# From Computer Integrated Manufacturing to Cloud Manufacturing

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Abstract.

Until not much time ago, Computer Integrated Manufacturing (CIM) was considered as a key philosophy to increase the capability and quality of production, increase the ability to produce according to the diverse customer requirements, as well as decrease of delivery times, while retaining the revenues in a highly competitive global market. However, in the last two decades, the CIM philosophy has lost importance. With the advent of communications and application developments to promote the interaction of different actors in manufacturing enterprises, other philosophies have emerged. One of them is Cloud Manufacturing (CM) that is supported by the latest advances in communications, computing and applications developments. According to Wu et al. (2013) CM 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". This paper analyses similarities and differences between the concepts of CIM and CM. In addition, the work shows the current state of the concepts and their potential and limitations for the future.

## 1 Introduction

The manufacturing environments have changed in order to achieve effective and efficient manufacturing strategies. The first changes were due to improvements in the mechanical aspects of manufacturing processes. The advances in mechanization facilitated mass production to meet the customers' requirements considering the quality and quantity of products. Thus, transfer lines and fixed automation were developed to achieve mass production. The next step of improvement resulted in the development of programmable automation (Foston et al. 1991) with the objective of accelerating the production process throughout the plant and increasing the quality of products.

The developments in information and communication technology (ICT) and the application of computers in the equipment have led to the emergence of various new manufacturing technologies, which are called as AMTs (Advances Manufacturing Technologies) (Hunt, 1987). Manufacturing enterprises can access to great number of AMTs with diverse features. Nevertheless, AMTs are not the complete solution for solving the problems of achieving effective and efficient manufacturing strategies.

The incorporation of ATMs by manufacturers has led to individual automation solutions which increased the need for a broad and systematic integration of manufacturing environments. In general, individual automation led to islands of automation in enterprises. The conformation of automation islands, the complexity of emerging manufacturing and communication technologies, increasing of market requirements as well as rising competition from abroad have forced the need of integration of the enterprises. The full benefits of automation in an enterprise are obtained through a planned integration. Several authors (Harrington, 1973; Liu, 1994; Vernadat, 1996, Nagalingam and Lin, 2008) have remarked the important benefits that can be achieved by pursuing the manufacturing integration in enterprises:

1. functional units of an enterprise can be easily communicated,
2. accurate data transfer among the manufacturing plant, and/or subcontracting facilities,
3. faster responses to required changes,
4. increased flexibility towards introduction of new products,
5. improved accuracy and quality in manufacturing processes,
6. improved quality of products,
7. effective control of data-flow among various units,
8. reduction of lead-times,
9. streamlined manufacturing flow from order to delivery,
10. a holistic approach to enterprise-wide issues.

In summary, integration gives an important competitive advantage by relating new and existing equipment as well as software, together with database management systems, data communications systems into a coordinated and efficiently management process. In addition, supplementary benefits can be obtained by considering cross-functional approach and integrating various technologies across all functional units of enterprises.

Integration of manufacturing enterprises has evolved from physical aspects to application integration, and then to business process integration (Vernadat, 1996). The integration of physical systems includes interconnection of manufacturing equipment, facilities, suppliers, customers and data exchange among the mentioned elements through computer networks. The combination and interaction of applications take into account the integration and interoperability of systems of diverse characteristics. Thus, the integration of applications considers sharing data and information among all equipment, facilities, suppliers, customers, distributed processing environments, and common services for execution environments. Finally, the integration also reaches the business activities where all functions, business processes and systems at an enterprise level (within an enterprise and beyond to business partners and customers) are taken into account. For example, relationship management with customers, e-commerce, global logistics, supply chain related applications are some relevant business activities to be integrated.

One of the most important outcomes of the search of integration in manufacturing environments was the developed of the concept of CIM, which was initially proposed by Harrington (1973). The earlier depiction of Harrington (1973) of the CIM concept considered to this as a control and communication structure to integrate a manufacturing system. However, the description of CIM has changed over time in function of the new ATMs, information technologies and the development of different paradigms associated with the business models. Therefore, manufacturing systems conceptually working with the initial CIM philosophy are not able to fulfill the requirements of globally distributed customers and compete with the capability of other enterprises. The former CIM concept was developed thinking on the internal integration of the enterprises and, for example, these do not have the capability of managing and exploiting the potential and strength that have geographical distributed enterprises. For that reason, more flexible and comprehensive methodologies have been required to overcome the physical distribution, sophisticated customer needs, facility sharing problems and communication obstacles. The concept of Distributed CIM (DCIM) has been coined in order to deal with the problems related with the physical interconnection of distributed enterprises, nevertheless more general and broad concepts than DCIM were developed, for example Virtual CIM (VCIM) and CM.

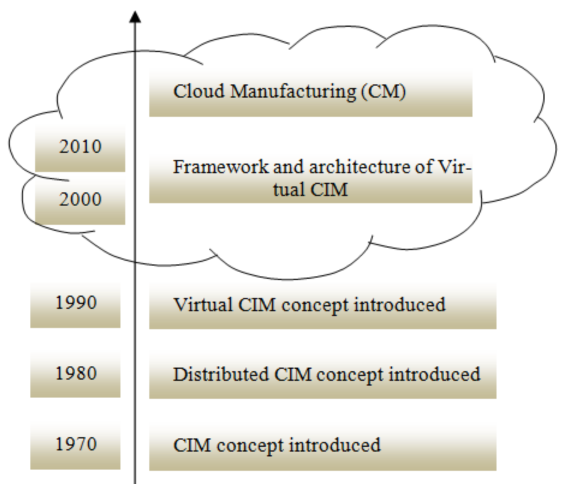


Figure 1. Evolution of key concepts for physical and conceptual manufacturing environment integration.

Figure 1 shows a summary of the evolution of key concepts for physical and conceptual manufacturing environment integration. In Figure 1, the last two items "Framework and architecture of Virtual CIM" and "Cloud Manufacturing" are concepts that depend strongly on the computing resources (e.g., networks, storage, applications, and services), therefore they are shown inside a cloud.

## 2. CIM concept

This section provides a reduced version of general architectural requirements for CIM. Many authors have proposed definitions for CIM (Nagalingam and Lin, 1999). One of the earlier definition of CIM states that it is the integration of manufacturing facilities and systems in an enterprise using computers and communication networks. Nevertheless, authors such as Rehg and Kraebber (2005) remark that CIM is a broader concept involving the integration of the total manufacturing enterprise through the use of integrated systems and data communications coupled with new managerial philosophies that improve organizational and personnel efficiency. Thus, Nagalingam and Lin (1999) consider that CIM is a management and manufacturing strategy valid for the newer application required today and for the future.

According to an initial vision of Nagalingam and Lin (2008), the CIM concept is able to fulfill with the requeriments of the competitive environment for manufacturing and the nature of the manufacturing enterprise in 2020 developed for a committee of experts commissioned for the National Science Foundation of United States of America (USA) in 1998. The committee of experts developed the report ¨'Visionary Manufacturing Challenges For 2020¨ (Committee on Visionary Manufacturing Challenges, 1998) where the most significant technical, political, and economic forces for manufacturing were identified:

- sophisticated customers will demand products that are customized to meet their needs,
- rapid responses to market forces are required to survive in the competitive climate, enhanced by communication and knowledge sharing,
- creativity and innovation are required in all aspects of the manufacturing enterprise to be competitive,
- developments in innovative process technologies will change both the scope and scale of manufacturing,
- environmental issues will be predominant as the global ecosystem get strained by growing populations and the emergence of new high-technology economies,
- information and knowledge will be shared by manufacturing enterprises and the marketplace for effective decision making,
- global distribution of highly competitive production resources will be a critical factor in the organization of manufacturing enterprises to be successful in this changing technical, political, and economic climate.

Nevertheless, the implementation of the original CIM concept is not forward due to several problems arise due to the dynamic nature of improvements in manufacturing applications and the impossibility of understand the most general implications of the concept by manufacturing manager.

New manufacturing and management strategies such as Lean Manufacturing (LM), Just-In-Time (JIT), Concurrent Engineering (CE), Cellular Manufacturing, agile manufacturing, responsive manufacturing, holonic manufacturing, distributed manufacturing, collaborative manufacturing and CM have begun to surface during these last decades. It is important to note that some of the mentioned terms are parallel concepts to CIM, while other terms were developed in order to address nowadays and future challenges considering the technical, political, and economic conditions of the manufacturing enterprises.

Some authors, such as Caillaud and Passemard (2001), proposed a methodology based on the relation between CIM and the particularities of the management of enterprises geographical distributed, which defined an extended production management. Nevertheless, a vision wider than the one of the previous authors that considers the globalization of the potential markets and production facilities, and the CIM philosophy has leaded to the VCIM concept. This new term was coined in order to focuses the CIM concept to the globalization of the potential markets and production facilities as well as the dynamic nature of improvements in manufacturing applications. According to Nagalingam and Lin (2008), VCIM is a more flexible and comprehensive methodology necessary to overcome the distance barriers, facility sharing problems and communication obstacles. Developments on VCIM are diverse including models and architectures for enterprise integration, evaluation methodologies for enterprise integration, and international collaboration. In addition, VCIM implementations involve integration of subsystems using network communications, application of wide-area networks, Internet and intranet based applications, information enhancement by data integration across various system boundaries. Furthermore, issues related to integration of client and server for manufacturing shop-floor automation, application of multimedia and hypermedia for VCIM environment, data management for VCIM systems, and others are to be investigated and integrated.

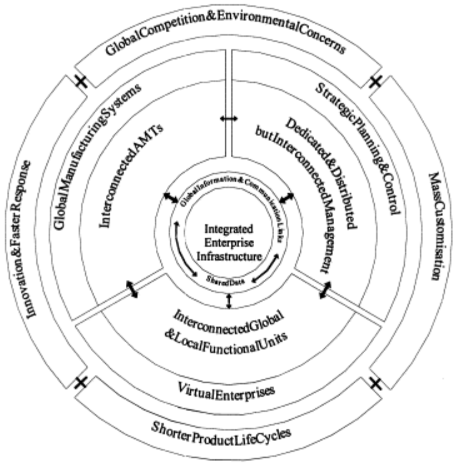


Figure 2. New CIM wheel formalizing the concept of VCIM (adopted from Nagalingam & Lin, 1999).

A first formalization alternative of the VCIM concept to represent the evolving process and the need of meeting the global market and actual environmental conditions, is the new CIM wheel, that was developed by researchers of the Centre for Advanced Manufacturing Research (CAMR) of University of South Australia and presented by Professor Grier Lin at his keynote speech at the Fourth International

Conference of Computer Integrated Manufacturing in Singapore in 1997. The concept of VCIM enhances the CIM wheel (See Figure 2) developed by the Society of Manufacturing Engineers (SME) in 1992.

New CIM wheel represents:

- the present world situation describing features such as global competition, environmental concerns, mass customization to satisfy the variety of customer requirements, shorter product life cycles of the product, and requirement for innovative products and of faster response,
- the global systems and concepts needed to address the present world situation,
- briefly how the concepts and systems can be realized,
- the need for global information and communication links, as well as the requirements to share information among systems,
- the final expected results of CIM, considering the global integrated enterprise through an integrated architecture.

The research on VCIM systems must consider a wide variety of aspects (Wang et al., 2004, 2007). Thus, the study must include the definition of architectures and modeling formalisms for enterprise integration, evaluation methodologies for enterprise integration, and collaboration platform for VCIM implementation through integration of subsystems. Furthermore, to facilitate the conformation of a VCIM system, network communications should take into account application of wide-area networks, Internet and intranet based applications, information enhancement by data integration across various system boundaries. In addition, topics related to the integration of customers and suppliers for automatic manufacturing activities and data management for VCIM systems must be investigated and detailed. Son et al. (2016) remarked that a lot of work needs to be done to build a real VCIM system and, in addition, they stated that few theoretical works have been done (Lin et al., 2000; Wang et al., 2004, 2007; Nagalingam et al., 2007; Dao et al., 2012, 2016) and real VCIM systems do not exist yet.

## 3. CM concept

According to Wu et al. (2013), Cloud Manufacturing is derived from the introduction and success of Cloud Computing (CC). The National Institute of Standards and Technology (NIST) defined CC 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 and Grance, 2011). CC has proven to be a disruptive technology in its initial application field of information technology (IT) (Wu et al, 2014). It takes advantage of existing technologies such as Utility Computing, Parallel Computing, and Virtualization (Foster et al, 2008). Some of its main characteristics include agility, scalability and elasticity, on-demand computing, and self-service provisioning (Putnik et al., 2013). CC is considered as a field of multidisciplinary research as a result of the evolution and convergence of several computer trends such as Virtualization, Distributed Computing, Storage, Content Outsourcing, Grid Computing (GC), etc. In fact, CC can be considered the business-oriented evolution of GC (Foster et al., 2008).

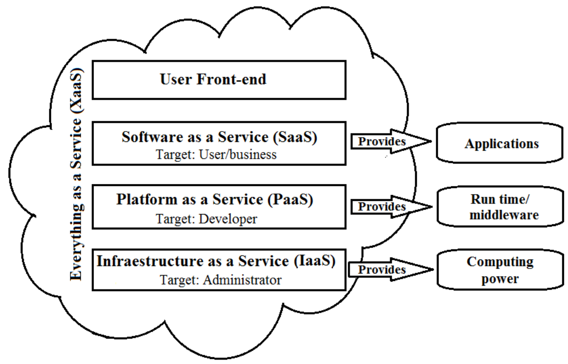


Figure 3. Cloud Computing: Everything is treated as a service (XaaS) (Based on Pallis, 2010; and Xu, 2012).

Pallis (2010) and Xu (2012) mentioned that in CC everything is treated as a service (i.e. XaaS.), e.g. SaaS (Software as a Service), PaaS (Platform as a Service) and IaaS (Infrastructure as a Service). These services define a layered system structure for CC, which is depicted in Figure 3. Processing, storage, networks and other computing resources are defined at the infrastructure layer (IaaS) as standardized services over the network. Clients of cloud providers can deploy and run operating systems and software for their underlying infrastructures. The middle layer (PaaS) provides services for developing, testing, deploying, hosting, and maintaining applications in the integrated development environment. The application layer offers a complete application set of SaaS. The user interface layer (User Front – end) enables seamless interaction with all the underlying XaaS layers (Pallis, 2010).

The implementation of CC means a paradigm shift of business and IT infrastructure, where computing power, data storage and services are outsourced to third parties and made available to enterprises and customers as commodities (Xu, 2012).

Building on NIST's definition of CC, many authors have proposed definitions of CM, including Li et al. (2010), Zhang et al. (2014), Zhang et al. (2010), Xu (2012), and Wu et al. (2012). In this direction, the concept of CM is considered as a new manufacturing paradigm, i.e. CM is a computing and service–oriented manufacturing model developed from existing advanced manufacturing models, e.g. Application Service Provider (ASP), Agile Manufacturing (AM), Networked Manufacturing (NM), Manufacturing Grid (MGrid), and enterprise information technologies under the support of Cloud Computing (CC), service–oriented and advanced computing technologies (Tao et al., 2011, 2012).

Many technologies have been used to support CM. Among all the technologies, CC and IoT (Internet of Things) influence the development of CM in a strong way (Wu and Xu, 2015). CM transforms manufacturing resources and manufacturing capabilities into manufacturing services, which can be managed and operated intelligently and unified in order to enable the complete exchange and circulation of manufacturing resources and manufacturing capabilities. CM can provide safe, reliable, high-quality, on-demand and cheap manufacturing services for the entire manufacturing lifecycle. The manufacturing concept includes the entire lifecycle of a product (Li et al., 2010; Zhang et al., 2014; Zang et al., 2011).

According to this definition, CM is a concept aimed to offer on-demand manufacturing services from networked (i.e. cloud-enabled) manufacturing resources, which imitates the service paradigm of CC promoting everything is treated as a service (XaaS), e.g. design as a service, simulation as a service, production as a service, assembling as a service, testing as a service, and logistics as a service. Since the manufacturing resources and capabilities are shared (as services) through the Internet, CM, in particular, is considered beneficial to small and medium-sized enterprises (SMEs) (Yu et al, 2015). Moreover, CM aims to achieve full shared use and circulation, high utilization and on-demand use of various manufacturing resources and capabilities by providing safe, reliable, and high quality, cheap and on-demand manufacturing services for the entire life cycle of manufacturing (Tao et al., 2011).

Figure 4 gives an idea about the abstract operation principle for CM. In a CM system, by means of IoT technologies (e.g. RFID, wired – wireless sensors, embedded system), different manufacturing resources and abilities can be intelligently sensed and connected into Internet, and automatically managed and controlled (Tao et al., 2012). Then, the manufacturing resources and abilities are virtualized and encapsulated into different Manufacturing Cloud Services (MCSs) that can be accessed, invoked, deployed, and on-demand used, based on knowledge, by using Virtualization technologies, Service-oriented technologies, and CC technologies (Tao et al., 2011). The MCSs are classified and aggregated according to specific rules and algorithms, and different types of manufacturing clouds are constructed. Different users can search and invoke qualified MCSs from a related manufacturing cloud according to their needs, and assemble them to be a virtual manufacturing environment or solution to complete their manufacturing task involved throughout the life cycle of manufacturing processes under the support of CC, service-oriented technologies and advanced computing technologies. Moreover, Figure 4 shows that there are three category users in a CM system, which can be described as follows:

1. Resource Providers: they can take the form of a person, an organization, an enterprise, or a third party. They own and provide the manufacturing resources and abilities involved in the whole life cycle of manufacturing process, where consumers were in charge.

2. Cloud Operators: they operate the CM platform to deliver services and functions to providers, consumers, and third parties. They deal with the organization, sale, licensing, and consulting of the MCSs, and provide, update, and maintain the technologies and services involved in the operations to MCSs and the platform.

3. Resource Users or Consumers: they purchase the use of the MCSs from the operator on an operational expense basis according to their needs. They are the subscribers of the MCSs available in a CM service platform (Tao et al., 2011).

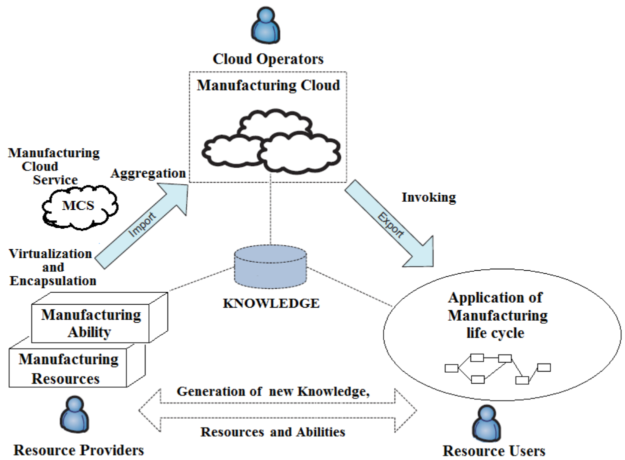


Figure 4. Principle for CM system (based on Zhang et al., 2014, and Tao et al., 2011).

## 4. Comparison of Philosophies

It is important to note that the concepts of CIM, VCIM and CM are not new, and VCIM and CM represent alternative philosophies to deal with competitive environment for manufacturing and the nature of the manufacturing enterprise. Table 1 summarizes the basic differences among CIM, VCIM and CM. From the focuses and the perspective of the philosophies, it can be understood that VCIM and CM are driving forces of the Fourth Industrial Revolution, while CIM is a driving force limited to local and centralized enterprises. Considering the objective of integration of the philosophies, CM was conceived for allowing vertical and horizontal cooperation of suppliers, customers, machines, enterprises in real time. Nevertheless, CIM is defined as an improvement process that never ends. In relation to the manufacturing perspective, CIM adopts the manufacturing as an activity of a company, VCIM as an activity of related companies, while CM as a service of related companies. The information technology perspective indicates that CIM is focused on the system, VCIM on the product, and CM on the service.

Finally, taking into account the philosophies' origin, it is worth remarking that CM arises of the application to manufacturing environments of multidisciplinary researches connected with the progress and union of several computer trends (Virtualization, Distributed Computing, Storage, Content Outsourcing, Grid Computing). On the other hand, in a first instance, CIM is an integration philosophy without direct association with specific information technologies and advanced manufacturing technologies.

Table 1. Differences among CIM, VCIM and CM.

| Parameters | CIM | VCIM | CM |
|---|---|---|---|
| Industrial Revolution | Driving forces of the Third Industrial Revolution | Driving forces of the Fourth Industrial Revolution | Driving forces of the Fourth Industrial Revolution |
| Focus | Integration of all activities of an enterprise, considering the following three basic elements: man, business, technology (Wu et al, 2007). | Integration of all activities in a network of enterprises to share resources and management objectives through information integration, in a cohesive manner to work as a seamless global CIM system. | Integration of 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. |
| Integration Time | The integration is achieved after a given period of time. | The integration is achieved after a given period of time. | Real-time integration. |
| Type of organization | Local and centralized enterprises. | World-wide cooperation of enterprises. | World-wide cooperation of enterprises. |
| Manufacturing perspective | Manufacturing as an activity of an enterprise. | Manufacturing as an activity of linked enterprises. | Manufacturing as a service of linked enterprises. |
| Information Technology perspective | System-centred. | Product-centred . | Service-centred. |
| Origin of the philosophy | Based on computers and communication networks coupled with new managerial philosophies. | Based on the CIM philosophy but including more flexibility and breath to overcome the distance barriers, facility sharing problems and communication obstacles. | Based on the developments of multidisciplinary researches resulting in the evolution and convergence of several computer trends |

## 5. Conclusions

It can be said that the concepts of Virtual CIM and CM are much related to each other. In addition, VCIM and CM are modern and extensive concepts to supply solutions to manufacturing enterprises looking for stay alive in the current dynamic, competitive and global markets. However, it should be noted that in recent times the philosophy of CM has garnered more attention than VCIM. One advantage of CM is that it has been considered as a strategy of integration of manufacturing companies that arises from the advances of technology, computer science, communication networks, and Internet-based business models that have been developed in various areas of knowledge. Therefore, since CM is a strategy directly related to new technologies, its practical implementation is of a bounded complexity. On the other hand, VCIM is a concept of integration conceptually stronger than CM due to its origin in the CIM philosophy, where technological advances are considered as tools to achieve integration objectives. However, the practical implementation of VCIM-based systems has been very complex for many managers because of the impossibility of understand the most general implications of the concept and the gap between the aspects to be implemented of the philosophy and the developed technologies.

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