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STUDY ON EFFECTIVENESS OF CLOUD COMPUTING IN IMPROVING THE PERFORMANCE OF MANUFACTURING INDUSTRIES

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Abstract

For the past few years, Cloud Manufacturing (CM) as a new manufacturing paradigm has accomplishing a huge amount of attention worldwide. Currently, many articles and review papers on Cloud Manufacturing are being published to speed up the research and to identify future trends. It is an emerging customer centric and service-oriented model to solve existing problems in traditional manufacturing. The aim of CM is to deliver and share ubiquitous on demand manufacturing service to consumers over internet which will enhance overall efficiency, reduce product cost, and allow for optimal resources. This is an innovative and web-based new paradigm which uses core information technology such as Cloud Computing, IOT, virtualization, radio frequency identification and service-oriented technology to solve complex manufacturing problems. However, the industry adoption of CM is still limited. The objective of this paper is to present fundamental concept model, participants, and architecture of Cloud Manufacturing. The paper also focuses on status of CM, benefits of implementation its model in industry and the future developments trends in manufacturing sector.

Keywords: Sustainable manufacturing, cloud computing, cyber-physical system, cloud manufacturing

I. INTRODUCTION

Cloud computing plays a pivotal role in the development of the global and sustainable manufacturing systems. Using cloud computing, product manufacturers and consumers interact with each other which helps in highly efficient rapid product development in minimum cost. A design and manufacturing cloud consists of collection of interconnected physical and virtual service pools of resources. Manufacturing industry professional need to know the characteristics of cloud computing-based manufacturing technology and its advantages as against the traditional manufacturing methods. The Internet- and web-based service-oriented system for machine availability monitoring and process planning is critical for sustainable manufacturing. This study discusses cloud manufacturing related research and development activities being carried out all over the world. It also presents the major challenges of developing and utilizing cloud computing technologies for manufacturing systems and services.

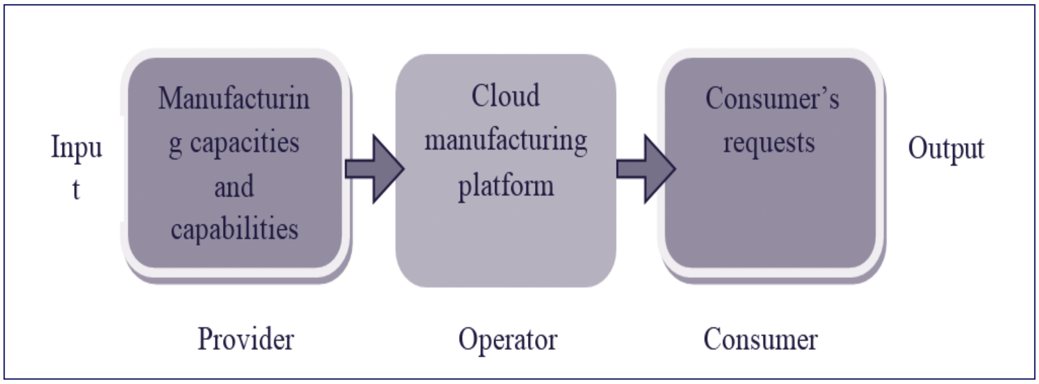
Manufacturing industry has always been a pillar industry of developed economics. To enhance national wealth and power reach nations are creating a high-quality manufacturing sector. As there is an increase in competitive pressure, rapid technology development and globalization, modern manufacturing requires a flexible and dynamic management. The traditional business models cannot sustain successful innovation because the old conventional ways of organizing work and services do not meet the level of agility, creativity and connectivity that companies require so that they can remain competitive in today's environment [1]. Hence, there is a need of adequate manufacturing approach, which addresses the issues and fulfills the current market demands and requirements. This gives birth to the concept of *Cloud Manufacturing.*

Cloud Manufacturing (CMfg) is a new manufacturing business model which is service oriented to share manufacturing capabilities and resources on a cloud platform. It merges the current informatized manufacturing technology and new information technology which transforms manufacturing resources and capabilities into manufacturing services. It builds a manufacturing service pool. CMfg is a platform where consumers can request services including product design, manufacturing, testing, management, and all other stages of a product lifecycle. Using this method, we can use the most sustainable and robust manufacturing route which results in customer centric supply chains. Modern technologies such as Cloud Computing, Service oriented Internet of Things (IOT), Virtualization, Radio Frequency Identification, Semantic web, and advanced high-performance computing technologies play a key role in CMfg. Customers could access the resources as services and manufacture their products. In this manner, they could use the distributed heterogeneous manufacturing resources for simple and complex tasks in supply chains. CMfg provides high quality, reliable and secure, relatively cheap and on demand manufacturing services to the users.

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 [35]. This short description is intended to serve as a means for broad comparisons of cloud services and deployment strategies while providing a baseline for discussion on the overall best uses for CC technology. The main factor which is restricting many industries to adopt CC technology is the security of their data for which they are mainly dependent on cloud service providers. Nevertheless, the main factor in favor of CC technology is that professionals get familiar quickly with its use as they are using IT extensively nowadays. Researchers have developed several models to identify the factors and to find their effect on adopting CM technology by any industry [36-41]. It is also noticed that CM has many issues that are restricting its acceptability to majority of users. It is always tough for the oraganisations to choose between a dedicated server within the oraganisation and cloud computing service provider.

The concept of Cloud Manufacturing was initially presented by the research group led by *Prof. Bo Hu Li and Prof. Lin Zhang in China in 2009*. After that, some related discussions and research were introduced. Some aspects of CMfg were studied by researchers while many other aspects of it need deeper investigations. It is a smart network manufacturing model that transforms manufacturing from production-oriented manufacturing to service-oriented manufacturing. The cloud manufacturing concept is recognized as one of the main directions in the development of the manufacturing industry. This network will provide high added value and global manufacturing services at low costs. The role of cloud of things in improving performance of small and medium enterprises in the Indian context is presented in [42] while the factors affecting the adoption of cloud of things are discussed in [43-47].

Fig. 1 Cloud manufacturing



II. CONCEPT MODEL AND PARTICIPANTS

The fundamental idea of cloud manufacturing concept is to confine manufacturing capacities, manufacturing resources and capabilities in networks. So that they can be available as services, according to the requirements and requests of consumers. In other words, manufacturing resources and capacities are transformed into production services that can be managed and operated in an intelligent and unified way. Cloud manufacturing reflects both the concepts of "*integration of distributed resources*" as well as concept of "*distribution of integrated resources*". As illustrated in Fig.1 a cloud provider, provides manufacturing resources and capabilities as cloud services through a cloud platform: a cloud consumer utilizes cloud services via a cloud platform to fulfill demands and a cloud operator operates and manages a cloud platform. Thus, cloud provider is an entity which provide manufacturing resources and capabilities as services for consumers. Cloud consumers purchase available manufacturing services from the provider. Operators manage the whole system and services.

Cloud manufacturing is often compared with other advanced networked manufacturing concepts e.g. networked, internet based, distributed and grid manufacturing. However, there are some fundamental dissimilarities. All the mentioned networked concepts focus on a single manufacturing task and the integration of distributed resources. They do not have a centralized operation management of the services and embedded access to physical manufacturing equipment, application, and capabilities. Moreover, due to almost lack of coordination between the resource provider and consumer these concepts are significantly less effective [2].

III ARCHITECTURE AND FRAMEWORK OF CM

Most researchers indicate manufacturing resources to be shared between three main types of actors participating in cloud manufacturing system. All of manufacturing capabilities require support from the related manufacturing resource, including soft resources (software, engineering, knowledge, skills, experience, business, networks etc.) and hard resources such as manufacturing equipment, computational resources, monitoring resources, storage and physical devices etc. Many researchers propose system architecture the development of cloud manufacturing platform. These architectures and structures of such platform differ in terms of number of layers and type of resources inserted in individual layers. Researcher Xu [3] presented a 4-layer system architecture which consists application layer, global service layer, virtual service layer and manufacturing resource layer. Lv [4] proposed a 5-layer system architecture including physical resource layer, virtual resource layer, core service layer, application interface layer and application layer. Similarly, different authors discussed CM architectures with different layers.

Most researchers designate manufacturing resources to be shared between three main types of actors participating in cloud manufacturing system. All of manufacturing capabilities require support from the related manufacturing resource, including soft resources (software, engineering, knowledge, skills, experience, business, networks etc.) and hard resources such as manufacturing equipment, computational resources, monitoring resources, storage etc. It is also necessary to consider other significant assets, the human capital of each individual employee and the social capital of the workers of the whole company.

Human capital is derived from competences, tactic knowledge, experience, skills, education, training etc. while social capital is composed of formal or informal relations among workers, teams, organizational units. The skills, experience, talent of individual people involved in cloud manufacturing system, as well as trust and collaboration of workers in company are the most significant and valuable resources of all enterprises operating in the manufacturing industry [5].

Fig. 2 Cloud Manufacturing Platform

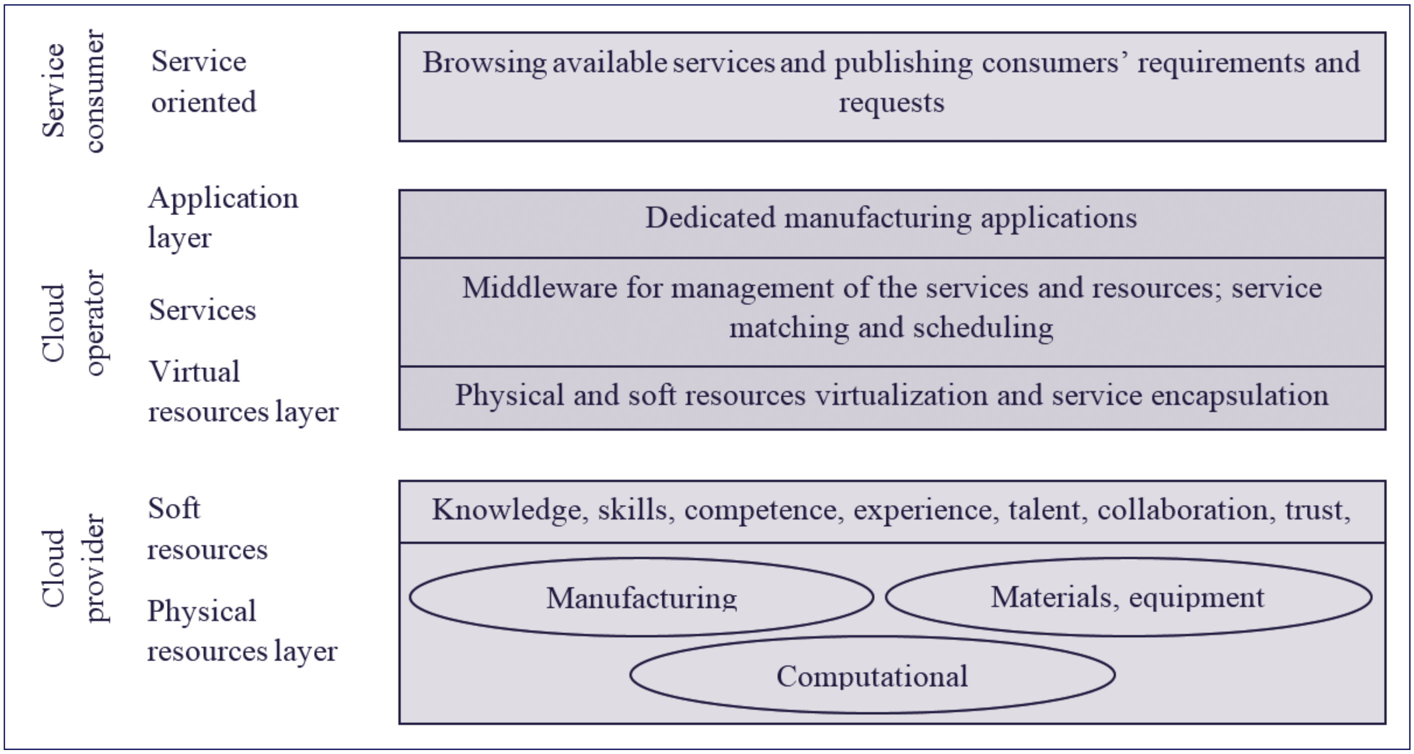


Fig. 2 shows proposed cloud manufacturing platform architecture consists of six layers: physical resources layer, soft resources layer, virtual resources layer, services layer, application layer and service-oriented resource layer. Provider collects manufacturing resources and capabilities into cloud. These resources are now accessible on demands and request of consumers. Provider's duty must also be to encapsulate and virtualized soft resources. A cloud manufacturing platform should also allow a variety of manufacturing resources and services to be connected. Platform should have the capability to identify the key information of the connected resources and to transform real manufacturing resources into virtual resources. Resource virtualization is the process of mapping resources from a real manufacturing to logical signals [6]. Operator's responsibility is to manage and operate a cloud platform and to utilize cloud services to fulfill user's demands. After requests of services by users, the virtual resource pool is searched automatically and a quick response for the request is given. Lastly, manufacturing services are output through the service-oriented interface layer.

IV CURRENT STATE OF CLOUD MANUFACTURING

A. Automation

In the realm of manufacturing, companies are implementing automated processes. Using automation, the supply chain becomes more global and these automation tools have an important impact on product quality and operations management. As automation adaption increase, automated equipment and process monitoring becomes more critical. Supervisory Control and Data Acquisition (SCADA), Distributed Control System (DCS) and Programmable Logic Controllers (PLCs) are some typical industrial control system. These utilized in both process based and discrete based manufacturing environments. SCADA is a system of software and hardware elements that allows industrial organizations to directly interact with devices such as sensors, pumps, motors, valves and more [7]. SCADA is typically utilized in gas and utilities industries. A DCS is a specially designed automated control system that consists geographically distributed control elements over the plant or control area [8]. It is commonly used in process intensive industries. PLCs are computer-based logic devices that control equipment and processes and they are often employed as a part of DCS system. Totally Integrated Automation (TIA) is one of the most advanced control systems proposed in industry, which offers a wide range of control technologies in both SCADA and DCS Environments. This TIA system is based upon open system architecture and promotes modularity and interoperability.

To establish machine to machine communication and to promote technology connectivity much work has been done. Developments in open architecture standards and communication will serve to facilitate automation technology. The MTConnect Institute [9] has developed open and royalty free communication standards based upon the Extensible

Markup Language (XML). As a result, to advance cloud manufacturing, the challenges associated with automation are: designing wireless smart sensor network based manufacturing system to keep track of actual time information, developing the unified standards for describing the functions, structure and behavior of interconnected equipment [1].

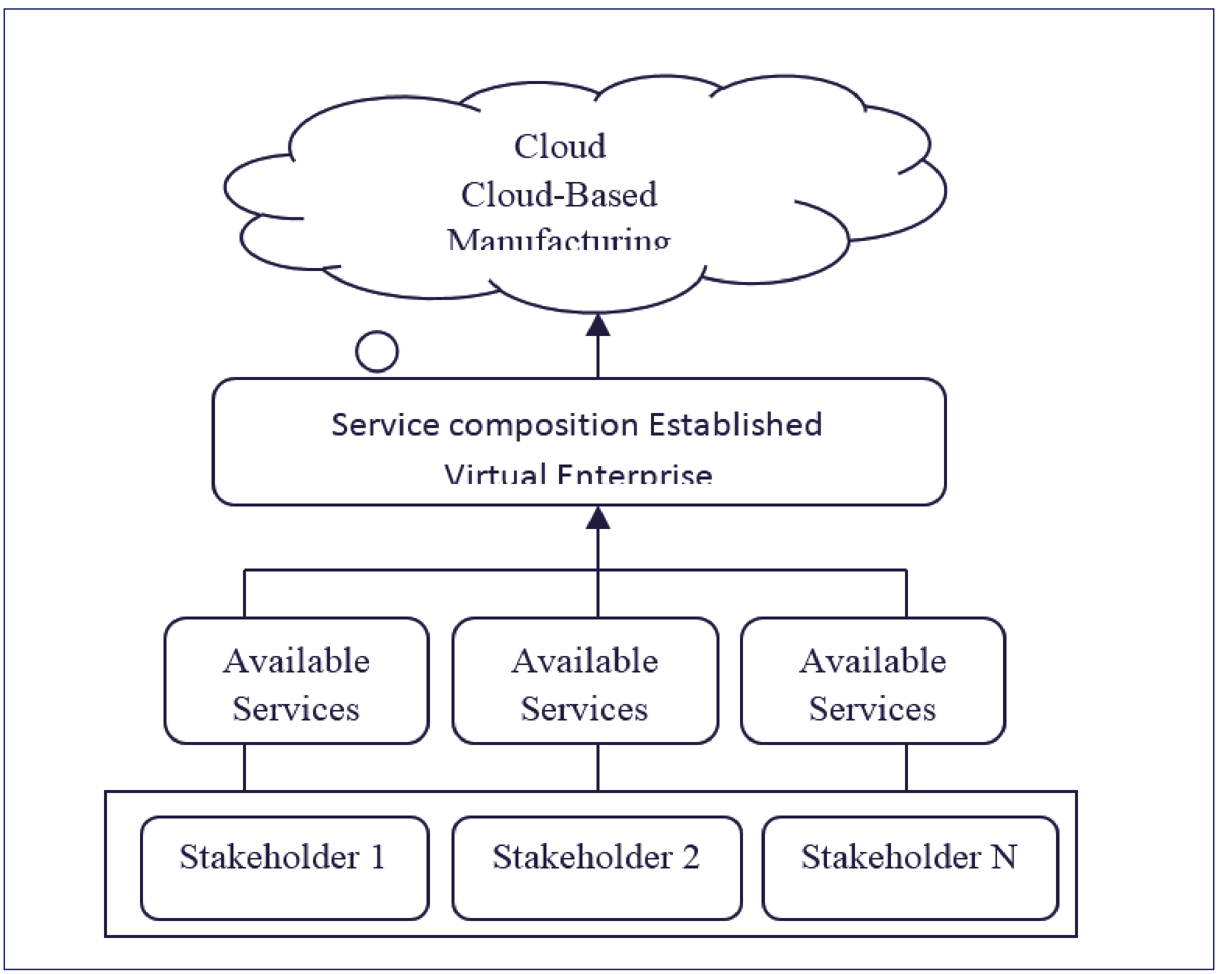
B. Inter-factory (PRPs) Integration

Researchers Wang and Xu [10] proposed interoperable Cloud Based Manufacturing System (ICMS). ICMS provides a cloud-based environment to integrate existing and future manufacturing resources (software tools and physical manufacturing devices), for that Virtual Function Block Mechanism and Standardize Description is used. Hence PRP is the key to ensure the efficiency of a CM platform. To implement PRP need is to create different cloud modes for different users grouping. Lu et al. [11] defined a Hybrid Manufacturing Cloud (HMC) which enables PRPs to create different cloud modes which can be private, community and public clouds. These created cloud modes can be used platform. HMC allows PRPs to define their own resource sharing rules for different clouds modes. In this way it increases PRPs control over their resources and enhance trust in the system [12]. Typical communication system used in the intra-factory environment such as Distributed Control Systems (DCS) is usually more reliable and allows faster transmittal of data than Supervisory Control and Data Acquisition (SCADA). However, they are not well suited for long distance communication.

C. Service Composition

Service composition represents the ability to provide useful manufacturing services to customers based upon available maximum resources. All the objects, features and resources that represents their state, information and mode operations are considered as services [13], which can be described, published and located over a network. Xu [3] discusses the formation of cloud manufacturing services which is enabled by the ability to identify, virtualized and package both tangible and intangible resources. He presents methodologies of identifying distributed resources which includes technology such as RFID, wireless sensor networks and global positioning system. One example of a CM service provided by Xu is STEP Resource Locator (STRL). This service uses an URL, Action and Query to identify a machine and task it with some request service instructions [1]. Zhang et al. [14] defines Resource Service Composition (RSC) as the integration of existing resources, which is used to form composite services in order to address complex manufacturing tasks. Authors discuss RSC has four stage lifecycle which are: design, deployment, execution, and post processing. These stages can be affected by numerous variables.

Fig. 3 Service Composition



Tao et al. [15] presents that the cloud manufacturing is in-part enabled by the creation of Manufacturing Cloud Services (MCSs). These services are formed when manufacturing resources are virtualized and encapsulated. He explains that MCSs can be categorized and combined into related manufacturing clouds. It allows consumers to select MCSs to form their required production facility. These services when working alone could be more difficult to perform the actions as per demands. Therefore, the combination of existing and available services from different enterprises is required which is known as Service Composition. It can perform both simple and complex tasks [16], [17].

D. Monitoring and Control of PRP Resources

Due to the dynamic nature of business environment, there are various uncertainties which can affect maximum business activities. These uncertainties disturb original schedule. Therefore, it is important to execute real time resource rescheduling adjustments. This can only be done if the real time resource status information across the cloud manufacturing is available. Yang et al. [18] proposed Dynamic Service Selection that utilizes IOT's real time sensing ability and huge data knowledge capabilities to improve service selection. IOT enables real time capture of disturbances and resource states. Big data technology is employed to extract knowledge about service qualities and market demands.

E. Flexibility and Agility

These terms are associated with the ability of a business to adapt market and environment changes in a productive and cost-effective manner. Panchal and Schaefer [19] define agility as the ability to successfully and quickly adapt expected and unexpected changes in the operating environment. They further emphasis that agility in manufacturing sector often deals with the ability to quickly adapt a manufacturing resource to produce a different component or assembly. Zhang et. al [14] discusses how the lifecycle of RCS's can be affected by numerous factor. These authors argue about the possible RSC interruptions. They state five forms of RSC flexibility are required for maximum system adaptability which is task, flow, Resource Service, QoS and correlation. These five categories are shown in Table I. The Management of RSC requires a Flexibility Management Architecture which is composed of three functional modules which is function, monitoring and coordination module. The function module is responsible for the construction, optimization, and execution of RSC. During RSC execution monitoring module monitors the variables which affects the RSC lifecycle and transmits information of abnormal changes to the coordination module. The Coordination module requests necessary adjustments to ensure continues smooth operations [1]. Hence, the challenges in terms of flexibility and agility to develop an effective resource virtualization framework for cloud manufacturing, which will increase resource sharing, reduce manufacturing cost, and accelerate product time to market.

Table I Flexibility Categories

Flexibility Type	Implication
Task Flexibility	RSCs can be constructed to adapt to many different tasks
Flow Flexibility	Many RSC paths can be used to reach the required final conditions
Resource Service Flexibility	Single resource services can complete many different tasks
Quality of Service (QOS) Flexibility	RSC can maintain a certain QoS, which is flexible
Correlation Flexibility	RSC can adapt to changes in correlation among resources

V. ADVANTAGES OF CLOUD MANUFACTURING

A. Hyper-Customized Solutions

Cloud based approaches allows manufacturing companies to enjoy the freedom of creating an infrastructure that is completely customized according to their current performance and future goals. Use of an efficient hosted cloud solution with combined initiatives into one platform, will reduce human and financial resource usage. Similarly, if manufacturing company grows it is essential that technology must be able to keep up.

B. Maximization of Performance and Efficiency

As the global competition is increasing, there is a constantly growing pressure for manufacturers to stay ahead of their competition in terms of accuracy, processing speed, benchmarks, response towards market and optimize cross channel interactions. Because of this highly competitive environment, power outages that cause downtime or data loss which can be devastating to manufacturing companies. Effective implementation of cloud computing offers a solution for that. With a single manufacturing system of record on hand, employees, suppliers, and partners can refer to one source for accurate information that ensures increased consistency while serving customers. As we know efficiency is about accomplishing more with fewer resources without compromising on quality. For a sustained growth, manufacturers must implement efficiency both for its own operations and for users. The way to do is through the cloud. Cloud based solutions decreases time-to-market and they are more straightforward than traditional methods. Thus, it saves both time and money. Embracing cloud computing also allows manufacturing teams to focus their energies on core business functions so that they can priorities core business functions [20].

C. Quicker Implementation

In hardware-based systems, investing in a new hardware and waiting for slow updates takes a lot of time which is eliminated in cloud-based systems. In cloud-based method web and updates are implemented rapidly without the interaction and labor costs.

D. Cost Effectiveness

Cost is a leading factor in conventional manufacturing methods, so that manufacturer choose cloud-based solutions. It gives them a big advantage since traditional systems contain a variety of expanses such as licensing fees, costs for updates, data storage, management fees, expenses for support and trainings, annual maintenance fees etc. This total expanse goes beyond the initial software purchase price. Cloud manufacturing reduces costs across operations and procurement, saves money on hardware and infrastructure. This frees up capital and creates more budgets for other areas of the business. A research conducted by Interactive Data Corporation (IDC) indicates that mature cloud adopters achieve millions of dollars in benefits.

E. On-demand delivery

To make on-demand delivery possible, a clear view of that demand is necessary. Smart, cloud driving manufacturing software can go through order history at different times and can use this data to create a forecast. Then according to this forecast demand and capacity planning are made. Any gaps can be easily identified and shared across the business for departments to plan and adjust their strategies as necessary [20]. According to the 2017 state of Manufacturing Technology report, 90% of manufacturing companies use cloud-based productivity applications which maximized their ability to effectively meet customer demand.

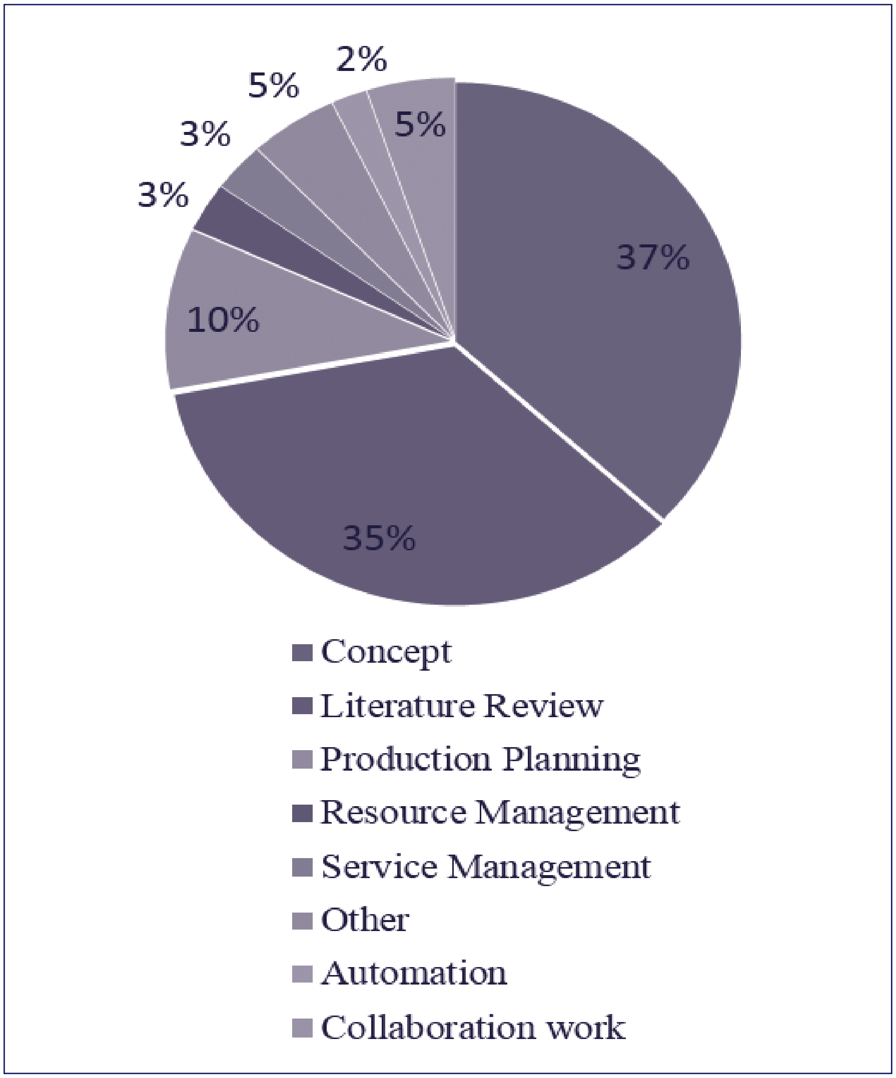
F. Accessibility of Features

Cloud based solutions come with faster updates, more features are implemented with each update. This way, it ensures industry is not lacking in terms of new core technology and features. This increases functionality of the system. Many cloud systems enable easy mobile accessibility, but caution required here, hence it puts attention on additional security concerns.

VI. FUTURE DRIFTS

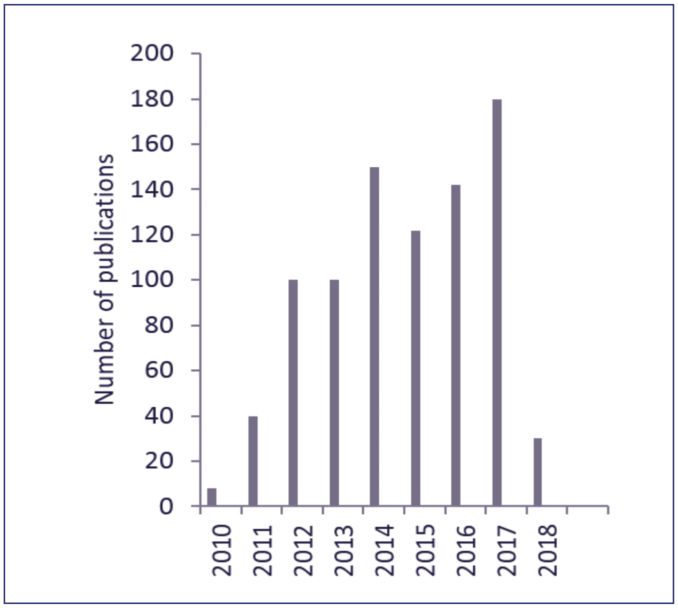
Research on cloud manufacturing has touched a huge variety of research topics. Some of them are related to operational mode, architecture, framework, user interface, security, resource and service related issues, energy consumption, supply chain, business process, logistics, transaction processes while some other are newly emerging topics like 3D printing, product and big data which are receiving attention recently. Fig. 2 shows various areas in which researchers are showing interest while Fig. 3 describes the number of publications on cloud manufacturing from 2010-2018. The statistics presented in the section are based on the data co

Fig. 4 Research Areas



collected on the date of 10 March 2018.

Fig. 5 Number of publications on CM from 2010-2017



A. Concept and Definition

Although researches on cloud manufacturing have been ongoing for years, still there is no unified and clear understanding about the concept. There are several major streams of research on cloud manufacturing, each of which have different perspective about the concept definition. In addition, the international cloud manufacturing community has not reached a consensus about the definition of cloud manufacturing [21]. Hence, there are some misunderstandings and questions towards cloud manufacturing. This clearly obstructs the further development and industrial implementation of cloud manufacturing. When defining the concept, both academic research and industrial implementation must be considered. Cloud Manufacturing is not an abstract concept for the manufacturing industry, but it is a concept driven by industrial requirements.

B. Customer Centricity

Over the last several decades, the evolution of manufacturing companies has been focused on process-based improvements. Methodologies such as Lean Manufacturing, Six Sigma, Cloud Manufacturing and Kanban are significantly increasing operational efficiencies. In the CM environment, manufacturing supply chain relationship will be customer centric which are defined by enhanced efficiency, reduced costs, increased flexibility, and improved capabilities. To derive these benefits creation of flexible manufacturing sequence is required enabled by pooling of resources from many different sources [1]. The key goal of a cloud manufacturing environment is to link users with needs, to resource providers. These providers will fulfill those needs while considering cost, schedule, and quality objectives of the user.

C. Robot

In the context of cloud manufacturing, it includes mainly robot control as a service and cloud robotics which provides a new technological approach to task execution and resource sharing. Adamson et al. [22] discussed the concept of adaptive robot control as a service in cloud manufacturing and presented associated enabling technologies for a distributed control approach for robotic assembly tasks. Wang et al. [23] proposed the approaches of cloud manufacturing and cloud robotics. He developed a cloud-based manufacturing system to support ubiquitous manufacturing. They addressed the issue of minimizing energy consumption of robot during assembly in a cloud environment.

D. Standardization

Standardization is of extremely importance to research and implementations of cloud manufacturing. The targets of standardization are diverse so that many standards organizations are focusing on their respective areas of expertise. It includes standardization of definition, standardization of service interface, standardization of core and enabling technologies, standardization of methods and procedure for the management and operation of a cloud manufacturing system, standardization of management network and standardization of communication protocols for machine to machine communication [24]. The basic purpose of standardization is to make applications more scalable, interoperable, and safe in the cloud.

E. Scheduling

To achieve the goal of providing on demand manufacturing services in cloud manufacturing, scheduling is one of the critical concepts. In manufacturing or production, scheduling can be defined as a process of arranging, controlling, and optimizing work or workloads. In the reference of cloud manufacturing, scheduling can be defined narrowly or broadly. In the narrow sense, scheduling refers only to the process of allocating resources or services to tasks, monitoring, controlling, and optimizing resource or service status to satisfy consumer's individualized requirements. In the broad sense, it emphasis on scheduling process in the narrow sense with many other activities such as task processing, service discovery, matching, composition and selection [25]. Thus, scheduling in the broad sense is a research topic which attracted huge attention in cloud manufacturing.

F. Hybrid Cloud

Hybrid cloud offers the benefits of both private and public cloud. It provides a greater flexibility to work between both the cloud solutions. For changing industry needs and cost, hybrid has an excellent performance. Users can protect their crucial data by storing it at the private cloud and in parallel can compute data using a resource stored in a public cloud [26]. Organization takes the benefits of cloud busting when there is an increase in application demand. Cloud busting is the situation in which application runs in a private cloud and can burst through a public cloud to utilize more resources. Hybrid offers additional resources to the organizations which can be used whenever required. Hybrid makes business more scalable and reduces the cost.

G. Information Security

In cloud manufacturing, huge amount of data from user and PRPs are shared with the service provider. This information can be quite sensitive which have data regarding the competitive advantage or strategies of the specific organization [12]. Security, including security of data, remote machines and operators is one of the most challenging issues that hinder the full application of cloud manufacturing. Therefore, CM service provider must ensure CM users that individual's information is in security system. This aspect of CM has not been solved yet. Large scale adaption of cloud manufacturing is almost impossible until security issue in cloud manufacturing is not solved.

H. Huge Data Analysis

During a running process of cloud manufacturing system huge amount of data is generated continuously. This data belongs to providers, users and operators, resources and services in the cloud and their transaction, consumers, and their orders. These data are of great significance for almost all activities in cloud manufacturing. As a result, big data analytics is a core technology for cloud manufacturing which help to convert the data from raw figures into actionable information and operations plans. Zhu et al. [27] discussed effective technologies for manufacturing big data cloud service platform. Yuan et al. [28] dealt with the issues of service data mining in cloud manufacturing and proposed a multi agent based data mining application model.

VII CONCLUSIONS

The manufacturing environment is changing rapidly mostly due to the innovation in Information and Communication Technology (ICT) and due to the Globalization. Hence a manufacturing system should be reconfigurable to adopt these dynamic environments. This system must have a goal of production of high-quality goods and enhancement in operational performance. Cloud Manufacturing which is emerging as a new business model is a possible answer to the current challenges in the manufacturing industry to remain competitive. The concept of cloud manufacturing is transforming the conventional manufacturing business model and allowing the manufacturers to create intelligent factory network. It is the right time for manufacturers to embrace the cloud. In this paper we reviewed concept model, framework of cloud manufacturing and recent studies in CM. We analyzed the drivers, current state, research areas and predicted the future trends. Lastly, the vision of cloud manufacturing development is promising but the research within this area is still in the initial stage. There is so more to grow with existing challenges in this field.

More and more professionals are getting knowledge and understanding of CM technology and its relevant benefits for different types of industries. Industries have got the idea that like Information Technology, CM technology can be used as a utility for making the existing manufacturing system more efficient, productive, and advance to survive in the market competition. It is equally important to analyze the challenges this technology offers from the user and customer point of view. It is the need of the hour to make it clear that CC technology can improve the productivity of any system as found in many studies.

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