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A Critical Review on Digital Manufacturing

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Abstract -*The fierce global competition and rapid technology development faced by manufacturing industry have been forcing enterprises to evolve at an unprecedented rate. In order to survive and succeed in such a turbulent and dynamic environment, enterprises are striving to improve their competencies to meet the requirements for rapid response to different market opportunities including massive customization of products, high product quality, low product cost, and rapid response services. Moreover, the sustainable concerns, not only on economy, but also on environment and society, also force enterprises to examine their strategies in the full lifecycle of the products/services and to engage in a new competitive climate. One of the technique that helped the enterprises is digital manufacturing which is originated from the numerical control technology and based on the concept of "digital earth". It enables the production in a digital space and focuses on the digitized technologies, such as digital modeling, digital machining, digital resource, digital service, and digital maintenance, for supporting the overall manufacturing performance optimization during the whole product life cycle. This paper reviews the different concepts, development ,applications, and benefits of the digital manufacturing.*

Key Words: **Digital Manufacturing (DM) , Computer networks , Rapid Prototyping , Digital Networks**

1.INTRODUCTION

Digital Manufacturing is a manufacturing process which, with the support of technologies such as virtual reality, computer networks, rapid prototyping and database, is based on customer demand so as to analyze, organize and recombine the product information, process information and resource information, implement the product design and function simulation as well as rapid prototyping, and then to perform rapid production to meet customer demand and quality standards. As a new discipline of manufacturing science, it synthesizes various manufacturing disciplines and represents the mainstream development direction of Advanced Manufacturing Technology.[1]

The conception of DM originated from the technology of Numerical Control (NC) or Computer Numerical Control (CNC) and the CNC machine tool. Digital design and digital management have fully developed along with the advancement of CAD and the development of material requirements planning (MRP). In the last 10 years, with the support of virtual reality, computer network, rapid prototyping, multi-media and so on, the simulation and prototype manufacturing of the design and the functions of product can be quickly realized by rapidly analyzing, planning and recombining, coordinating and sharing of all kinds of information (e.g., product information, process information, control information and resources information), to manufacture the product according to the user's requirements as soon as possible. All the processes involved with the above digital activities are related to DM. [2] In the process, the control parameters and control flow to manufacturing equipment are digital signals; all kinds of signal to manufacturing enterprises, including design information, process information, manufacturing information, management information and manufacturing knowledge and skill, are transmitted in the form of digital signals among manufacturing enterprises through the digital network. Speaking of global manufacturing, all users issue their demands through a digital network and enterprises can design and manufacture the corresponding product according to their own predominance with the help of dynamic alliances. The product itself will become a digital code or a digital mark in the currency along with the appearance of digital logistics. It is clear that the concept of DM is the result of the merging process of digital technology, network information technology, manufacturing technology and also the unavoidable result of the digitizing process in manufacturing enterprises, manufacturing systems and production systems. In the DM environment, individuals, enterprises, shop floors, devices, sales agents and markets form the nodes in the network over the Internet. On the other hand, DM contains the Control-Centered DM, Design-Centered DM, Management-Centered DM and Manufacturing-Centered DM. Currently, networked manufacturing is the implementation of the globalization of DM, virtual manufacturing is the entity of the digital factory, and digital products and e-commence are the dynamic federation of DM. The concept of DM is shown in (Figure 1)[3,4,5]

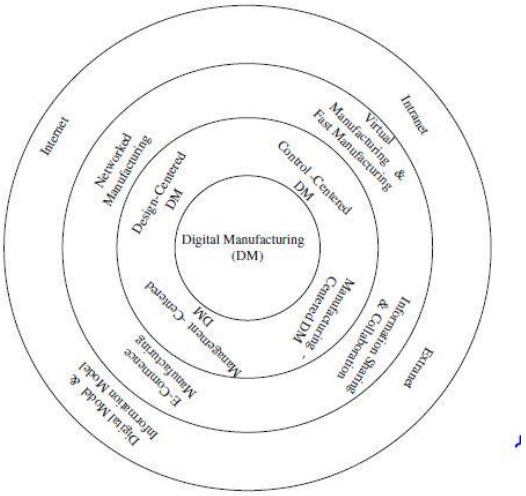

Figure 1 Concept of Digital Manufacturing

The digital manufacturing can be used in the following areas

- Manufacturing Planning
    1. Define High-Level Manufacturing Processes
    2. Process Planning (Assembly & Installation)
    3. Define Work Instructions & Work Flow
    4. Detailed Process Design & Analysis
- Detailed Resource Modelling & Simulation
    1. Process Definition and Validation
    2. 3-D Factory Layout
    3. Equipment, Tool & Fixture Simulation
    4. Ergonomic Simulation
- Validation & Virtual Commissioning
    1. Control Logic Validation
    2. Kinematic (Robotic) Validation
    3. Quality Assurance/Process Improvement Validation
    4. Sensor/Metrology Placement Validation
    5. Virtual Commissioning/Validation of Automation Systems
    6. Knowing that the Production System Works Prior to Launch: Priceless.

2. CONCEPT OF DIGITAL MANUFACTURING

2.1 Manufacturing Idea Taking Control for Center

The concept of DM is first generated from numerical control technology (NC or CNC) and NC machine tools. NC technology gives directions expressed in numbers and characters and controls machines with those directions. Not only does it control position, angle, speed and mechanical parameters, but it also controls temperature, pressure, flow and other parameters. These parameters can not only be expressed in numbers but also are measurable and controllable. If one device uses numeric commands to achieve its automatic process, we call it NC equipment. Obviously, it is far from DM, but is a very important basis for DM. With the development of numerical control technology, the multiple-machine has emerged, which is a manner to achieve integral controlling by one (or several) computer numerical control devices; this is the so-called Direct Digital Control. To achieve automation with many varieties and a small production batch, the collaborative operation between a number of CNC machine tools and one industrial robot develops in order to process a group or several groups of parts with similar shape and characteristics, thereby the so-called flexible manufacturing cell (FMC) is constituted. [6] Supported by a logistic automation system, a large-scale machining automation will be realized by combining a number of FMC or workstations together, which constitutes a FMS. FMS achieves the token, storage and control of material flow, the machining flow and control flow in the machining process by digital quantity. Digital control can make manufacturing processes automatic, detect and control parameters of the manufacturing process, notify faults and even propose decision making and the suggestion of maintenance. With the development of network and computer technologies, a Local Area Network (LAN) constituted by networking more than one NC machine tool could make the production processes of a number of workshops automatic. Furthermore, the controller or control system in each piece of equipment will become a node in the Internet, which leads to the manufacturing process developing in the direction of automation with a larger scale and at a higher level. It is the so-called DM idea that takes control for center.

2.2 Digital Manufacturing Idea Taking Design for Center

Since the development of computers and the combination of computer graphics and mechanical design technologies, computer-aided design (CAD) has been developed, the core of which is the database, the means of which is an interactive graphics system and the mainstay of which is engineering analysis and calculation.[7] The CAD system can describe an object accurately in two-dimensional and three-dimensional space, and improve the ability to describe products and productivity in the production process. The emergence and development of CAD lays the foundation for the automation and digitalization of the product design process in the manufacturing industry, which is the same as NC technology

and NC machine tools. First, the product design information in CAD will be transformed into information about a product's manufacturing and processing rules. The processing machines will be combined and ordered according to the scheduled procedure and work stages. Cutters, fixtures and measuring tools are then selected, cutting parameters are determined, and the maneuvering time and auxiliary time in each procedure are calculated. We call this computer-aided process planning (CAPP).We transform all plans including manufacturing, detecting, assembling, etc., and all information involving product-oriented design, manufacturing, processing, management, cost accounting, etc., into data that are understood by the computer and are shareable in all the phases of the manufacturing process, which makes the CAD/CAPP/CAM integrative, so that CAD rises to a new level. In recent years, computer networks have provided a platform to enable CAD technology to coordinate and cooperate to be able to design online. Network technologies and information technologies are developing fast, and multimedia visual environment technology, product data management system, distributed cooperative design and cross-platform, cross-regional, synchronous and asynchronous information exchange and sharing, as well as group collaboration and intelligence design between multi-businesses, multi-teams, many people, multi-applications, are all the subject of deep research and are entering into the practical stage, which forms a digital manufacture idea that centers on design.

2.3 Digital Manufacturing Idea Taking Management as its Center

Through the establishment and implementation of internal MRP, according to ever-changing market information, users orders and forecasts, aimed at the overall and long-term interests and through the decision-making model, we could evaluate the production and management of an enterprise, forecasts its future and operating conditions, devise an investment strategy and arrange the assignment of production, all of which form the highest level of the manufacturing production system— the management information system (MIS).[8] In order to support the management and production process in manufacturing enterprises to reconstruct and integrate rapidly in accordance with market requirements, there is a products data management (PDM) system covering the entire enterprise that involves the market demand for products, research and development, product design, engineering manufacture, sale, service, maintenance and other information in the product lifecycle, and thus the process integration centering on ''product'' and ''supply chain'' is achieved. Presently, enterprise requirement planning (ERP) is the modern management platform based on information technology is extensively applied, because ERP has both information technology and advanced management thought, so that the logistic, information flow, capital flow, working flow in enterprise management activities are easily integrated and synthesized.[9,10] Therefore, the DM idea that centers on management is formed.

2.4 Digital Manufacturing Idea Taking Manufacturing as its Center

In recent years, supported by the theory and technology of virtual reality and virtual manufacturing, network manufacturing and E-manufacturing, rapid prototyping and rapid manufacturing, according to users' requirements, we are able to analyze, plan and reorganize, coordinate and share product information, processing information, control information and resource information quickly, realizing the simulation and prototyping of manufacturing to produce design and function, and to produce products that meet user requirements quickly. In the whole life cycle of product manufacturing, whether manufacturing equipment /manufacturing process, whether manufacturing shop / manufacturing enterprise, whether manufacturing information/manufacturing network, whether manufacturing culture/ manufacturing personnel, various information (including design information, process information, manufacturing information, management information, even manufacturing knowledge and skills, manufacturing culture and manufacturing circumstance) in the manufacturing process, all transfers in the manufacturing process, and internal enterprise as well as collaborative enterprise, is in the form of digital information through the digital network. Users publish demand information through the network, and various global enterprises realize complementary advantages and make dynamic alliances to collaboratively design and manufacture corresponding products through the digital network, according to their superiority. In short, in the DM environment, a net woven by figures and information is formed over a wide area, and individuals, enterprises, workshops, equipment, products, dealers and markets will all become a node, a mark or a digital code. In the process of design, manufacture, sale and maintenance, the DM information and technology assigned by the product will become the most active drive factors that dominate the manufacturing industry. DM science fused by DM theory and technology and the theories and technologies of other

subjects will become the core of manufacturing science in the twenty-first century.

3. DEVELOPMENT OF DIGITAL MANUFACTURING

Manufacturing is defined in the Oxford English Dictionary as the action or process of manufacturing something; production, fabrication, and also the sector of the economy engaged in industrial production. Original manufacturing was accomplished by hand, but most modern manufacturing operations are highly mechanized and automated. The history of manufacturing is as long as the history of human civilization, and it has become the basis of human existence and development. We cannot imagine how the world would be without manufacturing, thus manufacturing develops with the progress of human beings, and manufacturing technology progresses alongside the progress of human society. In the long historical process, manufacturing has always existed as a skill. In early times, people processed rough fur by hand for warmth, hunted by creating simple tools and made the original equipment used for cooking. These simple tools and skills led to human progress. Manufacturing as the evolution of a skill made human history develop from the Stone Age into the Bronze Age, while early handcrafts and skills formed European manufacturing processes; for example, the ancient paraffin casting process is widely used in modern rapid prototyping manufacturing.

Modern manufacturing originated in the West. It gradually progressed into mechanical manufacturing in the nineteenth century and progressed in the direction of mechanization and electrification. From the 1980s, many new manufacturing methods and manufacturing concepts emerged, which greatly propelled the development of manufacturing. These new concepts guide us to analyze and anticipate the future of manufacturing, and these concepts (e.g., Automated Manufacturing, Agile Manufacturing, Concurrent Engineering (CE), Computer Integrated Manufacturing (CIM) and Intelligent Manufacturing, etc.) mutually promote and develop, analysis and looking ahead to future manufacturing. From this period on, manufacturing is no longer a single skill or technology, but a science including engineering science, organization science, information science and so on.

Since the middle of the twentieth century, science and technologies, such as microelectronics, automation, computers, telecommunications, networks and informatics, have undergone rapid development, and a tidal wave that has information technology at its core has been raised. The twenty-first century, which is marked by ‘‘network’’ and ‘‘informatization’’, will change the way of obtaining, processing, exchanging and using information and knowledge by human and will propel an unprecedented improvement of people’s lifestyle, production patterns and social structure. On this basis, new concepts, new theories, new technologies new ideas and new methods are endless. The concepts of digital library, digital valley, digital home, digital enterprise, digital economy and even ‘digital earth’, which is the common framework used to describe the time sequence and spatial distribution of various information on the earth , are the same as the research works, which are constantly being introduced and have begun to enter our lives. As the basis of the national economy, the manufacturing industry is shouldering the important responsibilities of providing technical equipment to national economic sectors and national defense construction and supplying living materials and wealth for people’s material life. For nearly half a century, as science and technology have undergone rapid development and a new technology revolution, and the manufacturing industry now faces the challenges of three major outstanding issues that are network, knowledgeable services, and the consequent complexity. Thus it is hard to control the nonlinearity, time variability, suddenness and imbalance of organizational structure and functions in manufacturing systems through traditional operation modes and control strategies. In addition, along with the rapid changes in market demand, global economic competition and the rapid development of high-tech, the profound revolution in the manufacturing industry is also further promoted, the depth and width of manufacturing activities are greatly expanded, and the manufacturing industry is developing in the direction of automation, intelligence, integration, network and globalization . Consequently, profound changes in the token, storage, processing, transmission and machining of manufacturing information takes place, so that the manufacturing industry gradually shifts from the traditional energy-driven state to being information-driven.[11] Digitalization has become the indispensable drive factor in the product lifecycle of the manufacturing industry, thus DM becomes a new manufacturing mode to adapt to the increasingly complex product structure, increasingly personalized, diversified consumptive demand and large manufacturing network, and naturally becomes an important feature in the future development of the manufacturing industry.

4. RECENT DEVELOPMENTS

Recent developments in digital manufacturing may be categorized into two major groups. The developments of the first group have followed a bottom-up approach considering digital manufacturing, and extending its concepts, within a wider framework, e.g. the digital factory or enterprise. The developments of the second group have followed a top down approach considering the technologies in support of individual aspects of digital manufacturing, e.g. e-collaboration and simulation.[12] According to the Verein Deutscher Ingenieure, the digital factory includes models, methods, and tools for the sustainable support of factory planning and factory operations. It includes processes based on linked digital models connected with the product model. At a theoretical level, several researchers have contributed to the definition of the digital factory vision and suggested how this vision could be implemented in reality (Figure 2).[13,14] Data and models integration has been a core research activity to support implementation. The introduction of consistent data structures for improving the integration of digital product design and assembly planning and consequently supporting a continuous data exchange has been investigated in the literature .Similar activities have focused on the definition of semantic correlations between the models distributed as well as the associated databases and the introduction of appropriate modelling conventions . On top of these developments, a number of methodologies for computer-supported co-operative development engineering, within a digital factory framework, have been published. Some researchers further suggested software architectures for relationship management and the secure exchange of data

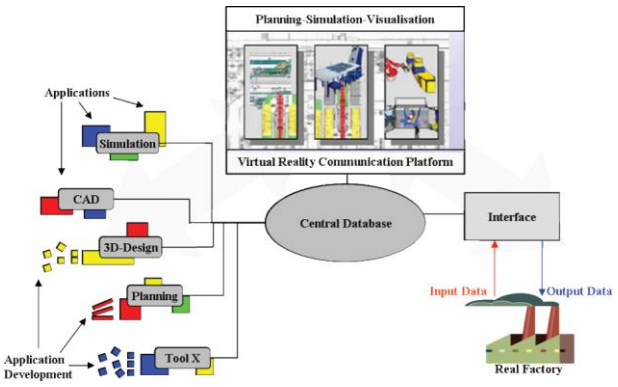

Figure 2 The vision of the digital factory

The new concept of digital enterprise technology (DET) has also been recently introduced as the collection of systems and methods for the digital modelling of the global product development and realization process in the context of life-cycle management. As such, it embodies the technological means of applying digital manufacturing to the distributed manufacturing enterprise. DET is implemented by a synthesis of technologies and the systems of five main technical areas, the DET 'cornerstones', corresponding to the design of product, process, factory, technologies for ensuring the conformance of the digital environment with the real one, and the design of the enterprise. On the basis of the DET framework, a new methodology has been suggested that focuses on developing novel methods and tools for aggregate modelling, knowledge management, and test on validation planning to 'bridge' the gap that exists between conceptual product design and the organization of the corresponding manufacturing and business operations (Figure 3) . From a technological point of view, new frameworks for distributed digital manufacturing have appeared on the scene. Recent developments focus on a new generation of decentralized factory control algorithms known as 'agent based'.[15] A software agent, first, is a self-directed object, second, has its own value systems and a means of communicating with other such objects, and, third, continuously acts on its own initiative. A system of such agents, called a multi-agent system, consists of a group of identical or complementary agents that act together. Agent based systems encompassing real-time and decentralized manufacturing decision-making capabilities have been reported . In such a system, each agent, as a software application instance, is responsible for monitoring a specific set of resources, namely machines, buffers, or labour that belong to a production system, and for generating local alternatives upon the occurrence of an event, such as a machine breakdown. Web-based multi-agent system frameworks have also been proposed to facilitate collaborative product development and production among geographically distributed functional agents using digitalized information .[16]

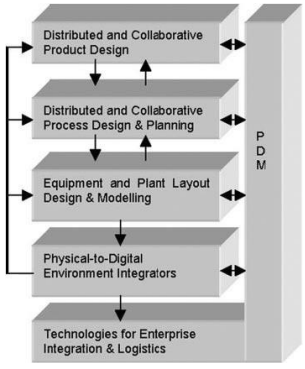

Figure 3 Structure of distributed manufacturing enterprise

The proposed system covers product design, manufacturability evaluation, process planning, scheduling, and real-time production monitoring. The advances in DMU simulation technologies during the 1990s were the key stone for the emergence of VR and human simulation in digital manufacturing. These advances have led to new frameworks that integrate product, process, resource, knowledge, and simulation models within the DMU environment . The VR technology has recently gained major interest and has been applied to several fields related to digital manufacturing research and development. Virtual manufacturing is one of the first fields that attracted researchers' interest. A number of VR-based environments have been demonstrated, providing desktop and/or immersive functionality for process analysis and training in such processes as machining, assembly, and welding. Virtual assembly simulation systems focusing on digital shipbuilding and marine industries, incorporating advanced simulation functionalities (crane operability, block erection simulation in virtual dock, etc.) have also been introduced by Kim et al.[17]Human motion simulation for integrating human aspects in simulation environments has been another key field of interest. Several methodologies for modelling the motion of digital mannequins, on the basis of real human data, have been presented. Furthermore, analyzing the motion with respect to several ergonomic aspects, such as discomfort, have been reported. Collaborative design in digital environments is another emerging research and development field. The development of shared virtual environments has enabled dispersed actors to share and visualize data, to interact realistically, as well as to make decisions in the context of product and process design activities over the web. Research activities have been also launched for the definition and implementation of VR- and augmented-reality-based collaborative manufacturing environments, which are applicable to human-oriented production systems.[18]

5. BENIFITS OF DIGITALMANUFACTURING

- Reduce Cost and Development Time for Process Design
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- Shorten Time-to-Launch for New Product Introduction with Faster Ramp-up for Production Systems
- Provide Manufacturability by Simulating Manufacturing Operations before the Start of Production
- Increase Quality by Validating Production Process Design
- Reduce and/or eliminate Prototypes and Physical Mockups with Virtual Simulations
- Improve Collaboration with Suppliers by Providing Early Access to design production Process, and Resource information
- Improve Concurrent Design Methods by Linking Product Design to Manufacturing & Controls Engineering
- Validate Manufacturing Processes, Production Systems, and operational resources through Virtual Commissioning prior to physical implementation

6. CONCLUSION:

Manufacturing industry is the pillar of the national economy. The most advanced manufacturing technology digital manufacturing is changing the game for manufacturers. Smart, connected products, assets and operations offer the potential for productivity gains, cost savings, and improved revenue. Transforming digitally, however, demands new thinking as operations and information technology converge. The outcomes of several researcher's study prove that the digital manufacturing technology provides the high production rate , cost optimization , provides customer requirements , etc in the industries . In the nearby future the digital manufacturing will play an major role .

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