and both the Purdue Reference Model for Control Hierarchy and ISA-95. The Purdue Reference Model of Control Hierarchy is a commonly used architecture model to define manufacturing operations management. It breaks the production lifecycle into different phases. Whether they serve as part of continuous production, job production or batch production, automation and information systems fall under this model (Adiseshan, N.D). ISA-95 is the international standard for the integration of enterprise and control systems. ISA-95 consists of models and terminology. These can be used to determine which information has to be exchanged between systems for sales, finance and logistics and systems for production, maintenance and quality. This information is structured in Unified Modeling Language (UML) models, which are the basis for the development of standard interfaces between ERP and MES (Manufacturing Execution Systems) (ISA-95, 2014).

Interoperability of various IT systems is an important topic in cloud manufacturing. Cuesta et al. (1998) introduced a concept integrating CAD and CAM systems for sheet-metal cutting. Rao et al. (2006) introduced an integration system for sheet-metal job shops. The integration of system design and closing the gap between design and production has potential. Alva and Gupta (2001) presented an automated design for sheet metal bending operation.

The model in Figure 1, maps the plant-wide information flow from the sensors to the boardroom in four distinct levels, from the most fundamental to the most advanced.

- Level 1 is for physical devices process, which includes an individual machine or machine tool as the smallest unit of the manufacturing system. This supporting equipment includes intelligent transportation, robots, and also laser, cutting, shearing and bending machines.
- Level 2 represents site manufacturing operations and controls. Different kinds of controller are used for automation of the diverse machines and devices in Level 1.

- Level 3 addresses plant-wide applications, including Manufacturing Execution Systems (MES), asset management and Material Requirements Planning (MRP) for production planning, scheduling and inventory control.
- Level 4 is the enterprise level. It consists of business systems and quality databases. It can integrate multiple Level 3 systems and ensure cross plant boundary cooperation.

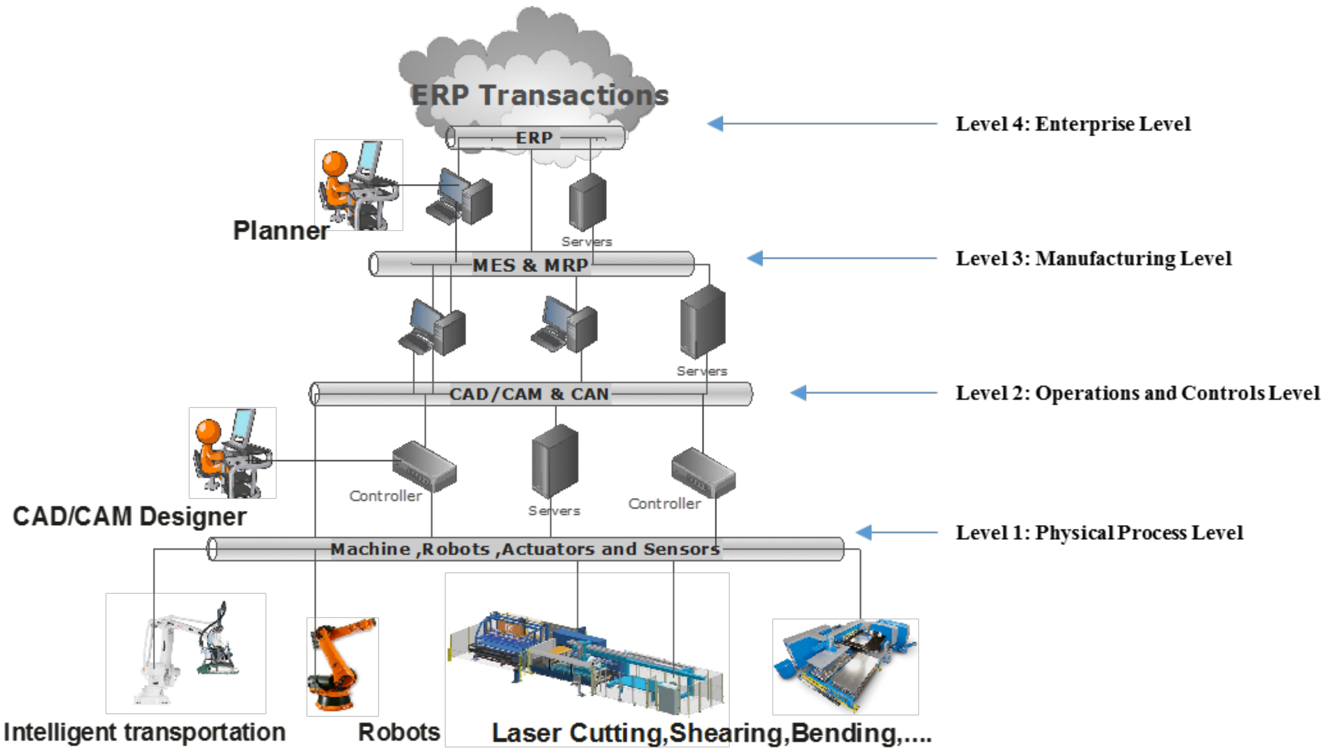


Figure 1. Integrated optimization platform in sheet metal processing.

Existing advanced planning and scheduling systems provide many features requested. However, there are some features of a cloud-based system for production planning and control, which differ from traditional stand-alone software solutions:

(1) Emphasis on supply chain integration for customers and suppliers by providing real-time access
(2) Possibility to conduct planning activities centrally for multiple factories and supply chain
(3) Integration of CAM processing of laser cutting, punching, bending, and nesting into integrated product data model
(4) Real-time event handling and key performance indicators connected to planned and actual production schedules

3.4 Cloud Manufacturing in the Sheet Metal Industry

A cloud manufacturing approach involves collaboration across the whole manufacturing process, and the cloud-based PPC and optimization problem in the sheet industry must encompass every link in the manufacturing process, as presented in the following sections.

3.4.1 Product design process

The manufacturing design process in SMF includes the use of various CAM systems. Typically, geometric design is combined with material information and decisions related to sheet type, machine, tool, and work sequence are made. In the case of 2D objects, the selection is made between using shearing and laser cutting. For 3D parts, CAM instruction is needed for bending machines as well. For manufacturing planning, these decisions have a great impact. Sheet size can affect nesting efficiency and tool selections may have consequences in terms of the frequency of setups. Also nesting principles vary in the case of push type make-to-stock production or high mix make-to-order type of production. Having idle capacity versus wasting raw material due to lower utilization is the decision to be made. When several machines have varying setups and layout is constrained by fixed conveyors or WMS (Warehouse Management System), balancing the line in various cases becomes an important task. Much of this is determined in the CAM and design process.

As an example, manual adjustment of the sheet metal size from available sizes of sheet metal influences the utilization rate of the different nesting layouts considerably. This highlights the point that the system needs fundamental reconfiguration in a few aspects of nesting algorithms with respect to the available amount of raw materials. The possible problem is that the optimization is the definition of local optimum point for each job even though there are possibilities to search for global optimum answers. The flexibility and interconnections of variables in different manufacturing processes should be taken into account in supply chain level optimization. The variables include speed for the machine actions, speed of tool changing, maintainability, durability and set up times. Figure 2 illustrates an integration of CAM processes into one single data element shared by CAM designers to cover all machine types and full integration into the PPC system for dynamic nesting.

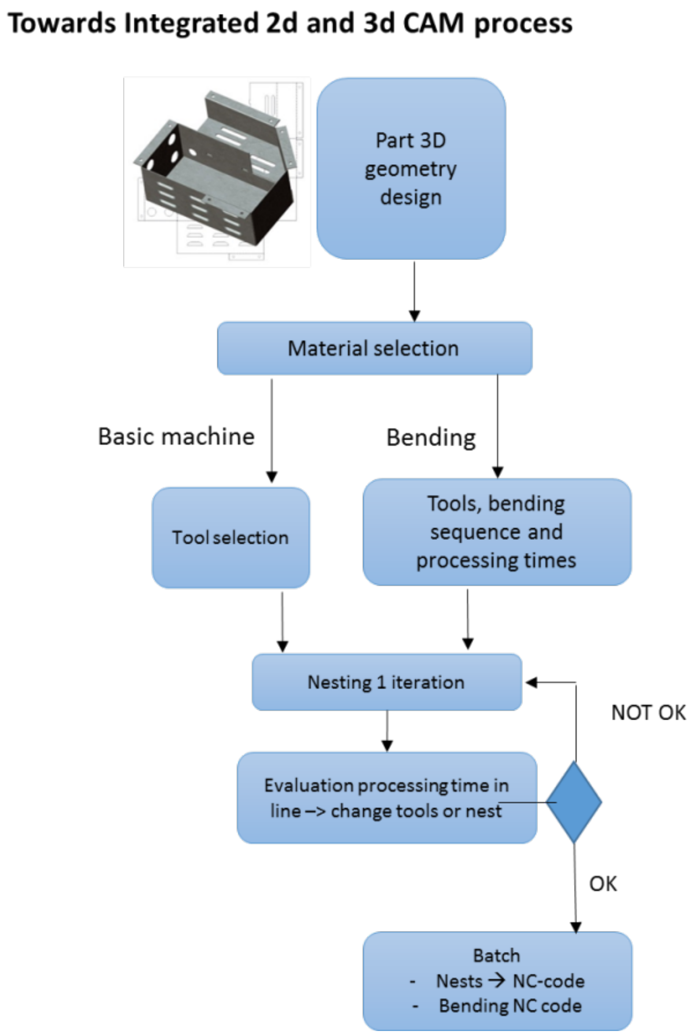


Figure 2. Integration of CAM processes.

3.4.2 Production Planning - Manufacturing Execution System

With regard to cloud-based optimization, production planning and especially scheduling has the highest potential for optimization. It ensures that customer orders can be fulfilled as requested. According to expert interviews, many SMF companies typically manage the capacity of different machines and machine sequencing using operators' experience. This means that many smaller SMF companies do not use available production planning techniques fully, but instead use first come first serve (FCFS) type of policies with rush orders.

Typically, MES is used to support the manufacturing facility and take care of the communication channel of shop floor and administration, and interface with the ERP system. It is very important that the two systems are linked so that the shop floor will know what is happening at the business level and vice versa. Such two way communication will result in the optimization of activities throughout all aspects of the manufacturing process. MES mainly covers resource allocation, operation scheduling and production planning. Typically, the production process for each product can be described as a working flow in the plant. The sequence of each flow is controlled by MES. Several robust algorithms for scheduling, and sequencing are available. A variety of sensor data from the machines, for example job completion, tool wearing and energy consumption are employed in manufacturing devices to collect real-time status information. Pre-emptive and closed feedback loop planning can be implemented by combining real-time sensor information with production planning zones (Figure 3).

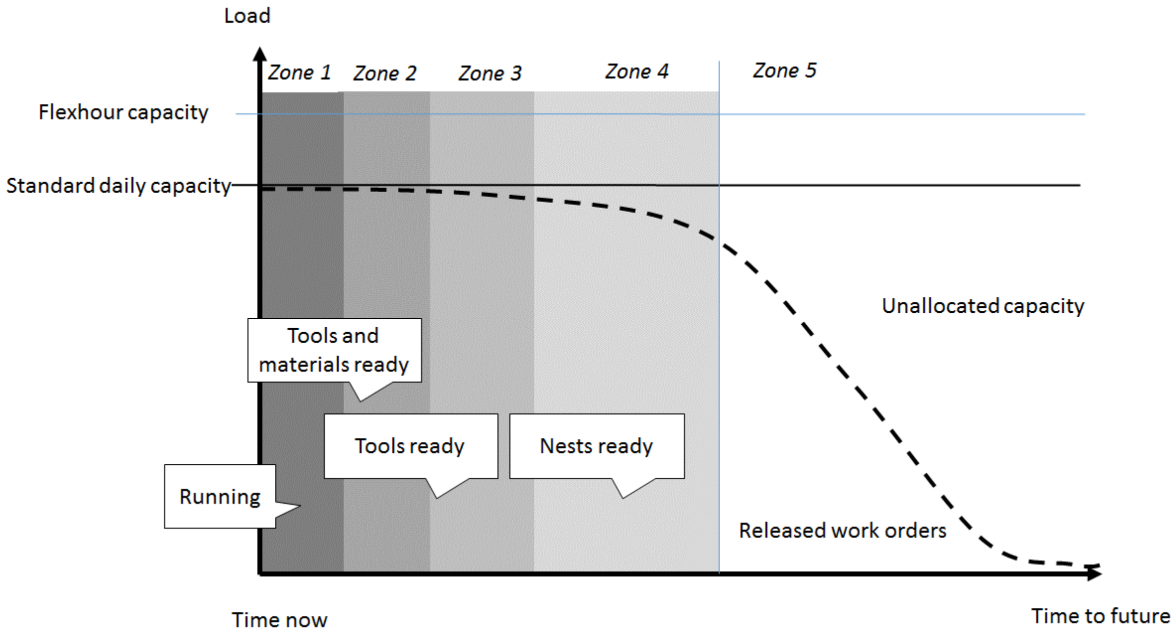
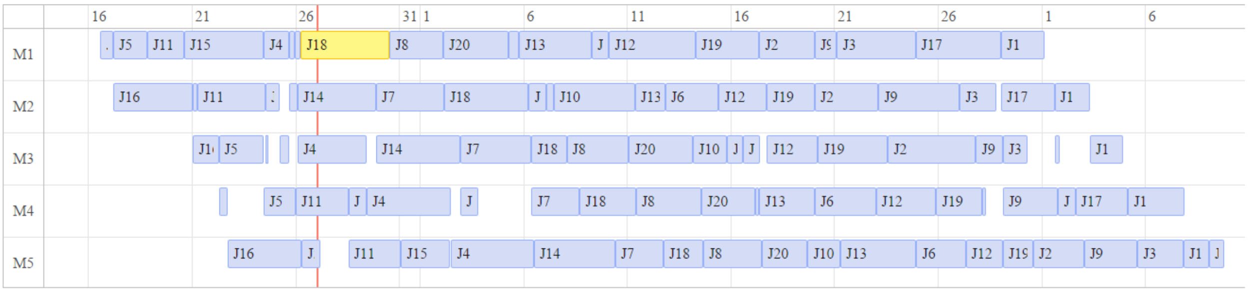


Figure 3. Production planning time horizon and dynamic planning.

A centralized service for production planning prototype was implemented to test the concept. Figure 4 illustrates a work center production schedule which is generated by the centralized scheduling engine offering production planning as a service. This functionality is fulfilled by changing parameters and adding desirable properties, and then setting up manufacturing job requirements and certain criteria, such as running sequentially or in parallel. A metaheuristic system changes the order sequences by minimizing the total processing time.



Production planning objectives

MIN total processing time

- *Tool setup time*
- *Material setup time*
- *Cassette change setup time*
- *Scrap change setup time*
- *Planned maintenance time*

Subject to:

- *Due dates*
- *Machine capacity*

Figure 4. Screenshot of the developed cloud-based scheduling service result and its objective.

3.4.3 Machine control

3.4.3.1 Shearing, punching and laser cutting

The main objective of using the basic machine is the maximization of utilization rate of sheet metal, and the constraints are the product shapes that need to be fulfilled and the size of the available sheets. Therefore, using a cloud-based solution can enable the testing of different algorithms for nesting and computational functionalities, supporting the parallel data mining, and maximizing the performance of analytics. These features are different to traditional computing environment.

In practice, the optimization problem can be formulated as follows: maximizing capacity utilization by re-sequencing orders, subject to external events and previous machinery on the line.

The optimal solution should be calculated and updated continuously subject to any changes in the production plan or execution sequence. In practice, this refers to the requirements of systems as follows:

- Pre-emptive operations, planning, and updating production schedule in real-time based on experience.
- Developing ‘plan-B scenarios’ in real-time and adjusting production plan quickly

- Integrating communication between each machine in the line to understand what might happen next.

3.4.3.2 Robotics

Robots are typically working as slaves in these types of production lines. The optimization of this discipline mostly relies on the movement and responsibility of the robots. The result of the interview indicates that one of the most important issues that need to be taken into account is the speed of the robot arms in movements and optimized timing. Today, movements for robots are programmed at the maximum speed of the robots without real-time consideration of subsequent movements. The basic movements of the arms have to be optimized not only based on the stacking area optimizations but also based on the minimum cost (including maintenance, etc.) of the movement for the production lines.

The robot movements in the execution could be optimized in terms of the timing of the robotic arm movements with consideration of the concept of time in different layers.

By using interoperability between machines in production line, the robot movements may have different modes: full speed, high-reliability night-shift mode, communication with robot and other machines for line level availability. This information could be used for pre-emptive planning and automatic routing changes in the case of multi-processors.

3.4.3.3 Bender lines

The timing of bending and other 3D operations plays a significant role in the flow of work in SMF. As the throughput rate of bending normally is lower than the other manufacturing units, optimization needs to rely on the timing and scheduling of the machines.

The role of bending time in production scheduling, possible buffer allocations and job sequencing is a promising field of optimizations for this section:

- Output sequence of jobs
- First stacking time measurement: Re-nesting parts on sheets
- Multiple parts into stacking
- New stacking buffering: Temporary to the sorting area.

4 Architecture for cloud manufacturing

4.1 Conceptual model of optimization

Based on the requirements and possibilities of cloud manufacturing, a prototype system for cloud-based production planning and control of SMF production was created. Figure 5 demonstrates the process of providing optimization services based on customers' requirements. According to the principle of manufacturing resource transfer, service-oriented cloud manufacturing includes three main parts: manufacturing resources and capabilities as input, resources operating platform with multi-optimization levels, and the output of manufacturing services based on demand.

The manufacturing resources and capabilities which are provided by a cloud service provider are virtualized in the cloud manufacturing platform, and they are available for retrieval by cloud service users. The capabilities are the ability to integrate resources and disseminate results when a task is completed. Capabilities across the whole manufacturing process are always bundled with particular resources. In other words, resources are the basis for achieving capabilities. In order to optimize the manufacturing resources and capabilities, the optimization issues are classified into different optimization levels. The multi-objective optimization levels provide support for achieving the on-demand use and circulation of manufacturing resources based on distributed customers' requirements. The following sections will present optimization possibilities in different levels.

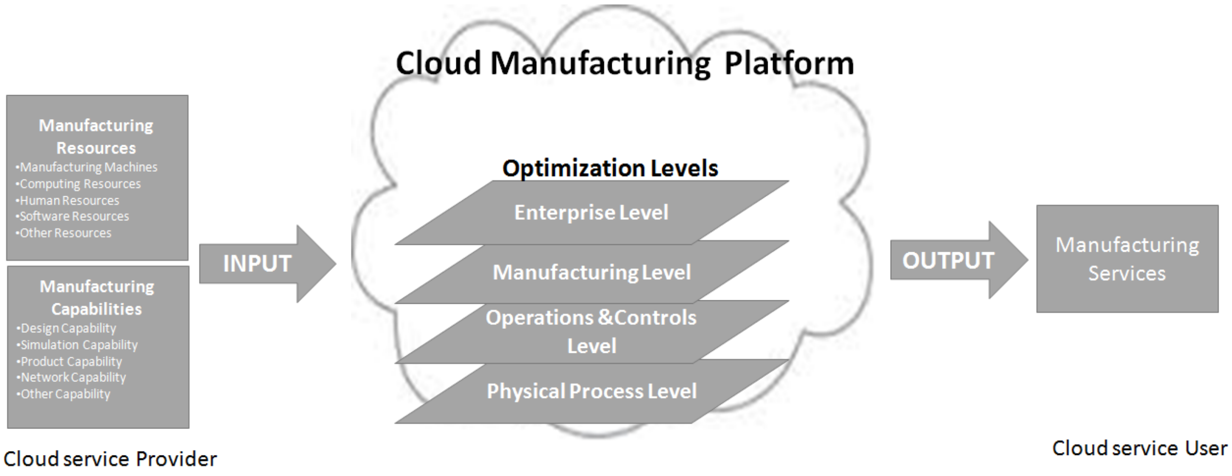


Figure 5. Conceptual model of optimization in cloud-based PPC.

4.2 Optimization Services in Cloud Manufacturing

Cloud manufacturing concept presented in this paper is a centralized platform supporting domain specific optimization tasks. Comparing this approach to agent based systems or distributed scheduling, the main emphasis is on shared real-time view and possibility to utilize the information rather than interaction between different decision making entities. Cloud manufacturing approach enables certain technical possibilities, but does not solve all behavior related challenges as information asymmetry and different power constellations which take place in supply chains. The extent of shared information must be agreed between partners. Additionally, the scheduling objective function can be adjusted and parameterized. This means that each participant may include those parameters, which are important for their business. For example, a company producing high volume HVAC (heating, ventilating, and air conditioning) components can appreciate fixed daily schedules aiming low raw material waste rate synchronized with assembly operations in downstream. On the other hand, a contract manufacturing company can charge more for fast delivery and raw material utilization is not that important in high-mix low-volume (HMLV) production.

Parameterization of production planning and scheduling is a complex process and it depends on company strategic objectives. There are different level optimization tasks in terms of temporality of the decisions and some of them may be contradicting with each other. Table 2 illustrates possible layers and examples of objectives at each level. The proposed layers indicate the hierarchical structure of an integrated platform of optimizations particular to this type of manufacturing. Based on the reference architecture proposed in the research motivation, a generic multi-objective optimization system has been built by using genetic algorithms (GA). Each domain can use the centralized system for proposing solutions. Templates for optimization problem formulation may be provided in the cloud system. However, the actual parameterization of objectives functions for each decision layer remains as a company level decision.

Table 2. Optimization objectives related to SMF in different layers.

Layer	Frequency	Optimization objectives	Optimization targets
Enterprise layer	Strategic Annual	Maximize return on investment (ROI) Maximize profit	Ensure current proposed product type, product mix and product volume can maximize the profit.
Manufacturing layer	Tactical Quarterly	Minimize lead time Minimize total proceeding time	Management of the manufacturing process. It is a central line for the whole life cycle of manufacturing.
Operations and control layer	Operational - production Daily	Maximize the performance – lead-time, capacity utilization, material utilization	Guarantee the efficient operation of the whole manufacturing system. Improve the communication with machines
Physical process layer	Operational – design Daily	Maximize the machine utilization Minimize the working time Maximize the material utilization Minimize the material cost	This contains the structure design and modeling and finite element analysis of product. It is the core object of manufacturing. Optimization in this category is also known as structure optimization.

Optimizations in each layer of operation have to be done separately, but the data and results must be shared among the all the decision levels as shown in Figure 1 (Section 3.2). In general, a supervisory level of Enterprise Resource Planning (ERP) acts as a gateway of data and information for a SMF. This layer of optimization (automation) also coordinates possible intra-enterprises data transactions and prepares the data for other levels for their real-time optimization.

4.3 Technical implementation

In order to present the technical implementation considerations of this platform, a demonstration system or a prototype was built. Each system has local level control and work queue. Machines receive instructions from the cloud-based production plan and requests from production control. Then the machines feed in information on actual progress vs. planned activities (See Figure 6). The actual progress information is retrieved from a network of sensors. To achieve effective management of the sensor data described above, the cloud manufacturing platform needs to offer the following two primary functions: (1) the effective distributed storage of sensor data, and (2) the efficient parallel search, filter, and statistics of sensor data (Bao et al., 2012). The cloud computing model is used to get all the local factory-related data and provide optimized results to improve machine performance.

Cloud computing is used to provide on-demand service of computing facilities and database. The machining optimization can suggest an initial setting and accept feedback from the real machining process.

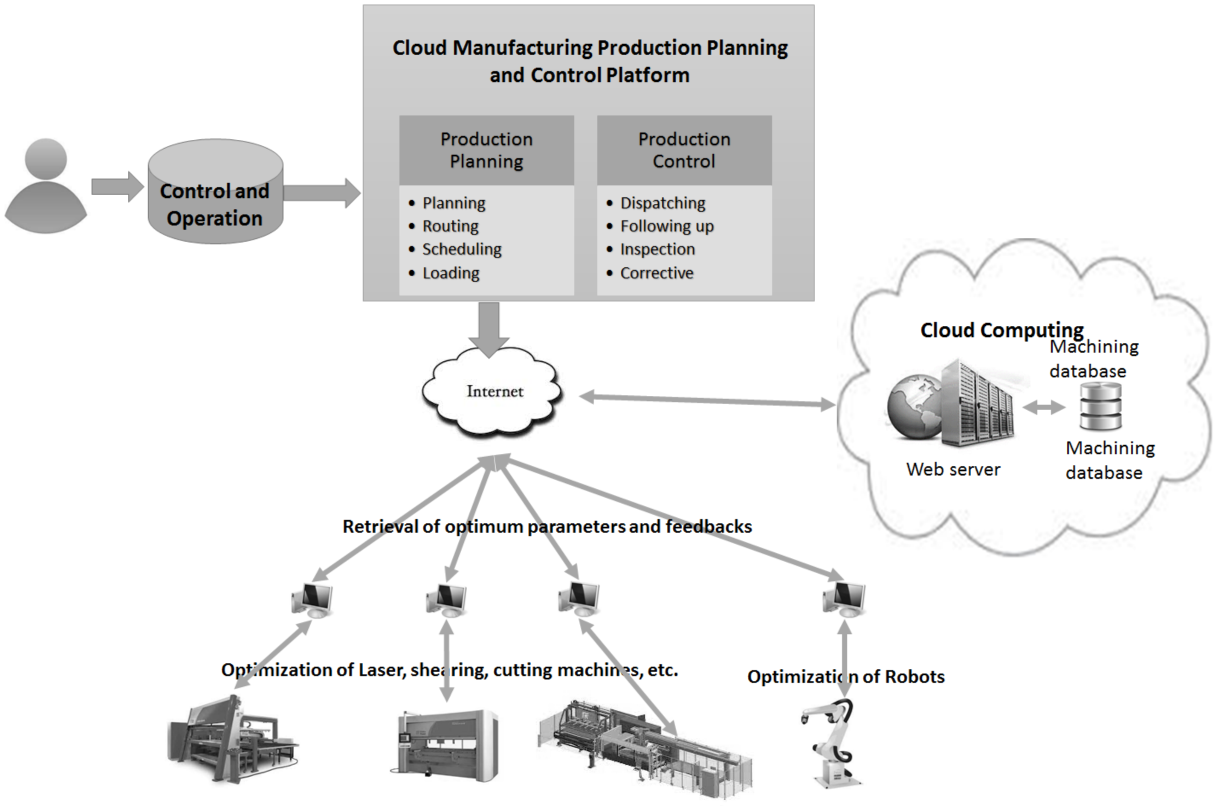


Figure 6. Structure of cloud computing-based optimization system.

A holistic view of the key aspects of conceptual system structure is depicted in Figure 7. It allows a wider perspective of implementing the cloud-based PPC into the cloud manufacturing concept. It describes the cloud manufacturing as a whole manufacturing process. The customers and suppliers have a different API to plug into this cloud manufacturing platform. Several cloud services are also integrated into this platform with the aim of optimizing production processes, factory planning, and design. Centralized computing power can be used to solve production planning, allocation scheduling, tooling and setup decisions. Algorithms may be updated, and all the machines may obtain the benefit of the latest versions as these are offered as cloud services.

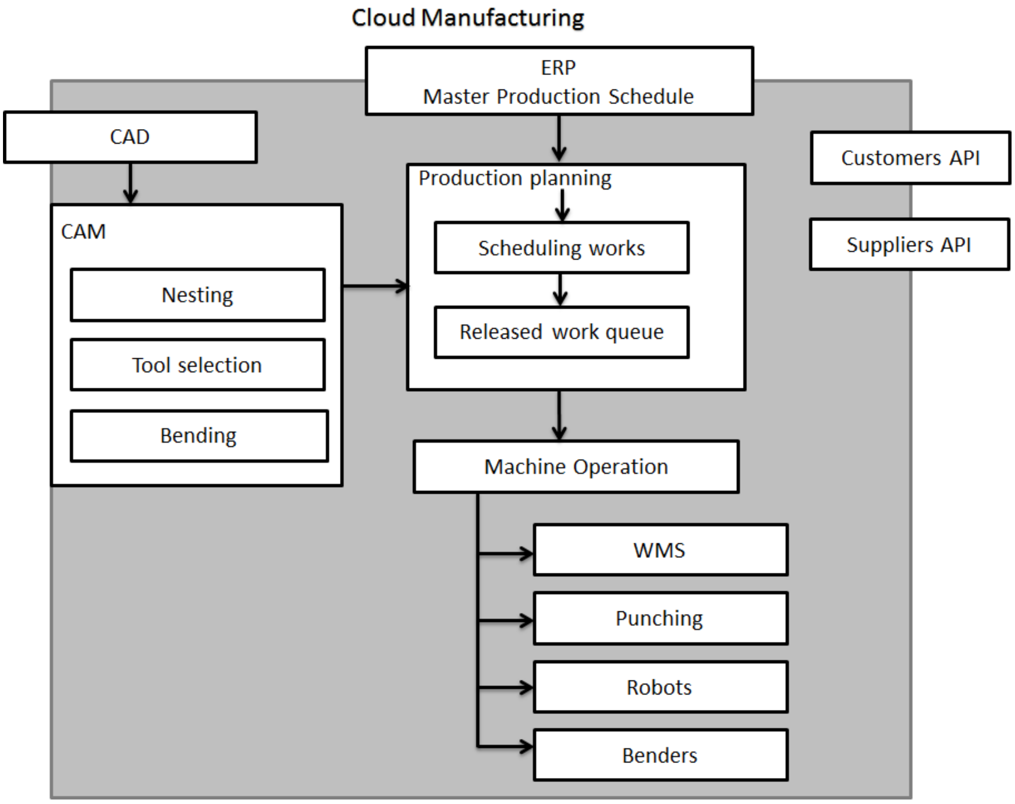


Figure 7: Cloud-based PPC structure in the scope of sheet metal processing.

Based on the collected requirements and specifications, a common data model is developed for integrated production control system. The main entities and their relationships are described at an abstract level in Figure 8. All machines and planning tools need to share the same structured data in both planning and execution phases.

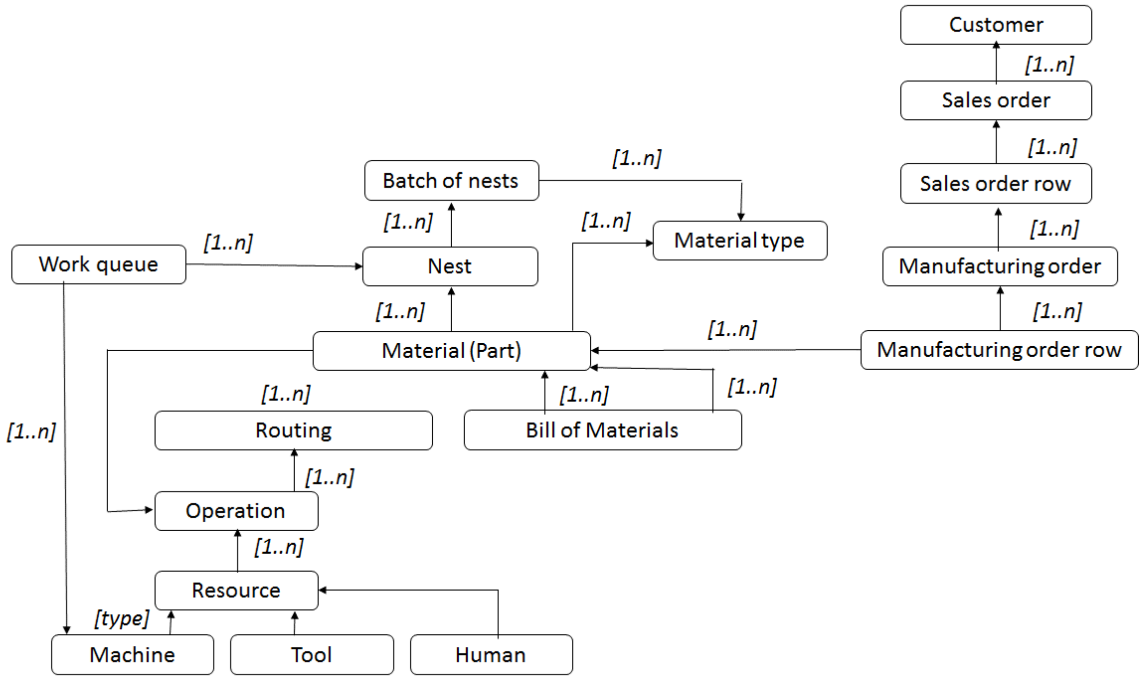


Figure 8. Entities related to cloud-based production planning and control.

The prototype system was developed and tested with actual data collected from an existing production line. The validation of the scheduling system was conducted only in simulation, not in a real production environment. Some observations from piloting showed that production lines may be complex and consisting machines of different generations and types. Flexibility of configuration and adjusting the platform for each situation is an important property. Ability to adjust is related to communication, line configuration and company specific optimization objectives. Testing showed the importance of ability to operate easily in different and changing environment.

5 Conclusions

A new smart manufacturing model - cloud manufacturing has been proposed to fulfill the requirements of networked and dispersed production in sheet metal manufacturing. The cloud provides a collaborative environment that can give people who manage a sheet metal manufacturing (SMF) agility, more transparency, and empowerment through more effective collaboration.

In this paper, the functions and requirements of a cloud-based production planning control and continuous operational optimization are presented in the sheet metal manufacturing context. With the aid of the concepts, the technical conceptual structure and data modeling were established when implementing the prototype system. Based on the initial piloting test, the strategy presented in this research could help manufacturers to build capacity within their organizations, and to securely and reliably collaborate with other manufacturers, and stimulate the growth of the cloud for the next wave of business productivity and optimization.

It is very important for both academics and industries to notice that the application of cloud manufacturing will be a long-term process, and it will gradually develop in many factories. In order to be successful, factories should have a good foundation for the internal integration of information and processes. Therefore, there is a relatively high entrance standard to implement cloud manufacturing for a majority of manufacturing companies. For a sheet metal manufacturing environment, a vision of plug-and-play supply chain requires integrated information management and process management. The real-time scheduling and modular approach will be developed to enhance the flexibility of the system further. A centralized cloud-based system gives opportunities to accommodate different algorithms and try to improve or integrate cooperation between different algorithms.

The future development of cloud manufacturing will face many challenges in key technologies. Security is the major challenge in any networked computer system. Because cloud manufacturing is highly reliant on networks, it also involves the security issue. The greatest challenge facing cloud manufacturing is maintaining internal security. Maintaining security and protecting data in cloud manufacturing are both important for two reasons: (1) data often represents a large amount of money due to labor intensive tasks, and(2) data often represents knowledge and provides companies with a competitive edge. Based on the experiences from this study, it is believed that further research into cloud manufacturing will accelerate the development of an intelligent, networked, service-oriented, digitalized manufacturing industry.

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Toward a cloud-based manufacturing execution system for distributed manufacturing

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ABSTRACT

This paper illustrates the needs and challenges for the management of distributed manufacturing in a multi-company supply chain and processes these further as features of new IT systems. Requirements are collected from manufacturing companies and combined with insights from literature in the field of current ERP/MES system drawbacks, advantages, needs and challenges. The findings show that the needs and challenges in data integration inside SME networks are closely related to the limitations of current supply chain solutions. Current ERP-solutions lack extended enterprise support and a shared cloud-based approach. On the other hand, current MES solutions can operate the manufacturing process, but not for distributed manufacturing. As an answer to the requirements, we made a proposal for the core of architecture for next generation of MES solution in this position paper. Moreover, a pilot software tool has been developed to support the needs related to real time, cloud-based, light weight operation.

1. Introduction

Today's business supply chains for complex products are likely to involve a number of autonomous organizations. The competitive market requires that these supply chains are highly agile, effective and efficient. Agility and effectiveness are obtained by forming highly dynamic virtual enterprises (VE) within supplier networks [12]. All these highlight the importance of information technology in integrating suppliers and other partners' firms in a virtual enterprise and supply chain [11]. Interoperable enterprise systems are the key to enterprise integration [39].

Supply chain management (SCM) is a way of obtaining horizontal integration benefits without its formal ownership costs. SCM, the integration of key business processes among industry partners, adds value to customers, tightly links together several consecutive elements of the industry value chain, from upstream suppliers, to subassembly manufacturers, to final manufacturers, to distributors, to retailers, to end-customers, in order to make the processes more efficient and the products more differentiated [2]. The internet has brought forth numerous possibilities to increase this flow of information, and encouraged companies to form closer integration of their information services (IS). The adoption of the internet and turbulent market conditions have forced small and medium-sized enterprises (SMEs) to adapt their way of undertaking business, from traditional practice to e-business [4]. Arend and Wisner [2] suggest that many firms with 500 or fewer employees, i.e. SMEs choose to make SCM part of their strategy implementation, while other SMEs shun it.

The development of the enterprise resource planning (ERP) solution has created an opportunity to manage supply chains within and beyond the organizational scope [30]. This high value-oriented supply chain enables a high level of integration, improves communication within internal and external business networks, and enhances the decision-making process. In this way, the management of VE beyond different partners can be improved.

Current ERP technology provides an information-rich environment that is ripe for very intelligent planning and execution logic. Yet little has changed since the late 1970s in terms of the logic associated with such applications as forecasting, reorder point logic, MRP, production scheduling, etc. The current systems are now just executing the old logic much faster and in real-time. The area is ripe for innovative new approaches to these old problems [18].

Theoretically, ERP can solve the strategic problem at the upper level, and mainly handle internal and external relevant resource issues. Nevertheless, there are many limitations of ERP. It is precisely because of integration that the ERP system provides an industry standard for specific types of business. On the other hand, it also limits the flexibility and lowers the competitive advantage

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of an enterprise. ERP may also limit progress in SCM from the strategic perspective [1].

Particularly in the manufacturing industry, current ERP-solutions appear short in terms of supporting multiple plants, multiple suppliers, and lack functions such as inventory control, management planning and production order processing. Therefore, to manage the factories, manufacturing execution systems (MES) are designed to perform functions such as production control, maximize the workload of equipment, release unneeded machine tools, etc.

Nowadays, the problem is how to integrate all these applications and solutions in a single platform in order to bundle all virtual enterprises into one supply chain and manage them centrally. The research question addressed in this paper is: *what are the needs and challenges of integration for integrated supply chain coordination for distributed manufacturing networks?* The object of this paper is to present a new system based on current solutions to solve problems of integration of distributed manufacturing networks through VE form by using new technologies and new infrastructure.

Various system solutions are evaluated in this paper. After discovering the limitations and shortages of each solution, new requirements and challenges are summarized from real cases. In attempting to highlight the practical issues, Six cases are analyzed. Interviews and discussions with key managers and operators in these companies are used to collect and assess the information. Each of these companies contains a network of manufacturing supply chains. The case study reveals some important and unique requirements. Consequently, a new cloud-based solution with new infrastructure is proposed to fulfill these market requirements. This solution is named as NetMES.

Our paper has two major contributions. First, we discuss the limits of current software solutions as applied in distributed manufacturing. Second, we give guidelines on how to develop comprehensive software. This new solution integrates both the concept of ERP and MES. We report this empirical solution and provide a prototype to fulfill the gap between practices and academic research.

The rest of the paper is organized as follows. Section 2 introduces the current situation and approaches to managing virtual enterprises. Section 3 describes the method used in this paper to collect data. Section 4 performs an analysis and discusses the case studies. New challenges and requirements of distributed manufacturing networks integration are then summarized. Section 5 presents a solution and a prototype. Finally, Section 6 presents a brief summary and conclusion.

2. Current situation and approaches

2.1. Centralized ERP

The rapidly changing needs and opportunities of today's global market require a higher level of interoperability in data systems to integrate diverse information systems to share knowledge and collaboration among VEs. This includes partnership with the business partners which live in this dynamic environment on a day-to-day basis [35]. Although the core of VE is to effective exchange information, it is not an easy task due to the heterogeneity of information resources.

ERP provides a comprehensive transaction management system that integrates many kinds of information processing abilities and stores data in a single database [1]. In the era prior to ERP, information processing and data were typically spread across several separate locations.

The installation, re-programming and configuration in current ERP-solutions are very complicated processes that take too much time and planning resources. The solutions are usually hierarchical and centralized entities. ERP integrates all up-to-date information in a single application. Theoretically, this single major source ERP can feed SCM solutions. However, current ERP-solutions do not scale up very well to the whole networked supply chain. Indeed, the jointly agreed standards on data integration also delay the implementation of the next generation of SCM-solutions. Different kinds of SCM-solutions are not automatically interconnected, which makes data integration harder to achieve. One of the fundamental issues in networked supply chain coordination is that current solutions do not take manufacturing processes into consideration sufficiently so that lean production would be practically functional [47].

Akkermans et al. [1] highlight four limitations of ERP: (1) lack of extended enterprise functionality; (2) lack of flexibility in adapting to changing supply chain needs; (3) lack of advanced decision support capabilities; (4) lack of open, modular system architecture.

The needs of networked supply chain coordination are associated with innovative processes in which new materials and components are designed. There is a need for interfaces for intelligent applications that will transfer the information into knowledge that can be used in decision making. Employees must be integrated with user-based interfaces with intelligent devices and applications when there is a need for new education methods that will be used in fast information distribution [33]. Panetto and Molina [33] suggest that the future of SCM software lays in malleable and intuitively user friendly software tools that can become an integrating factor, rather than a barrier, to development. Jacobs and Weston [18] predict a greater focus on SMEs in the development path of ERP developers, something that may bring simpler and lighter commercial versions to the market and end up making this kind of solution more attractive.

Izza et al. [17] posit that the challenges of EAI-technologies lie in heterogeneity dissimilarities and lack of semantic interoperability. Different applications execute their own data and process models, which leads to different applications not being automatically interconnected. Primarily, supply chain coordination is based on the trust between different actors in a networked supply chain. This highlights the need for the secure data interchange and standardized services between the actors [39].

ERP-solutions should support other solutions and operating systems more extensively. This would lead to the easier execution of integration of different systems and applications [43]. Consolidation of the ERP-software providers will affect the development of ERP-solutions. ERP-solutions are equivalent in the needs of the biggest global companies, but they do not necessarily answer the needs of local SMEs. Universally applicable ERP-modules do not fit to the last detail the needs of local SMEs [18]. The increase of service-oriented solutions will enable the systems to be more easily configured. In the future it will be easier to bring the solutions into services because the modules will be tailored more specifically for certain branches of industries. Future solutions must become more intelligent. Data mining, intelligent tools and expert-systems will contribute to decision making. Simulation will be a significant element in integrated networked supply chain coordination [18].

2.2. Connection between upper level and lower level in the organization

Even though ERP is used to integrate dispersed information, manage all the centralized information and improve the management within the organization, it is more relevant to the upper level (management level) of the organization. However, in many organizations, the detailed and traceable data about production at lower level, such as the shop-floor control, are unavailable. And yet these data are precisely the key cost drivers in manufacturing environment. In today's complex manufacturing operations environment, it is necessary to find a new way to meet the changing production demands in real time.

Manufacturing execution systems (MES) are software packages used to manage factory floor material control and labor and machine capacity, and to track and trace components and orders, manage inventory, optimize production activities from order launch to finished goods, etc. Some of the larger ERP-solution providers have incorporated MES-related capabilities to offer this specialized functionality and fill the shortcomings of traditional ERP-solutions [9].

The integration of ERP and MES requires the easy sharing of information across the systems. MES systems typically take production orders from ERP systems and link quality control, scheduling and material information. Receipt of goods and some low level material handling functionality, including serial number generation for products may be supported as well. Performance dashboards and advanced statistics reporting may be included in the system to provide an overall view of production cells and lines [28]. It is an information bridge between planning systems and manufacturing shop-floor control systems.

Using MES provides benefits to SMEs in supporting different types of production and processes. It reduces manufacturing cycle time and data entry time; it optimizes the inventory and warehouse; it improves product quality and empowers the plant operation people; it improves customer services and quickly responds to unanticipated events [29].

The latest developments in MES systems have included building flexible workflows and applying the latest software technologies to support distributed manufacturing. Holonic MES is a non-hierarchical (hierarchical) system, and it supports flexible hierarchies, which can be formed dynamically through aggregation. It possesses the characteristics of MES and also the properties of failure recovery and security certification [6]. Cheng et al. [6] developed a system framework for computer-integrated MES to support integration. Later, Cheng et al. [6] continued integration work between multiple MES and ERP systems for interoperability. The concept of holonic manufacturing system in this context means building workflow-based protocols for flexible communication between ERPs and MES servers. Valckenaers and van Brussel [38] have also worked on the same theme. Their solution adopts hierarchical design and relies on agent technology on communication and decision-making which means orders, machines and product parts each are considered as a corresponding computing agent in the control system. This method is used to predict the workload of the machines and forecast routings of the products. For a near future solution, Valckenaers and van Brussel [38] suggest systems that are able to route and schedule themselves by taking into account any changes. Holonic systems are heterarchical when applied to a small system as discussed in this paper but have flexible hierarchical characteristics by using aggregation when larger. Component based software supports this type of architecture [10].

User interface development has also been discussed in the literature. User interface and general usability of MES software systems is a very important feature. For example, Cooper [7] has patented some transaction control features of a user interface. Later, when web technology has matured, web access systems and mobile terminal access have received increasing interest. There are patented solutions available on this side as well [8]. Lan et al. [22] propose an integrated manufacturing service system which is a Java-enabled solution, together with web techniques, employed for building such a networked service system.

However, existing MES lacks the capability of adaptability, reorganization and configuration. It is unable to adjust its architectures and functionalities following changes in enterprises, businesses and organizations, thus hindering the wide adoption of MES software [23].

Simply integrating ERP with MES not solves the potential issues, such as the time lag between the actual occurrence of shop-floor control data and its recognition in the front office ERP systems at the management level. Broadly speaking, a clear picture of the entire shop floor is not available in real-time. High level managers cannot see what issues exist on the floor and what inventory shortages might impact delivery to the customers.

One the other hand, the information from front office may not be communicated to the shop floor until the MES download the data from ERP. Changes in ERP have been made in real-time do imply the real-time in MES. This disconnection may cause other issues.

Due to the lack of capability of adaptability in current ERP systems and MES, new technologies are introduced to improve the capability.

2.3. Cloud-based solutions

Cloud computing represents a combination of various IT technologies: hardware virtualization, distributed computing (grid computing, utility computing), internet technology (service-oriented architecture, web services, Web 2.0, broad-band networks), system management (service level agreements, data center automation) and open source software [24,45,46]. Cloud-based solutions can be described as web-based applications that are stored on remote servers and accessed via internet by standard web browsers [24].

Cloud-based solutions run on a SaaS (software as a service) layer in the cloud architecture. They are demand-driven and charged by metered time, instances of use, or defined period [15]. The set of functionality provided by cloud-based solutions is richer than in-house counterparts [27], and it is faster, simpler and cheaper to use [3]. By adopting a cloud-based solution, the shortage of current ERP-solution can be covered.

The main benefit for companies in choosing a cloud-based solution is that almost no local IT resource investment is required [24,40]. Companies can utilize the flexibility of cloud resources dynamically to meet peak demand without investing in in-house resources [40]. Also, a cloud solution can handle the weaknesses of their current system regarding redundancy and high upgrade cost because Cloud is a virtualization of resources that maintains and manages itself [44].

Nevertheless, most of the challenges and risks are basically security concerns due to the migration from one business model to another. Besides, companies lose the governance over their valuable data and they have to accept that the cloud solution provider will control a quite large number of important issues and areas of their own business process [26]. Some relevant issues are vendor lock-in, compliance challenges, and cloud provider acquisition [19].

Cloud computing is already practical in many business applications. Nowadays the major application vendors are actively building cloud-based application infrastructures, exploring relationships with cloud hosting providers, and promoting SaaS based software [14].

Xu [42] raised the concept of smart manufacturing with cloud computing, which is cloud computing adoption in the manufacturing sector. It is interesting to know that with a cloud-based solution, manufacturing companies can eliminate the IT resources and outside support and maintenance, but in the meantime companies are able to develop better-integrated and more efficient processes [34]. Based on a particular case in the Elkay Manufacturing Company, which adopts a cloud-based solution, an average IT person's workload has shifted to higher level functions, and his or her skillset and knowledge base have evolved significantly in the process [34].

Based on Moad's observation [25], manufacturers were still new to cloud-based applications in 2011. But now, they are no more concerned with cloud in terms of its performance, uptime or security of the public networks, but rather they are much more interested in how and when vendors will continue to enhance the functionality of cloud-based systems, particularly with things like business intelligence and industry-specific capabilities.

For manufacturing companies, cloud-based MES solutions allow the standardization of manufacturing sub-processes across multiple plants in many countries. This concept is attractive because it acquires manufacturing assets around the world and leverage best practices internally within the entire organization [14].

However, there are still many challenges connected with bringing MES to cloud. MES tends to be highly industry and process-specific, which means highly customized for a specific process running at specific plants. It needs to be able to quickly change when processes or requirements change [25]. However, customization is still a limitation for cloud-based solutions.

3. Methodology

Due to the nature of the research question addressed in this study, it is appropriate to conduct qualitative research. That is, qualitative research is employed to understand people and their social and cultural context [31]. In this paper, it is important to understand, from the case companies' perspective, what are the new requirements and challenges they perceive when using new technology to manage the organization. Quantitative research, on the other hand, is intended to obtain numerical outputs and the meaning they represent [36].

To collect the needs and requirements for distributed manufacturing, interviews were conducted at six different small and medium sized companies, which all have their own products and manage suppliers as a focal point in the manufacturing chain. From a manufacturing point of view, all the companies have organized their production processes as flow shop type organization. Different products follow very similar routings and use similar resources. The company products at each case company included manufacturing of the following products:

- Electrical appliances,
- HVAC pumps,
- Boats,
- Customized metal profile products,
- Heating equipment,
- Electronics control systems.

The interviews were conducted with several stakeholders in each company during 2010 and the results were recorded in the form of requirements specification. We search for patterns in these companies and summarize the consistent requirements. This is not a typical approach for case study research, but commonly used in software engineering when building common understanding of the required features for a system. These six case companies are in different phase of enterprise systems development. So there are different levels of expectations. Although the number of companies studied is small, for a requirements specification phase the companies cover a reasonably wide range of manufacturing characteristics and the key requirements are captured. Therefore, these six cases are sufficient for the purpose of our analysis. Certainly, for wider generalizations, a survey type of research method, probably with industry specific questions, should be conducted.

4. Requirements analysis

The result of the requirements collection from six companies was organized as common requirements specification document. Initially, the collected data set was recorded, which was then consolidated in a requirement document for further refinement.

4.1. Functional requirements

From the interviews, it was noticed that most of the companies base their IT-architecture in several heterogeneous applications. The whole SCM system is comprised of several applications, services and sources of information. Many different kinds of ERP-solutions, SCM-applications, electronic business applications, portals and transactions between companies in the network will make the whole architecture a complicated entity. This leads to even more complicated data flow and systems integration, especially in the manufacturing related activities.

The specified requirements from each case company were collected individually. There are four important requirements that need particular illustration:

- Company A would like to increase transparency in the supply chain by automatizing stock and sales information gathering. In addition, it wants to create an electronic insurance registry and update all the insurance information into this database, Company B would like to create a practice that will show a production schedule to suppliers on a weekly basis. With utilizing such a system the supplier will be able to supply components more accurately.
- Company C has trained its employees to use the current ERP-system more effectively. Their ERP-system includes a feature that enables different partners to coordinate and supervise information in the supply chain. The information includes, for example, ordering information and status updates. The company would also like to determine the development of the ERP-system from the customer point of view. In addition, there is a need to optimize call-off stock.
- Company D would need transparency of quality data in multi-factory environment. The purpose is to increase ramp-up performance.

In order to systematically analyze the requirements, eight general requirements for distributed MES system design are summarized in Table 1. This table illustrates the collected requirements and the frequency of their appearance in all case companies.

4.2. Real-time requirements

Being able to show real-time information from production is an important feature for any MES system. In context of distributed cloud-based MES, Real-time information exchange between companies is both functional and non-functional requirement at

Table 1
Requirements for distributed MES.

ID	Requirement	Freq
1	Order tracking in supply chains	5
2	Real time view on work queue	5
3	Capacity view	4
4	Materials traceability, serial numbers	3
5	Test records	1
6	Sales order – EDI connection	2
7	Purchase orders – EDI connection	2
8	Product information – work instructions for suppliers	2

the same time. It is a functional requirement in a sense that user interfaces are needed to see production status at suppliers and other parts of the supply chain. It is a non-functional requirement in the sense that the information synchronization should be transparent between suppliers, manufacturers and sales units.

The reliability of real time manufacturing data is important when the information flow is being automated. The message receiver must have trust that the transferred information is authentic. It would be ideal if all the counterparts had the same cloud based system and the data model in use, but in practice that goal would be impossible to reach. Companies have different types of ERP and MES systems which need open interfaces for integration. Open interface definitions are in a central position in order that the integration can be executed using the best technology with the most cost effective partners.

4.3. Analysis

The following features were proposed as critical to such a program: (1) the system should be easy to change: when the business changes, the system should evolve as well, not hinder; (2) a production employee should be able to change the production flow related fundamentals of the program without aid from an IT-professionals; (3) supply chain information sharing should lie at the very base of the program (accessible through the Internet); (4) the system should be based on open source code for legal sharing of modules and solutions; (5) the system's user interface should be the internet, (6) the system should be made entire new, without old remnants of source code, as in today's ERPs; (7) the software should always be up-to-date: if the system is light and internet based, it will be; (8) the system should support flexible and lean production options; (9) the information database should contain highly detailed data; (10) the electronic accountancy and inventory should be closely tied to the physical dimension (by efficient tracking systems). Furthermore, users require access of this system via the internet without restrict of location. Simultaneously, the protections of users' sensitive data and information are required.

To summarize the results of the analysis from cloud technology point of view we can see that the mentioned requirements have some features, which are not part of standard MES systems and where cloud technology could offer some solution.

- Routing of manufacturing operations may change within the supply chain and the companies that need to access the data may vary from time to time.
- Transparency between operation steps occurring at different locations has traditionally seen as supply chain or purchasing management issue, but in distributed production, a common view on production schedule helps planning.
- Quality and test data need to be shared between manufacturing partners along the routing.
- The participating companies of manufacturing network may vary from project to project and ability to reconfigure the access should not require IT projects.

Current EPR and MES systems are not very good at this type of fast structural change. Information sharing between partners working together in common projects is actually a typical feature for cloud based social media sites rather than operational manufacturing systems. The concept of linking and sharing data between entities in a similar way would have novelty.

5. Prototyping a solution – NetMES

5.1. Concept and objectives

To fulfill the requirement and challenges presented in the results part, a software tool was designed to illustrate a potential solution. Although this solution has focused on key requirements, it includes new business process and planning, sequencing algorithms, and a new infrastructure based on existing MES technology. If successfully implemented, such a software solution could prove very beneficial to multi-company SME-intensive networks (Fig. 1).

The NetMES system was eventually implemented in one of the interviewed companies and its network. In this solution, the cloud plays a role as a platform in the evolution of MES. Since cloud computing is already practical at the business application level, it is very reasonable to build MES based on web services and provide a standard for information sharing/transferring environments. Cloud technology will be adopted in order to support monitoring, information exchange and also other real-time interactions.

Andon systems are core elements in this NetMES. They are used when a problem occurs in the production lines. "Andon" is a visual

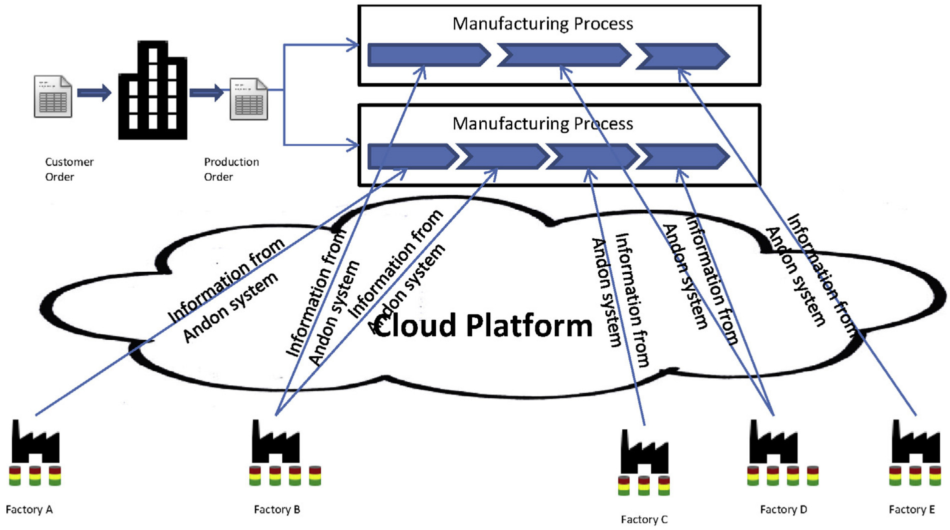


Fig. 1. Integrating ERP systems with MES systems.

control that is used to notify the status of machines and manufacturing line in the manufacturing process. This concept was first invented by the Japanese for Jidoka (automation in English) and refers to the principle of stopping work immediately when a problem occurs [37]. Andons are used by Toyota and quickly adopted by many Japanese and American manufacturing companies [21]. They can be used to control the quality of production and improve the defect detecting processes.

Andon comes with an alarm to alert workers when there is a change in status. When the alarm is activated, it directly indicates a problem on a particular production line. A worker can stop the production line to call for help to adjust a machine or fix a quality defect [21]. Then workers study the problem and solve it together. Although productivity is lost due to line stop page, the overall system performance is improved [21].

In this NetMES solution, the Andon systems will recode all the production line problems and send the real time status of each production line back to NetMES. In this way, high level decision makers can provide a critical response to problems and avoid costly downtime.

This solution is based on the concept of virtual enterprises, which combines the power of several independent enterprises to achieve complex manufacturing processes. When an organization receives a new order from a customer, the order can be converted to production orders, and different factories will be selected and assigned to the manufacturing processes. Conversely, this MES can be used to collect real-time information from the Andon system and transform this information to the higher level organization.

5.2. *NetMES functionality set*

Most manufacturing companies use ERP or an equivalent system to determine product manufacturing and the production planning process. NetMES is used herein to translate this plan into work instruction, and elaborate the method of dealing with real resources and real plant floor execution. The NetMES system is a web browser based MES system for distributed (multi-site) production planning and control system. The key features of the system include:

- Support for multi-site manufacturing,
- No installation required – a web based system,
- Connections to external systems such as ERP,
- Tracking and tracing within the entire extended enterprise,
- Providing KPI data master for production.

From the theory point of view, the NetMES application is a shared production view for managing the extended enterprise. The term "extended enterprise" represents the concept that a company is made up not just of its employees and its managers, but also its business partners, its suppliers, and even its customers. The extended enterprise can only be successful if all of the component groups and individuals have the information they need in order to do business effectively.

The NetMES concept relies on external master data for materials, bills-of-materials, customers, suppliers, which all should be stored in the ERP system. The system focuses on capacity management, work queue, and traceability information within the extended enterprise.

NetMES occupies a very important technical position. In attempting to connect the factory floor to the executive levels of the enterprise, it occupies the space between low-level control automation systems and high-level ERP system. It acquires product orders from the ERP system, and converts this product demand into an execution order and passes process instruction to the control automation system. After product operation and execution is done, the product status is updated and information is sent back to NetMES. Later on, the order status will be fed into the ERP system.

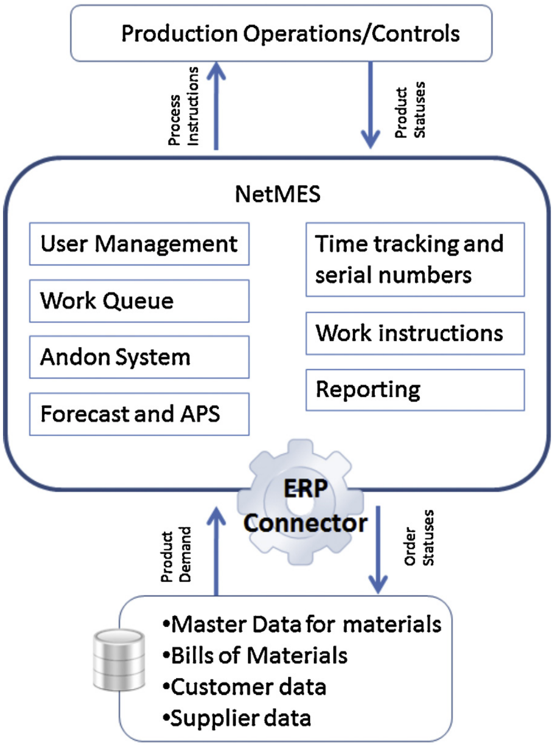


Fig. 2. NetMES key functionality blocks.

The positioning of NetMES is presented in Fig. 2. This figure also shows the main functionalities provided by NetMES. The NetMES system should offer functionality for managing the order flow similarly for people within the company as well as the suppliers, retailers, etc. The planned key functionality blocks in the NetMES software package include: (1) user management, (2) work queue, (3) Andon system, (4), forecast and APS, (5) time tracking and serial numbers, (6) work instructions, (7) reporting, and last but not least, (8) ERP connectors.

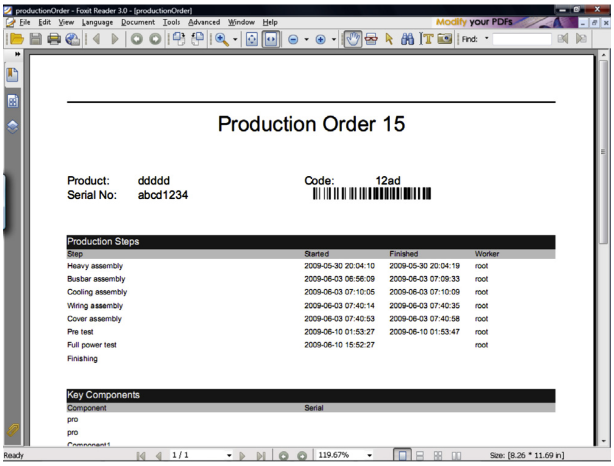
5.2.1. *ERP connector*

The NetMES should be directly coupled to the planning system to retrieve production orders from the ERP system and also all other inputs; in this way the NetMES can provide upload information as necessary. This ERP connector acts as an information gateway, without significant information processing. The communications should be two ways so the MES can keep the planning system properly informed about plant activities such as labor data, inventory changes, and work order progress. Other methods of data entry and reporting can easily be accommodated.

While the planning system has the aggregate data on inventory, the detail can easily reside at the local level—the MES. "Dock To Stock" operations are accomplished here with regular updates to the planning system. A current map of all inventory and storage locations, including WIP, is maintained.

Also, the NetMES provides the workflow visibility and event notification required to ensure that manufacturing meets the enterprise information demands. ERP and NetMES offer varying types of functions and features. The functionality of this part includes:

- Selecting and importing production orders from ERP,



Production Order 15

Product: ddddd
Serial No: abcd1234
Code: 12ad

Production Steps

Step	Started	Finished	Worker
Heavy assembly	2009-05-30 20:04:10	2009-05-30 20:04:19	root
Busbar assembly	2009-06-03 06:56:09	2009-06-03 07:09:33	root
Cooling assembly	2009-06-03 07:10:05	2009-06-03 07:10:09	root
Wiring assembly	2009-06-03 07:40:14	2009-06-03 07:40:35	root
Cover assembly	2009-06-03 07:40:53	2009-06-03 07:40:58	root
Pre test	2009-06-10 01:53:27	2009-06-10 01:53:47	root
Full power test	2009-06-10 15:52:27		root
Finishing			

Key Components

Component	Serial
pro	
pro	
Component1	

Fig. 3. Production orders with planned assembly timings.

- Importing BOM and key components,
- Importing referred materials from ERP,
- Building a link to work instructions in the PDM system.

5.2.2. *Work queues*

A work queue screen displays prioritized job operations scheduled in each factory and the status of production orders. This work queues screen is presented in Fig. 3 as an example. This view can be used at production line level or to present a multi-factory production queue for production managers and line managers. The functionality of this part includes

- Viewing all orders for factory and sort the view,
- Adding a new production order,
- Connecting BOM, routings, work instructions for production orders – applying localized routings and components for each production line,
- Viewing status for each factory – capacity, lead-time, etc.,
- Printing production order documents for tracking,
- Toggling between key components view and production steps view,
- Production scheduling: optimizing the production queues,
- Printing friendly view.

5.2.3. *Andon system*

The Andon system supports quality control especially in volume ramp-up situations and continuous improvement. Each production line has an Andon system to present its working status and to collect data about the product line as shown in Fig. 4. If problems occur, the workers can active the alarm, and the alarm indicators will be displayed on the NetMES. By using Andon functionality the workers on the production lines can record Andon cases and report issues to a centralized database. It provides a critical response to workflow problems in order to help avoid costly downtime by immediately alerting the maintenance and quality teams at the first sign of trouble. Factories producing the same products can compare practices and learn from each other. High level managers can monitor the real time situation in the factories. The functionality of this part includes:

- New cases and descriptions,
- Processing of cases according to workflow (R&D, supplier etc.),
- Controlling Andon "traffic lights" according to status (Red: production downtime required; Yellow: the problem is under process; Green: OK),
- Connecting cases with production orders in the database.

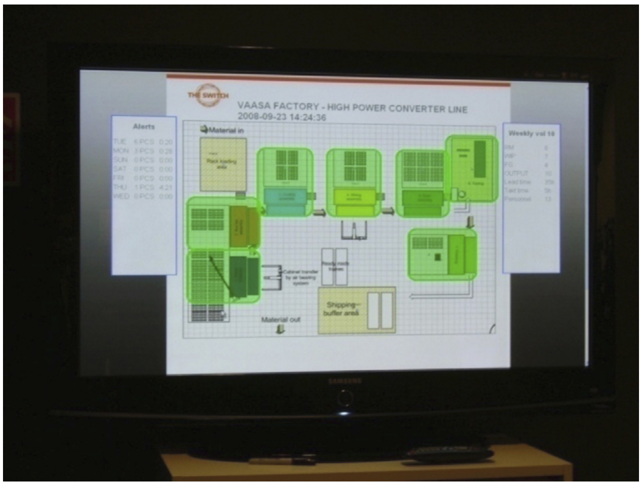


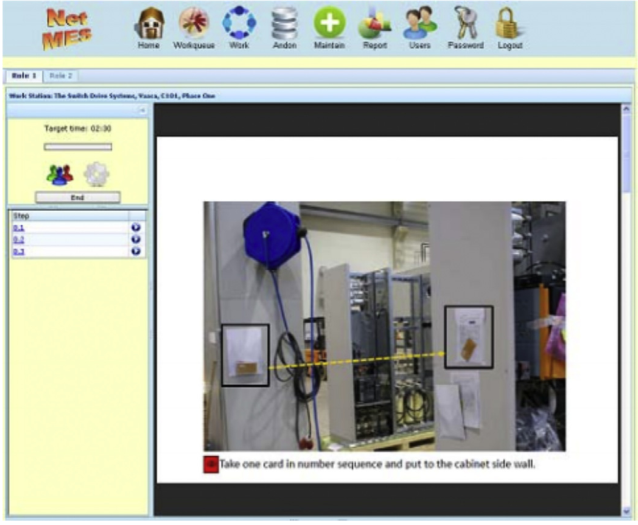
Fig. 4. Andon status displayed on NetMES.

5.2.4. *Worker screen – time tracking and serial numbers*

Because NetMES directly interacts with the execution and operation on the factory floor, it should provide a direct view for workers. This easy to use interface is developed for workers working on the factory floor. It includes touch screen monitors as well as bar code readers to simplify data entry while reducing mistakes. This worker screen includes a list of work to be performed, specific instructions and requirements to execute the work, quality inspections of the work, and sign offs indicating the work is complete. The worker can also report working status through this worker screen. For instance in Fig. 5, it depicts the user interface for worker screen.

The workers' view in NetMES is based on work instruction, which is controlled by the user ticking each part completed and recording components. The system also maintains work time calculation and notifies if the planned time is exceeded. The key features for this functionality include:

- Recording operation time stamps,
- Recording S/N for components,
- Providing tact time reports based on recorded information,
- Including test records for FPY calculation,



Work Station: The Switch Drive Systems, Vaasa, C101, Place One

Target time: 02:30

Step
0.1
0.2
0.3

Take one card in number sequence and put to the cabinet side wall.

Fig. 5. Area elements in operator screen.

- Work instructions – viewing current work instruction for each stage by connecting bar code readings with instructions,
- Maintaining work instructions for each plant.

5.2.5. Dashboard

Production planning and control reports are presented as dashboards. These provide real time analytical information of various activities. Dashboards may be designed for wall displays or small embedded web-applications that can be used in corporate intranets and supplier extranets. Typically, the reporting and dashboard system may include the following features.

- KPI report for FPY per line/factory based on throughput,
- Production order report,
- Reporting progress of production,
- Current capacity report,
- Test reports.

This personalized, role-based dashboard displays production information from a summary level to a detailed level. The dashboard delivers real-time information to speed up decision making and improve business processes. These screens are simple and easy to handle.

5.3. Technical implementation

The overall architecture of the system will be based on a three-tier model: user interface, business logic and data layer. Fig. 6 illustrates the architecture overview. This architecture is developed to overcome the drawbacks of client-server architecture. These three layers stay separated at the time of deployment for this cloud-based NetMES. The system uses enterprise beans in the business logic level and hibernate system for data layer access. The data layer includes all the integrated data and centralized database. The business logic layer acts as the connection between the users and the database. The user interface layer is responsible for receiving the user's input data and results display. The users can switch interface views according to their needs and keep them exactly the same under data models. It is based on a Struts framework. The WAR/EAR packages should be installable on a JBoss application server system. The system should support Java EE clustering also Microsoft.Net and other equivalent technologies. User authentication is based on Java EE security provided by the application server software.

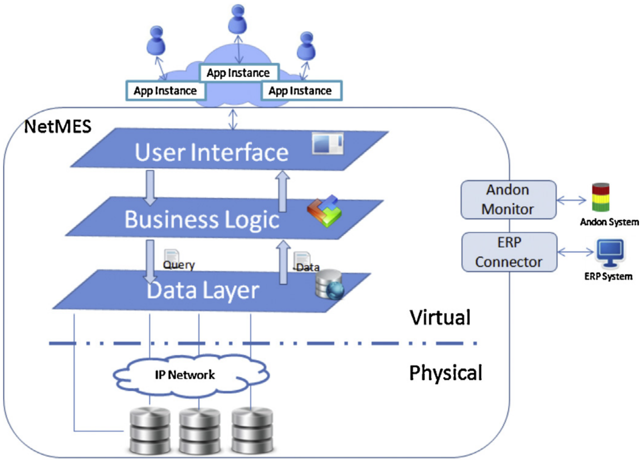


Fig. 6. NetMES architecture overview.

This NetMES is a high-performance and easily expandable information system with a centralized cloud server synchronizing local server databases and serves multiple factories at the same time. The open architecture enables easy system integration with a specific supply chain and manufacturing execution.

As mentioned earlier, this NetMES is designed as an information system that interacts with the ERP system. It acts as a messenger between the factory floor and the ERP. The ERP system focuses on global planning and business process across the whole enterprise and is an intra-enterprise system. On the other hand, NetMES responds to collecting data from the factory floor and transacting in real time to ERP.

The Andon system is a specific component integrated into NetMES to monitor wireless Andon system signals in the environment and send a record of all signals to the NetMES centralized database. NetMES enables monitoring over the entire Andon environment status on one screen. More importantly, the data transmitted from the Andon system and communicated to NetMES via the cloud is real-time, so the specified recipients will know the moment that an Andon alert is triggered.

The NetMES supports multi-factories with different instances. Each factory with its dedicated application instance over a shared NetMES platform in a hosting cloud environment has access to different factory floors and physical control over the manufacturing processes. The control data will be sent back to the ERP system. This cloud-based NetMES can provide an effective collaboration environment with employee agility and transparency.

5.4. Database construction

The NetMES is composed of several functional models that handle products, production lines and projects. Fig. 7 demonstrates the high level data structure of NetMES. The diagram depicts the relationship of distributed manufacturing. The multiplicity is shown to help understand the system better.

This model has a high level of abstraction. It is illustrated by a top-level representation where the taxonomy has been captured in nine key base classes. Each of these top-level classes is detailed with its attributes. The main classes are described as follows:

Project: once the customer order is coming, it is considered as a project. The project includes control over the production planning, and cost analysis. It enables the manufacturing for a specific requirement. The project lifecycle and status information are available to users.

ProductionLine: in a factory, many production lines are operated at the same time. Each production line has one Andon system to monitor the events occurring on that production line. The Andon system is a signboard incorporating signal lights to indicate which production line has a problem.

WorkQueue: a production line of the manufacturing plant consists of several production works. WorkQueue is used to arrange the working sequences in that production line.

AndonCase: when an event occurs during the production, an alert will be activated on the Andon signal board. The production stops and the issue should be recorded and reported to high level management. Each event is reported as one case and includes one serial-number.

Inventory: the maintenance of item inventories is very important. Inventory control supports a number of business processes, such as continuously monitoring stock level and automatically reordering.

WorkOrder: it contains the manufacturing process for production work orders. This includes creating work orders from production orders.

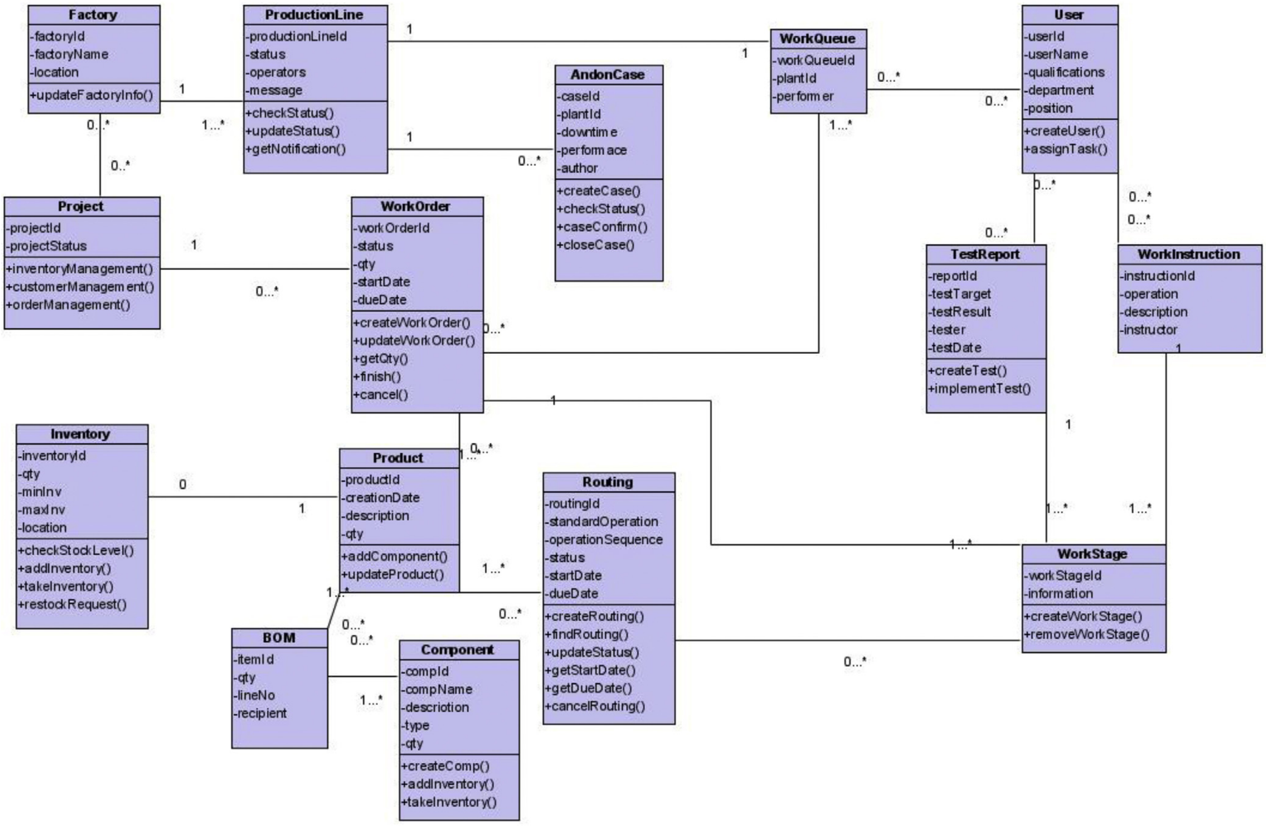


Fig. 7. NetMES class diagram of data structure elements.

BOM: BOM enables a list of required components and the routing of assemblies for the demand products.

WorkInstructions: this is included in BOM since every build process requires a bill of materials that outlines what components are required to successfully build the finished goods.

WorkStage: there are several stages to produce one product. The manufacturing process encompasses a variety of activities. WorkStage is used to organize the execution of a production.

5.5. Cloud security issues

In cloud-based environment, the physical database is replaced by a virtual database. Data are transferred throughout the cloud. Consequently, security issues regarding data storage and privacy can arise.

One approach suitable for manufacturing contexts is to store data locally in the factory level server and then synchronize with the centralized cloud database.

Users do not know the exact location of their data, and they can hardly prevent unexpected risk to the data storage due to their lack of rights to manage the data. It is a question of trust when users accept cloud-based NetMES as public cloud. The pilot implementations have been done by using a private cloud approach.

In order to ensure data confidentiality, integrity and availability, the NetMES capabilities have been extended. A tested encryption schema should be used to ensure that the shared storage environment safeguards all the data. Moreover, access controls will be adopted to prevent unauthorized access to the data [16], such as providing strong authorization, authentication based on the user's role, monitoring user activity, and single sign-on (SSO) [20].

Furthermore, privacy issues in the cloud environment need to be addressed. Therefore, standard procedures such as service level agreements (SLA) should be required [32].

6. Discussion

A cloud-based new MES infrastructure to integrate information exchange between companies has been proposed for distributed manufacturing. The proposed system has been designed to operate in situations where suppliers need to input significant manufacturing related information and provide this to other participants of the delivery along the supply chain.

The technical solution is a centralized system, where companies can link each other's data without heavy IT integration. The system is based on a layered architecture. The top layer supplies various kinds of flexible user interfaces so the clients can access this integrated system remotely. The middle layer is used to receive requests from users, manipulate the data, then convert them to useful information and present them back to users. The bottom layer is a collection of data from different sources. In this data layer, storage devices are consolidated by using storage virtualization techniques. It is very interesting that the logical representation that an application on a server uses to access data, which is called the business logic layer, is abstracted from this data layer as an independent layer. It is responsible for maintaining the mapping tables and presents logical entities to the users. For instance, when the business logic layer sends a request to access the data, the data layer will address resolution and access to the correct physical storage device. Subsequently, read and write instructions go directly to the business logic layer, and are ready to be presented to users.

This particular three-tier model is supported by a cloud-based infrastructure. It is different from the traditional deployment methods. Before cloud computing taxonomy was well defined, it was common for companies to have their own local files and application servers, as well as local storage devices. But now, the cloud infrastructure relocates resources and provides a centralized data center and virtualized server.

From the technical perspective, this cloud-based infrastructure provides direct data access for multi-factory management. This infrastructure can also reduce the constraints on an organization's ability to quickly adapt to evolving business needs. At the same time, it can rapidly respond to the provisioning of new services or other applications to this existing platform. Because of the cloud-based platform, each instance of this architecture is adapted to specificities of each application case.

Based on preliminary experiences, the advantages of this solution can be summarized as follows:

- Users only need to install web browsers to use this cloud-based system. It minimizes technical complexities and infrastructure.
- It provides an easier way for supply chain and manufacturing execution and control and it maximizes the benefits of IT systems.
- It provides a flexible platform to integrate different applications.
- It effectively constructs the connection of information from different factory floors.
- It provides a platform to share experiences of the cooperative team.
- Different users can have different customized views to monitor different information.
- It supports the decision making process and simplifies the business processes.

7. Conclusions and future work

The first ERP-like application was developed in the early 1960s. With the idea of controlling the business information flow within companies, ERP is limited to fulfilling functions outside companies, namely the entire supply chain. Especially in a global market business environment, ERP-solutions lack flexibility in adapting to the changing needs of the supply chain.

Considering this situation, today's standard product tracking and ERP-solutions seem ill-fitted to answer these needs. A first step toward greater supply chain integration seems to be product centric, light-weight product tracking systems, aimed at securing a greater degree of delivery reliability and automatic delivery failure detection. Cloud-based technologies present opportunities to respond the new needs of flexible information exchange between different partners. For further informational supply chain integration (developing the aspects of material and production planning from the point of view of the supply chain), a comprehensive system is needed. While current supply chain management (SCM) systems are cumbersome for the average SME to implement and maintain, a new generation of internet-based, light-weight, easy-to-use-and-edit MES systems could become the answer for such companies. We believe that the requirements collected for the prototype development as well as the NetMES system present some insight about what near future manufacturing execution systems should include. To support the claims put forth in this position paper, NetMES has been developed to support different factories with different production layouts and process types. From a technology point of view, this new infrastructure can be seen as the next evolution of migration of different applications on one platform.

There are several items on the future research agenda. Firstly, network level standardization work on product identification numbers, locations, factories, revisions, should be done. Companies need to develop master data to support working in distributed production. Secondly, practical experiences on cloud-based systems and portals combining manufacturing information need to be collected. What are the benefits observed in the long run and what are the concerns? From a technology point of view, further work is needed on developing smart systems for data synchronization between factory level databases and cloud level databases. Data security remains an important research area related to use of cloud.

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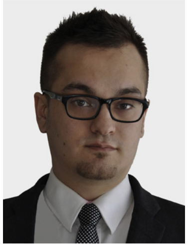

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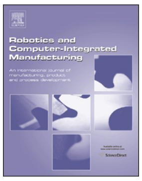

The role of wearable devices in meeting the needs of cloud manufacturing: A case study

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ABSTRACT

Cloud manufacturing is a service-oriented, customer-centric and demand-driven process with well-established industrial automation. Even though, it does not necessarily mean the absence of human beings. Due to products and their corresponding manufacturing processes becoming increasingly complex, operators' daily working lives are also becoming more difficult. Enhanced human–machine interaction is one of the core areas for the success of the next generation of manufacturing. However, the current research only focuses on the automation and flexibility features of cloud manufacturing, the interaction between human and machine and the value co-creation among operators is missing. Therefore, a new method is needed for operators to support their work, with the objective of reducing the time and cost of machine control and maintenance. This paper describes a practical demonstration that uses the technologies of the Internet of things (IoT), wearable technologies, augmented reality, and cloud storage to support operators' activities and communication in discrete factories. This case study exhibits the capabilities and user experience of smart glasses in a cloud manufacturing environment, and shows that smart glasses help users stay productive and engaged.

1. Introduction

After the epic changes of the world business caused by three industrial revolutions, we are in the midst of fourth industrial revolution, referred to Industry 4.0. It is a convergence of the physical world with the digital world, and it facilitates the vision of the smart factory [16] which enables centralized decision-making while requires distributed manufacturing equipment and resources [49]. The traditional manufacturing industry has been gradually superseded by a global chain of resources and various stakeholders. Therefore, a new dynamic and world-wild business model is needed.

Cloud manufacturing (CM) has emerged as a new solution to address all these challenges. It is a manufacturing version of cloud computing [32,49]. In this context, manufacturing resources and capabilities are virtualized and organized in a resource pool [24,32], therefore, all the partners in CM can perform real-time and collaborative manufacturing tasks [42].

The Internet of things (IoT) is a paradigm that takes advantage of sensor networks, also being known as "ubiquitous computing". The basic concept of IoT is the pervasive presence of objects, such as radio-frequency identification (RFID) tags, actuators, mobile phones and sensors [9]. IoT and its relevant technologies rapidly gaining ground in CM with its position and status known in Industry 4.0 evolution. More "things", even people, need to be connected to the internet.

In this new stage of digital manufacturing, resources and services coordination and adoption in cloud infrastructure may only have to involve minimal human intervention [47,49]. Many e-services were developed to allow the control, operation, monitoring, and diagnosis become remotely [6,14]. However, CM covers the entire manufacturing lifecycle from pre-manufacturing (argumentation, design, production, and sale), manufacturing (product usage, management, and maintenance), and post-manufacturing (dismantling, scrap, and recycling) [24], some activities in the actual manufacturing processes require human involvement. Mostly, they comprise running and execution of sophisticated systems/machines, and also some after-sales services supporting the primary products (i.e. field services, maintenance, diagnosis, user assistance, and training, etc.) [8,32].

The interactions between humans and machines are emphasized in Cyber-physical systems (CPS) [33,48]. Mezgár [26] also pointed out the outstanding importance of collaboration and cooperation among users in networked enterprises. Human resource is considered as one type of manufacturing capability [49], and it includes employees, skills and knowledge required to complete a specific job. Unfortunately, the knowledge is rarely documented [44]. It always requires sophisticated training and advanced

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knowledge to participate and enable CM activities. Therefore, how to best support human activities becomes a central aspect of the modern working environment, and it opened up an enormous set of new research opportunities.

Even though, the integration of humans with software and hardware is one of the fundamental requirements to satisfy this new development in the industry [31]. In previous studies in CM area, human resources and management were rarely discussed. It is important to appreciate this consideration. Based on an analysis of previous studies, we noted some weaknesses of the current research in CM:

- Insufficient methods to support field services.
- Lack of collaboration among operators.
- Lack of communication between field services and the back office.
- Inefficiently knowledge management in the field.

The existence of wearable technology forms an integral part of the IoT. Based on Brauer and Barth's [5] study, they conclude that wearable technology can boost employees' productivity by 8.5% and life and job satisfaction by 3.5%. Although different kinds of wearable devices are available in the market, they are still in their infancy. In the manufacturing industry, wearable technology has the potential to be useful, but the question arises as to how we can use these devices in manufacturing and how these devices can improve manufacturing efficiency.

In this research paper, we investigate the application of wearable technology to visualize manufacturing information and to allow hands-free interactions in order to communicate with other users in CM networks. Due to almost no information concerning its successful application in industry [2], and also the lack of academic research on the strategic aspects of human resources management in CM, the case study method was chosen for this investigation. The company is a laser machine builder, and they sell machines to customer companies. They also provide a centralized helpdesk and remote assistance as well as training, etc. This paper will provide an example of the wearable technology, specifically refers to smart glasses, supporting CM.

Our proposed mechanism deals with the workers (i.e. maintenance technicians, machine operators and helpdesk units) in various locations, as the “things”. All the workers can be connected in a virtual environment in the internet so that they can collaborate more effectively on troubleshooting issues. Smart glasses are adopted in this research to support the collaborative manufacturing training, maintenance and management of different participants and departments.

We found out that applying wearable technologies can increase the value of CM, avoid waste and increase sustainability, at the same time it can help to reduce risk and prevent human error on the shop floor. We will perform a pilot study to evaluate the use of wearable technologies (smart glasses) in improving the communication channel. This research outlines the following issues in a specific case company:

- Description of wearable devices and how they enhance workers' tasks in the factory.
- Definition of three distinct profiles of wearable devices users.
- Collecting data generated by wearable devices and the forming a human cloud.
- Processing a large dataset by using some form of cloud technology.

2. State-of-the-art review

2.1. Cloud manufacturing (CM)

Cloud computing and the IoT have moved from buzzwords to practical business principles recently. The idea of the “cloud” is progressively transforming the way that enterprises do business, especially IT-related businesses [35]. With the support of cloud computing and the IoT, CM has appeared as an innovative manufacturing paradigm. CM is a new, multidisciplinary domain that encompasses state-of-the-art technologies such as networked manufacturing, a manufacturing grid, virtual manufacturing and agile manufacturing [15,24,35,49]. It is a value creation manufacturing process across globally networked operations [35]. It involves global supply chain management, product service connection and the management of distributed manufacturing units [26].

Under the umbrella of CM, manufacturing resources and capabilities can be intelligently sensed and connected into the wider internet, and automatically managed and controlled using IoT technologies (e.g., RFID, wired and wireless sensor networks, and embedded systems) [37]. These resources and capabilities can be fully shared and circulated based on users' demands on a virtualization layer (Qanbari et al., 2014). Xu [49] uses two important concepts to describe CM: “integration of distributed resources” and “distribution of integrated resources”. Providers publish their resources into this CM platform, and then the distributed resources are encapsulated into cloud services and managed in a centralized way. Consumers can use the cloud services according to their requirements. They can request services ranging from product design, manufacturing, testing, management and all other stages of the product lifecycle [49]. The problem is how the physical world and the internet world of ICT can connected without a gap.

Cyber-Physical Systems (CPS) was proposed a few years ago [34] to enable the interactions between computers and humans through many new formations by using today's computing and networking technologies [3,22]. Because the physical world is not entirely predictable, the CPS will not be operating in a controlled environment, and must be robust to unexpected conditions and adaptable to subsystem failures [22].

CM provides a cooperative work environment, not only for enterprises but also for individuals, enabling collaboration among the entire manufacturing ecosystem [53]. Although the concept of CM mirrors the definition of cloud computing, most of the resources in CM need to be operated manually by humans [13]. This manual operation is unlike the virtual resources in cloud computing. In addition to the performance of manufacturing equipment, human activities in providing field services also have a significant and direct impact on the quality of products. It is very difficult to maintain a high-performance operation because the system consists of a group of devices, such as robots, numerical control machines, sensors, and so on [29]. Similar findings are available in Ren et al.'s [35] research in which they classify cloud services into two types: OnCloud services, run entirely on a cloud platform, and OffCloud services, which need additional operation by an operator via a cloud platform. In order to improve the quality of manufacturing processes and products, the focus must move to improve the performance of people. As such, human activities and field services management must be considered as an important factor [7,13]. Ford et al. [10] suggest that enhanced human–machine interfaces and collaboration software are drivers of distributed manufacturing.

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2.2. Connecting humans in cloud manufacturing

Dual resource constraints (DRCs) arise from capacity constraints stemming from both machines and human operators [50]. Advanced robots and process automation devices will change the current human–machine interaction standards [36]. Smart connectivity and the ubiquitous sensing of distributed manufacturing resources are critical features of CM [35]. Machinery, robots, lines, items and operators on the shop floor will be acting in a strong, connected, decentralized and autonomous network. The shop floor will be dominated from the ICT perspective by easy-to-plug-and-work devices as well as by the seamless exchange of information [36].

Hu et al. [13] created a classification of CM services in terms of the degree of human involvement. The first type of services can run automatically without human resources (such as computing resources). The second type of services involves human and purely manual activity which has nothing to do with proficiency (such as a whereby a driver's driving skills have little effect on the quality of logistics services), while the third type of services is ranked based on the skill level of the worker in question (for instance, a lathe operator's skills can seriously affect the quality of a product). Wu et al. [47] emphasize in their research that a high degree of automation will be required to ensure the efficiency and effectiveness of machines and manufacturing processes on the shop floor with minimal effort, but this does not imply the absence of human beings.

The scope of human resources in CM formation varies depending upon different definitions. To put it more simply, human resources are those personnel who are engaged in the manufacturing process, i.e., designers, operators, managers, technicians, project teams, customer services, etc. [43]. Lv [23] defines human resources as including those technology personnel and management personnel needed in the product development process. They are the most precious resources involved in the activities of the manufacturing business, and a great deal of knowledge and experience are stored in the minds of such personnel [23].

Since human resources are also an important manufacturing resource and assets, it is crucial to consider humans as being connected to the internet. Michel [27] provides an example to describe the importance of considering interconnections among people, processes and data within this conception of the IoT. The idea of the Internet of Users (IoU) as a deeper level of IoT application in cloud manufacturing has been proposed [38]. Users (including service providers, consumers and operators) of CM are primarily internet users, while the IoT is an enabling technology to realize connections and communication among these users and to form the IoU.

2.3. Wearable technologies

The IoT refers to machines, automation controllers, and other physical devices being connected to the internet [27]. In order to connect different human resources in the same manner as manufacturing resources, the subset technology of the IoT – wearable technology [41,45] – can be used.

The IoT encompasses market segments including connected cars, smart applications and many others [45]. “Things” in wearable technologies refers to wearable devices equipped with microchips, sensors and wireless communications capabilities. Such networked wearable devices are utilized to detect the posture and motion of the wearer's body, track activities and collect data in the background [19,30,41]. Wearables will increase the importance and improve the capability of the IoT in the industrial environment. Linking manufacturing resources by the IoT can achieve the monitoring and optimization of the entire production process.

In the manufacturing industry, more flexibility is required in today's dynamic business environment. Wearable technologies can fulfil this requirements. Different applications offer promise in such areas as production, warehousing, logistics, maintenance, safety and security. For instance, wearables could be helpful in monitoring ambient conditions to ensure safety on the shop floor or on location. Wearables could also take the form of authentication devices that restrict access to a facility.

One of the best known wearable devices comprises smart glasses. Smart glasses consist of a head-mounted display (HMD) as an output device in front of the person's eyes to present data from the background information system; a wearable computer for processing/computing power and supporting the glasses' operation system; a set of sensors to collect information for data inputs. Video cameras and eye/head-trackers are essential to determine the position and orientation of the user [2,40]. Users can observe the environment without distractions. It consists of two essential elements: the ability to access information in real-time and the ability to communicate in real-time. Augmented reality (AR) technology is used to visualize real-time information on wearable devices, while the cloud infrastructure is implemented to achieve real-time communication.

AR is often defined as the real world enhanced with important additional information that is generated by the computer in real-time, such that human senses can be enhanced [20]. AR enables registered annotations and 2D or 3D virtual objects (from a predefined database) to be interactively integrated into a real environment in real-time [18,39,40]. Users can see the real world as composed of virtual objects and perform real-world tasks through guidance of specified computing virtual computer objects (VCO) [18].

Smart glasses provide the functionality of a smartphone in a hands-free format of a HMD instead of a smartphone screen. The wearer's surroundings can be transmitted by additional information (audio and video). Users of the glasses can request directions to a location and have them displayed before their eyes; they can also receive a notification of and respond to an incoming call or email [46].

Another important element of smart glasses is the “cloud”. It is vital to note that the IoT – especially wearable technologies – and the cloud go hand in hand. Generally, a large amount of data is generated by the IoT to help users better manage many aspects of their daily lives, and these data need to achieve distributed real-time storage and aggregation [25]. Cloud computing is powering the wearable technology revolution. It allows for the large dataset generated by wearable devices to be captured, analyzed and made readily accessible whenever users need it [5,45].

Cloud-based data storage and data processing increase the capability of smart glasses. Real-time information, which is rendered on the user's HMD, is generated from the cloud and then the graphical overlay is shown over the physical world image. On the other side, smart glasses need to sense the surrounding environmental information and feed it directly into a cloud-based analytics system.

Currently, the major limitation is an appropriate HMD technology. Today's massive HMDs are aesthetically unappealing and uncomfortable, especially as regards the limited field of view. Improvements in size, weight, functionality and style are required to make this technology fully usable. Several promising technologies, such as laser retinal displays, are on the horizon to address this issue [40].

2.4. Smart glasses

At the moment, smart glasses are used for business in several potential areas, such as managing field services and assembly,

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Table 1
Summary of current applications in the manufacturing industry.

Functionalities	Descriptions	References
Monitoring	Continually monitoring and assessing the manufacturing system and the status of machines	[27]
Control	Achieving excellent control of machines and supporting manufacturing operations (e.g., process planning) based on real-time monitoring	[7]
Optimization	Providing optimization solutions and improving productivity by wirelessly gathering data from assets in real-time	[27]
Autonomy	Combining wearable computing and knowledge management can achieve self-diagnosis and self-heal	[2]

remote technical support, navigation and mapping services, and security solutions. Porter and Heppelmann [28] summarize four groups of smart products, functions and capabilities, namely monitoring, control, optimization and autonomy. It is believed that collaborative technologies and wearable technologies will be rapidly adopted in the manufacturing industry, due to the way in which the modern manufacturing model is related to numerous high technologies. Potential current applications and functionalities, which can be built on the IoT and wearable technology, and which benefit the whole industry across the manufacturing process, are listed in Table 1.

There is an enormous opportunity for wearable computing in manufacturing, especially smart glasses solutions such as Google Glass. Plex promotes its cloud ERP as a comprehensive solution for manufacturing, in which the “IN-YOUR-EYE ERP” is integrated with Google Glass and allows people to work without using their hands. Both the glasses and the system are used to record and manage different information. Users will be able to get real-time information captured by ERP, such as production data, the status of machines, transactions, etc. [12]. Procore is another example of integrating Google Glass with its project management platform to retrieve information and make data available across various devices, including smartphones, tablets and computers [17]. Wearable glasses allow workers to make better and quicker use of business information. Thomas and Sandor [40] demonstrate a scenario in the manufacturing industry whereby wearable AR can help assembly line workers to improve their industrial working processes.

User experience is another factor to be considered. Smart glasses will increase the effectiveness of interaction, making it more natural and spontaneous [36]. BMW announced the use of AR as a visual guideline in real-time for its workers. The application consists of glasses and headphones. This device enables seeing and hearing of exact instructions about how to repair a car, while at the same time he can ask for information about what tool is right for the next step of assembly or repair [20]. It provides an opportunity to reduce costs by allowing employees in the field to report back to the back office and access relevant information while they are still on site. In this way it can reduce or eliminate the need for a repeat call-out. Similar tutorials are readily transferable to other sectors of human activity. They can serve as training and educational applications for students in schools, in preparing manuals for purchased goods (e.g., furniture), or in the rapid training of employees for any device. On the other hand, field service engineers can remain productive by collecting visual information and feeding it back to head office, while leaving their hands free to complete the tasks they are engaged in.

Overall, the technologies and problems mentioned above highlight the possibilities and needs for the development of a comprehensive solution to support humans and machines connected in terms of CM.

3. Methodology

3.1. Research purpose

The present study engaged with a manufacturing company to survey the business requirements of human resources and activities management in a CM environment.

A CM system is defined as the centralized management of distributed factories and their distributed manufacturing resources, such as machines, tools, materials, people and information, to produce a value-added physical product based on a specific customer's requirements. Its ultimate goal is to cover the entire manufacturing lifecycle. Numerous studies have been carried out to understand manufacturing resources' virtualization and sharing processes. Resource productivity becomes the top priority. Although human resources are also important elements to fully realize the formation of the CM process, insufficient research has been done in this area. Hence, we focus on both human resources and human activities, and we propose an integrated solution to manage the interconnection of and collaboration among humans with different roles. Our solution can support field service management in terms of CM.

3.2. Research method

This research is conducted based on a case study of a real factory. Company A is a global organization that provides sheet metal processing machinery. Its customers are sheet metal fabrication factories. They order customized metal sheet fabrication lines combining punching or laser cutter machines with automated bending and sorting capabilities from company A. In this particular research, the case study is an appropriate research method because the aim of this study is to gain an overall understanding of CM management activities, as well as to define the business requirements and technological possibilities. This type of study usually seeks out both what is common and what is particular to the case, but the result regularly presents something unique. This unique element is portrayed as the key to success – at least potentially – be copied by other companies [4, p. 89].

Domain experts were interviewed twice to collect details about the current context of their working environment. The interviews were performed according to the semi-structured interview guide of [52], complemented by delicate face-to-face interviews as suggested by [11]. This approach helped the researchers to reduce possible misunderstandings during the process of information gathering. Additionally, workshops with participants from several business units and other domain experts were organized to verify and validate the collected business requirements. These activities resulted in a broad understanding of the requirements, challenges and optimization opportunities.

Based on the observation and analysis of worker activities on the shop floor, several processes were identified for improvement, such as the operator's machine control capabilities, maintenance skill and repair operations, and also the factory helpdesk processes. Table 2 summarizes the main requirements related to field service management. All the requirements are classified by their priority (1=essential, 2=important, 3=nice to have). This high-level business requirements table can be interpreted from three aspects: (1) it classifies the users into three types and confers roles in CM, (2) it defines the content and range of information flow for each user type; and (3) it also clearly specifies our research scope and limits.

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Table 2
Business requirements.

Strategic requirements	Functional requirements	Stakeholders	Priority
Information gathering	Set up a local video stream, use indoor cameras to detect multiple production lines and events simultaneously, and then make a video record for remote control, post-verification and analysis purposes.	Helpdesk unit	2
	Workers can make a record of their actions and share it with others for the purpose of sharing knowledge and experiences.	Machine operator	2
	Workers can make a record of their actions for workforce tracking and monitoring to achieve performance management purposes.	Machine operator	2
Interoperability	Workers can communicate with each other in real-time.	Machine operator	3
	Workers can communicate with the helpdesk unit in real-time.	Machine operator, technician Helpdesk unit	3
	A helpdesk unit can provide remote desktop control and assist workers on site or else monitor the machine's operation and status.	Helpdesk unit	3
	A helpdesk unit can provide mobile training to guide the workforce or to send working instructions to machine operators.	Helpdesk unit, machine operator	1
Visualization	Workers can receive office information such as a working schedule and production planning information in real-time, and this information should be visualized to workers in real-time.	Machine operator, technician	2
	Workers can receive warning messages from machines once errors occur.	Machine operator	1
	Workers can easily pick up spare parts.	Technician	1

4. Applying smart glasses in cloud manufacturing

4.1. Cloud manufacturing reference model

Fig. 1 presents the reference model of humans and machines both connected to and embedded in the CM process with specific information flows. It serves as a fundamental structure for the CM implementation and a business solution to connect humans with machines. In order to implement such an architecture, a communication channel needs to be established whereby factory information is available in real-time to support the humans (i.e., the users) on the shop floor. It provides a flexible and agile collaborative enterprise architecture.

There are two core components to enable this communication channel: the “Internet of Machines” (IoM) and the “Internet of Users” (IoU). Fig. 1 also describes the relationships and dependencies between the various machines and users to manage the business in CM environment.

- IoM: All the manufacturing resources, i.e., machines, equipment, robotics, devices are connected to the Internet. Their manufacturing capabilities are perceived by the adoption of the connecting sensors, embedded systems and RFIDs, and all the related data are collected to achieve automatic control and monitoring. The adoption of IoT promises that the CM system will have a real-time understanding of conditions, events and material movements in the physical world. This IoT not only enables the manufacturing resources' virtualization but also supports intelligent operation.
- IoU: The data generated by wearable technology will form as a “human cloud”. The users on the shop floor include operators controlling and manipulating the machines on a daily basis, and technicians who can perform supervision, maintenance and repairing services. The IoU describes the connection between and communication among the users. Besides those users working on the shop floor, administrators and remote assistants are also part of this IoU as other users. The administrators' main tasks include monitoring the shop floor in real-time and making adaptations when risks arise or errors occur. Remote assistants mainly work in the help center and respond to the urgent events and hotlines. This three user types are emphasized based on business requirements in previous Section 3.2.

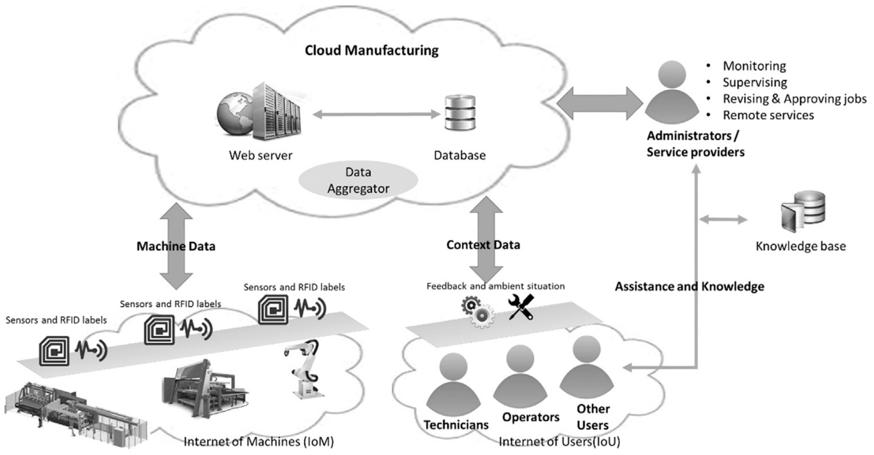

Fig. 1. Reference model of humans and machines in the cloud manufacturing process.

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This cloud-based data management architecture is implemented to support the real-time data capture and data integration with production planning and control (PPC) and machine execution systems (MES). Because the data can be captured from multiple sources in the distributed local factories, a data aggregator is needed to integrate the data. It provides important functions, such as a domain service, a location service, server load balancing, and more. As mentioned above, this architecture needs a central repository to manage and maintain all the machine and human data with integrated transaction standards and integrated platform. Therefore, cloud-based data storage is required to fulfil the functionalities related to data processing.

The knowledge base is also an imperative component. It is a document library that retrieves knowledge from users' activities. It includes how to control the machines, how to operate the equipment, how to use the devices, and so on.

4.2. *Architecture design*

Company A manages all the production lines in the form of CM, and its customers are cloud services consumers (while company A is hosting this CM platform as a cloud services provider). Company A provides cloud services such as monitoring, supervising, revising and approving jobs, and remote services to fulfil any field service management requirements.

Fig. 2 shows a CM architecture that represents all the required functionalities and services, integrating for:

- A real-time data capture service: for real-time data acquisition from the machines/equipment/devices/robotics through the embedded intelligent sensors. Moreover, field services technicians and operators are also connected to the CM process through smart glasses. All the data are maintained in the cloud-based repository, effectively sharing these data between the back office and the shop floor. The ability to capture real-time insights into the back office can also benefit other business functions. More specifically, the technicians and operators need real-time information about machines capacity, status, working schedules, and locations. These real-time information can enhance their job performance in operating procedures.
- A process monitoring service: the helpdesk unit can monitor the production process in real-time. The users can access all the relevant actual and historical data based on their roles, and the data are available to different users in different views. It provides data analysis and management suggestions on multiple screens as a communicational interface for creating a virtual presence in the environment. It is also crucial to track a given worker's performance. Daily monitoring can improve performance and productivity. In this way, it is easy to provide a benchmark of working steps.
- Fieldwork assistance service: the users are mainly machine operators and technicians. They send notifications of upcoming maintenance tasks and give the operators a warning when a component fails. They can receive data through mixed-reality technologies in order to enhance their capabilities and skills. This collaborative and valuable co-creation environment is an extension of knowledge management. Furthermore, the field service is becoming increasingly complex, requiring more variability of skills to reach resolution. Smart glasses can enable faster, more dynamic intelligence that is not available from reviewing static manuals that are outdated the moment they are published. Therefore, remote tutorials are provided as well. The technician can follow exact instructions about how to repair while at the same time he can ask for information about which tool is right for the next step of assembly or repair.

The “cloud” infrastructure is a projection of the supporting architecture for an integration of “mixed-reality environment”, “real-time management business model”, and “communication channel for collaborative management”. It consists of three layers: a presentation layer, a business layer and a data layer.

- Presentation layer: this supports all the interfaces, presentations and communications for users. The traditional single screen

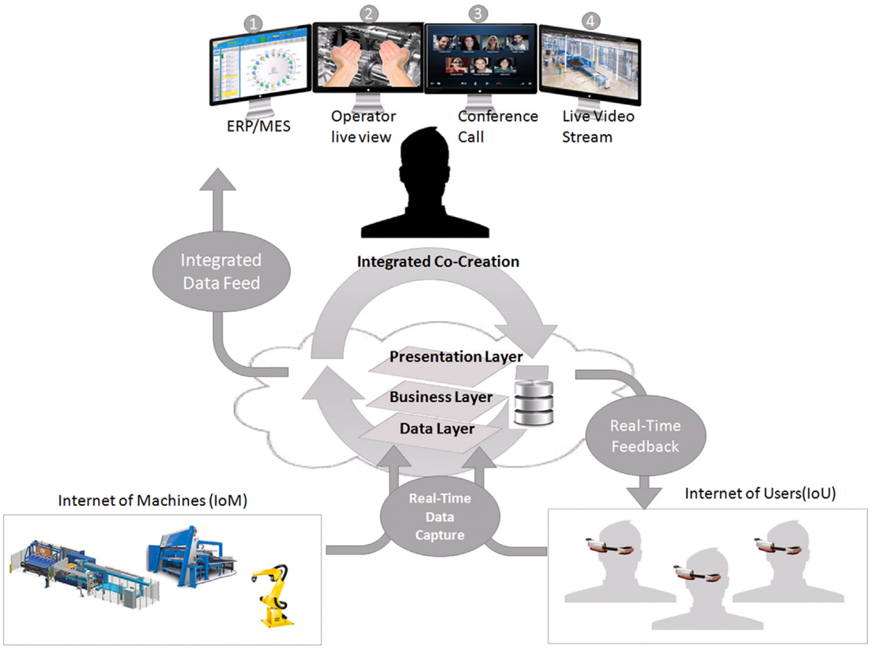

Fig. 2. Overall system architecture for implementation.

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desktop environment needs to expand to large screens for control, monitoring and communication features. Therefore, this presentation layer provides two different kinds of display, one for the back office and one for field workers.

- Business layer: this defines applications and functionalities such as collaboration among users, sharing telemetry from machines to users, and real-time information from the shop floor to the back office, etc.
- Data layer: this represents a cloud-based data repository and data management, including knowledge bases. The technologies used to implement this data layer comprise querying, selection and refinement.

In fact, in the back office of the helpdesk, a browser-based dashboard detailing production status is displayed on several oversized flat screens (see Fig. 2). This specific solution includes four environments:

1. Production management feeding from ERP/MES systems: this screen is used to display the task list, production planning and working schedule of current equipment/machines. It is imperative to keep the information in ERP systems up-to-date and accurate.
2. Operator's live view from smart glasses: this is a wearable technology enabling a first-person point-of-view, while footage of the operators' activities can be streamed to this screen for later reference. This function can help the technician to diagnose and repair problems more quickly.
3. Conference call for a collaborative environment: collaboration with experts via a conference call in distributed locations leads to remote assistance on the tasks – such as repairs – and this approach saves the expense of providing an on-site service. The technicians can connect with the maintenance supervisor or a peer to get advice and training in real-time on the site. These conference calls can be recorded and stored as reference material for future jobs. Videos can also be used as evidence for use in disputes or investigations.
4. Real-time video streaming from the local production line: the screen can provide the helpdesk unit a general idea about the factory. Therefore, the helpdesk unit can always be aware of the real-time situation in the factory.

The capabilities for video calling and AR applications of smart glasses were appreciated as being highly useful for both operators and maintenance technicians. Smart glasses include sensors, accelerometers, cameras, microphones and other capabilities that can be used to collect and transmit various types of user information. The real-time connection between them and the helpdesk allows for significant time-saving and improved field services. When data captured by smart glasses is fed into a cloud-based data repository in the data layer, the presentation layer will push the refined and analyzed information out to the browser-based dashboard and show on helpdesk unit's screen. By using smart glasses, real-time insights and instant feedback can be provided to the helpdesk unit – this will enable remote assistance and services. Fig. 3 shows that services can be supported by smart glasses for different stakeholders, namely machine operators, technicians and the helpdesk unit. The scenario includes: operators receiving field service guidance and assistance; technicians receiving assistance while performance maintenance services; the helpdesk unit providing remote technical support; and workers picking spare parts, etc. As they work, employees can keep their hands free and their eyes focused on the task at hand. They are not interrupted by the need to key or scan information into a mobile device. It promises a productive means of mobilizing workers.

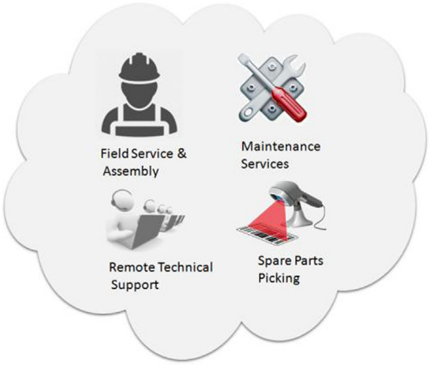

Fig. 3. Services can be supported by smart glasses.

5. Technological implementation

Although wearable technology has previously been adopted, it is still at an early stage when it comes to the devices on the market, with plenty of room for improvement. In this particular case, the Vuzix smart glasses are used to implement the “human cloud” solution as part of this CM solution. Vuzix provides the platform for third parties to pilot and port their apps into this new open AR environment. Vuzix's device is being used for warehouse applications, and the company is getting ready to release an application for field service [46].

The current version of Vuzix M100 adopts a WQVGA screen with a full-color display (428 × 240 resolution). It includes several sensors, such as GPS, proximity, three degrees of freedom head tracking, a three axis gyro, a three axis accelerometer, and a three axis mag/integrated compass. Once the Vuzix SDK is installed, the M100 behaves like any Android device: build, deploy and debug, etc. This gives developers more power than is the case with other similar products. The M100 is a full-fledged Android 4 device where all the APIs are accessible.

Fig. 4 shows an architecture and runtime environment for our solution. The architecture is built on a plug-in concept on the glasses, a set of basic functionalities accessible to all users, and a cloud-based processing approach. The top layer comprises all the desired functionalities available in field service support, such as a monitoring service, an evaluation service, a task retrieval service and a remote assistance service. These services can be utilized in different combinations to fulfil different requirements. The AR server supports the registration of different users with smart glasses and the retrieval of the glasses' sensor data.

Having this wearable system enables hands-free operation – workers can still receive information while performing other simple tasks [40]. With this requirement, the operators rely more on the situational awareness of smart glasses. The observe-orientate-decide-act loop (OODA) is one of the crucial decision-making models [1,21,51]. The solution described in this research will use the same model. It achieves situational awareness by detecting human actions and their locations, and then the sensors will collect relevant data and render back to the AR server. Based on this information, the augmented content from the AR server will be sent back and be displayed on the smart glasses.

5.1. Use case of smart glasses

The purpose of this pilot study was to assess the usefulness of smart glasses at the application level and to set the stage for future work to determine the proper setup for CM. The creation of use

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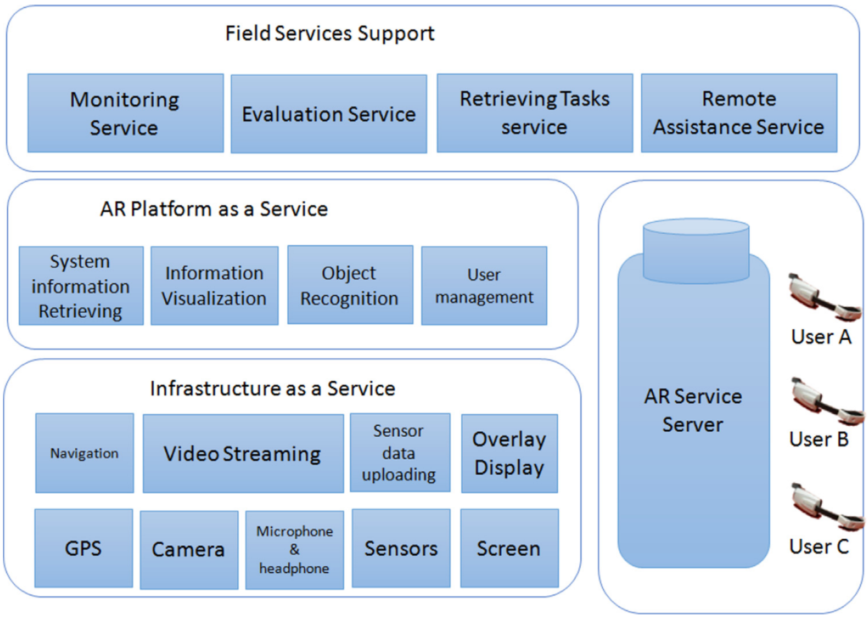

Fig. 4. Runtime environment of wearable devices in cloud manufacturing.

cases helps to determine key functionalities better. All in all, five possible use cases (Overview scenario; Operator Working scenario; Maintenance scenario; Online service scenario; Video Mix system) were identified related to the improvement of the work processes, the safety and quality processes, supply chain management, and reliability-related activities. In this paper, only the onsite maintenance scenario is described from the communication channels for the roles and relevant tasks on the factory floor. This generic use case presents how company A provides field maintenance services to their customer factories. This use case is selected because it is more representative and complicated than others.

When a customer identifies the need for a maintenance service, he/she might have difficulty to describe the current fault or issue. Company A needs more information about the status of the machine/equipment/device and potential error codes to give the customer a hint for a potential solution. If it is a trivial case, the technician is required to solve the problem.

The activities performed by the technician are depicted using a UML use case diagram. We observed prolonged times for fixing

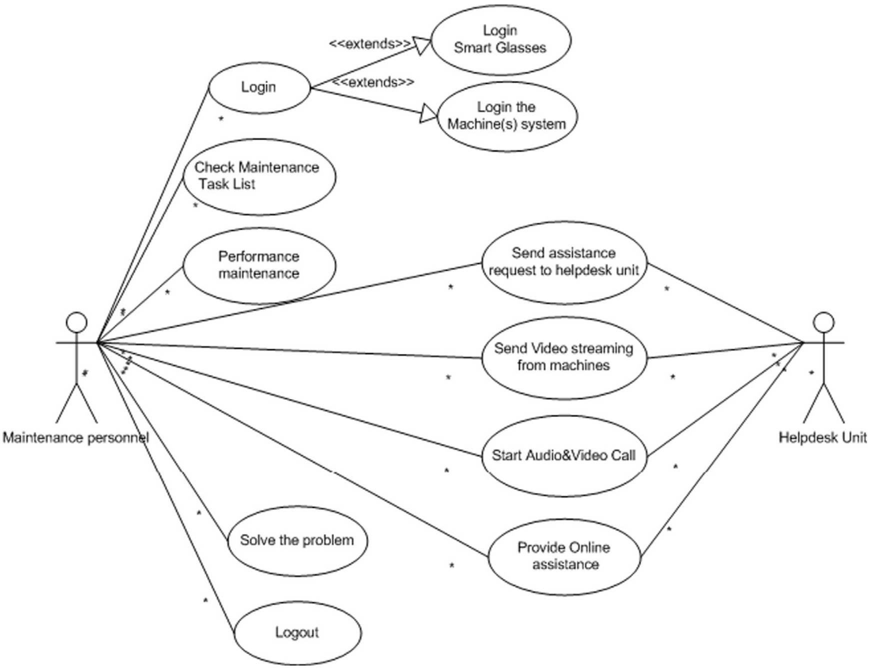

Fig. 5. Use case for the hands-free concept for technicians.

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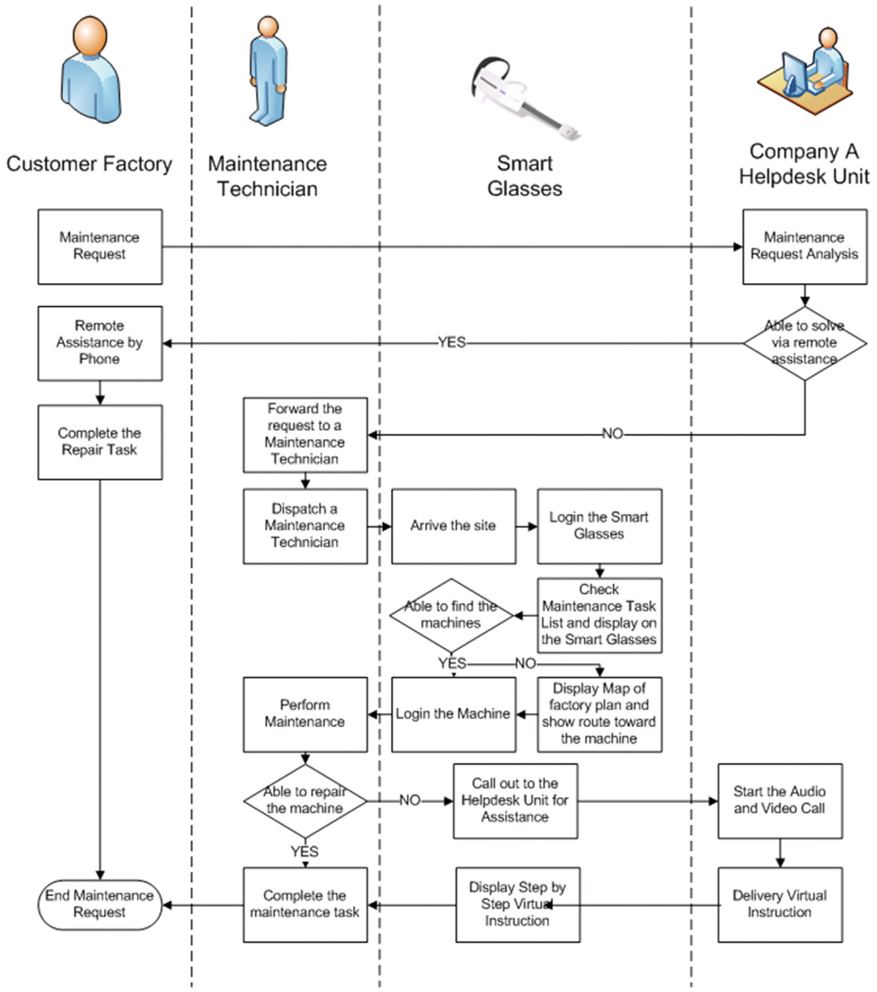

Fig. 6. Workflow of the maintenance service.

faulty machines. Wearable devices can provide considerable improvements in this abovementioned scenario. We focused on implementing new functionalities, such as showing the telemetry, machine usage history, etc., on the smart glasses, and providing a customized menu for calibration and settings, and enabling a remote connection with helpdesk personnel. Fig. 5 shows the use case map for maintenance and remote assistance.

Fig. 6 demonstrates the maintenance service scenario. First, the customer detects an error or warning at the local factory, and then he can send the repair order to the helpdesk unit. If the problem cannot be solved by a remote aid, an available technician will be sent to the site and will check the problem physically. The service technician is sent to the site to repair sophisticated machinery and production facilities. When the technician arrives at a facility with his smart glasses, the glasses will display a list of tasks and show the machines needing attention. If he is unable to locate the machine, a route throughout the facility will be displayed on the smart glasses and will take him to any machine that requires servicing. The technician can initialize a video call with the technical support representative at the helpdesk unit when the problem cannot be resolved. The technician can share his field of vision with the remote specialist, who then helps walk the technician through his task. The video call can be recorded to capture the performance of the activity by the maintenance technician. The helpdesk unit will provide a step-by-step working procedure. The helpdesk unit can also deliver virtual instructions via the smart glasses, and then the technician can provide extra assistance.

There are two main advantages of using AR-based smart glasses. First, when completing maintenance tasks, a technician mainly uses his hands. Therefore, the smart glasses can provide a hands-free working environment, which can enhance his performance of the task. Second, the technician can connect with the helpdesk unit in real-time, and the helpdesk unit can get real-time feedback from the shop floor. This can increase both the technician's skill and the helpdesk unit's knowledge accordingly.

5.2. Scenario examples

To show the functionality of maintenance support, a maintenance scenario was developed. A technician received the maintenance request and visited the factory. The technician logged in the smart glasses and called the helpdesk unit for assistance. Once the video call was established, the maintenance supervisor and remote specialist could see the situation at the site. The scenario is illustrated with different examples in Fig. 7, such as when the technician is setting up the tool (a), repairing the wiring (b) and operating the controller (c).

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Fig. 7. Maintenance scenario examples (a) tool setup support, (b) wiring repair guidance, (c) operating the controller.

Fig. 8. User experience of smart glasses.

In this solution, we explore the possibilities for the use of state-of-the-art technologies – namely smart glasses – to lower risk and prevent human error on the shop floor, as well as to achieve value co-creation. The scope for collaboration will be aided by the smart glasses and functionalities such as instant communication and file sharing. More research can should be conducted in order for the technology to become more widely implemented and adopted on the shop floor in practice. Fig. 8 provides an example of using smart glasses to identify machines and display machine datasheets on the right-hand corner of the screen.

Fig. 9 illustrates the screen of a barcode scanner provided through smart glasses. This solution can free up the operator's hands for picking up spare parts while performing maintenance jobs. The red line indicates a precise area where the barcode will be read, and then the detailed information about the scanned spare part will be displayed on the screen. This information can be shared with other operators. This function can be used for other purposes as well, such as warehouse management.

6. Conclusions

CM aims to encompass the entire product manufacturing lifecycle, from market analysis to design and production, testing, training,

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Fig. 9. Barcode scanner via smart glasses. (For interpretation of the references to color in this figure, the reader is referred to the web version of this article.)

usage, maintenance and, finally, dismantlement [24]. A CM business model can help SMEs to innovate their processes and the product and production sides, and even other processes across the entire product lifecycle. It is very important to emphasize that the focus of CM is no longer only selling products to customers, but also providing services for the customers. Especially in machinery industry, services are offered with the machines. But in current academic and industrial areas, the purchasing step, maintenance and training sides always be neglected and not be addressed sufficiently.

The IoT, as a representation of ubiquitous computing, is changing the way machines, devices and pieces of equipment are connected. Likewise, wearable technology as a subset of the IoT now provides the possibility to connect people. This medium is an attractive alternative to existing manufacturing techniques. Our goal is to connect workers into this CM system as human resources and to design a communication channel between the shop floor and the back office. This communication channel ensures that while workers operate on-site, administrators or a remote help-desk unit can collaborate and provide remote assistance or services to them. Besides, all the parties of this CM system are continuously aware of machine availability. In this research, we presented the use of wearable AR – namely smart glasses – to support a hands-free working environment in the factory. We designed a set of interactions utilizing related functionalities. Finally, we also developed a series of visualizations to demonstrate the idea.

Smart glasses represent a new approach to business communication. There are numerous applications available, such as navigation guidance; however, there are not so many innovations in the manufacturing industry. Therefore, our solution can fill the research gap and also provide the following managerial implications to organizations:

1. This solution can be easily applied to SMEs for monitoring and assisting their field service objectives because they are flexible, portable and low cost.
2. Workers can wear the smart glasses to receive specific virtual guidance and instructions when they are performing on-site tasks, such as repair, maintenance and training.
3. The smart glasses can provide mobility, unifying the manufacturing shop floor and the top floor in real-time.
4. This approach can help workers to stay productive and engaged.

Advanced technologies in personal wearable devices, combined with CM concepts, provide an opportunity to co-create value and streamline human–machine interactions. This approach will help manufacturers to create customized information and assess workers' performances and improve workforce productivity. Additionally, more and different functionalities can be developed, such as in logistics processes, and smart glasses can support order picking; in the manufacturing process, workers can wear them to assist them in bin picking; in the Research and development (R&D) process, smart glasses can be used to conduct and improve the communication channel, and make sure the right knowledge is transmitted to the right people at the right time. It can improve after sales services, such as deliveries, hotlines, etc., and can also improve after-market response times and service levels. It introduces real-time supplier collaboration to compress the value chain. Smart glasses will play a major role in supply chain operations in the near future.

Although the present smart glasses solution totally alters manufacturing, and it can offer even more possibilities for manufacturing – it is a controversial solution. We encountered specific challenges and limitations when we conducted our research and this practical implementation, such as massive HMDs are uncomfortable and the smart screen only covers a tiny fraction of the entire eye-field, which will generate headaches. Besides, disconnection due to poor wireless network connections in many sites is a real issue for the service technician. Other issues are also found, such as privacy, safety, and legal challenges must be taken consideration [41], and overloaded information may cause extra effort on filter the information and delay on the judgement [10,20]. Consequently there is a good potential to further discuss the acceptance and the utilizations in manufacturing industry.

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