A Review on Productivity Improvement using Digital Manufacturing Approach

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Abstract - *Mass customization becomes leading trend due to variety of the requirement of fast changing world. Product development techniques and technologies are getting reformed to meet the customer demands. Computer Integrated Manufacturing and Flexible manufacturing are now becoming essentials to meet the dynamics of the product development. Technologies like virtual reality, augmented reality and digital mockups are getting consumed by the industries. Above all, Digital manufacturing is becoming essential to simulate, validate and decide the best suite of manufacturing to the industry to reduce their product development lifecycle. Digital factory, smart factory and Intelligent manufacturing are taking foot forward to cop up with the industry dynamics.*

Key Words*: *Digital manufacturing, mass customization

1. INTRODUCTION

Digital manufacturing is an emerging area within Product Lifecycle Management, that supports collaboration across several phases of the product lifecycle which has been evolved from manufacturing initiatives such as design for manufacturability, computer integrated manufacturing, flexible manufacturing, lean manufacturing. Digital manufacturing is a network driven, technology based approach to manufacturing, integrates modeling, simulation, visualization, data analytics, manufacturing, supply chain and logistics processes by a digital link to define, manage and collaborate the overall product life cycle, Importance of digital manufacturing technologies as they reduce time to market, cost and increase the efficiency of products and processes by analyzing the data for an optimal design even before it is built. Also, author listed trends which helps to digital manufacturing like CBDM (Cloud-based design and manufacturing), CPS (cyber-physical systems), IoT (Internet of things) and application of digital manufacturing in different areas [1]. The conventional method is an in-line process in which the product is designed, and the drawings are forwarded to shop floor for manufacturing the prototype. While digital technology is a cyclic process in which the product is designed conceptually and innovated in computer aided design software. These designs and the processes are simulated for checking the feasibility of manufacturing the product. The product is inspected at every stage of the manufacturing process by the inspection techniques and tested by computer aided quality control methods. The supply chain management is also digitized for effective inventory and producing customized products. Digital manufacturing is the use of an integrated, computer-based system comprised of simulation, 3D visualization, analytics, and collaboration tools to create product and manufacturing process definitions simultaneously. Digital manufacturing evolved from manufacturing initiatives such as design for manufacturability (DFM), computer-integrated manufacturing (CIM), flexible manufacturing and lean manufacturing that highlight the need for collaborative product and process design [2].

2. LITERATURE SURVRY

Irjet Z. Zude, C. Dejun and X. Shane investigate that 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. Digitalization has become the indispensable drive factor in the product lifecycle of the manufacturing industry, thus digital manufacturing 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 [2].

P. Parital, S. Manchikatla and P. K. Yarlagadda found that digital manufacturing is an emerging area within Product Lifecycle Management, that supports collaboration across several phases of the product lifecycle which has been evolved from manufacturing initiatives such as design for manufacturability, computer integrated manufacturing, flexible manufacturing, lean manufacturing. Digital manufacturing is a network driven, technology-based approach to manufacturing, integrates modeling, simulation, visualization, data analytics, manufacturing, supply chain and logistics processes by a digital link to define, manage and collaborate the overall product life cycle, Importance of digital manufacturing technologies as they reduce time to market, cost and increase the efficiency of products and processes by analyzing the data for an optimal design even before it is built. Also, author listed trends which helps to digital manufacturing like CBDM (Cloud-based design and manufacturing), CPS (cyber-physical systems), IoT (Internet of things) and application of digital manufacturing in different areas [1].

M. R. Feno and A. Cauvi states simulation and Digital factory concepts are applied to support manufacturing design process, considering the whole system lifecycle. Author has discussed conceptual assembly line design and its performance measurement at early stage. Also, at preliminary design, how digital tools are more and more can be used to evaluate process are needed for quick drawing of assembly line configuration and reactivity in solution performance analysis. 3D layout design and enhanced visualization could make it easier to communicate with different disciplines that take part in a new part in a project, where as it is hard to understand the impact of equipment selection and placement in factory floor when activities are expressed in 2D flow diagram. He also discussed assembly system approaches, direct assessment, analytical, simulation. Also modeling techniques for simulation-

(1) Conceptual modeling and abstraction,

(2) Hierarchical modeling,

(3) Modular design,

(4) Functional simulation,

As well as, assembly system conceptual design with different approaches,

(1) System description,

(2) Preliminary analysis,

(3) Conceptual modeling,

(4) Detailed design,

(5) simulation., with using Tecnomatix Plant Simulation (by Siemens PLM software) and Witness (by Lanner group) [3].

A. Caggianoa and T. R found that digital modeling and simulation tool can minimize design time and cost in case of complex system. Simulation has a central function in digital factory, it can be applied to support decision making on the appropriate strategy. It follows to map a set of decision variable to a proper performance measures which are essential to appreciate the behavior of manufacturing system. Analysis and improvement of a manufacturing cell are typically carried out through a decision-making process involving several issues to be taken into consideration. Advanced simulation tools and their joint employment are very effective to support this process, as they allow to deal with a number of aspects as diverse as facility layout, material handling system design, manufacturing system capacity and throughput analysis, To deal with manufacturing cell layout and robot motion. Case study on small batch production (aerospace industry) and mass production (automotive industry) is discussed in the research. 3D motion simulation has employed to verify reachability of objectives and safety of movements throughout the manufacturing cell (Ergonomics at the workplace), it also proves essential to allow for a virtual verification of the activities that robot, operator has to carry out in the cell. Discrete event simulation is used to evaluate performance of the reconfigured manufacturing cell in terms of throughput time for a batch of products and utilization of the resources and bottleneck identification. Number of experiments are carried out for different condition to select the optimal condition for getting maximum production with optimum resource and time, by using DELMIA QUEST software [4].

M. Klimenta, R. Popovicb and J. Janekc studied case on company, which manufactures wooden stools has studied by researcher to understand the plant layout, manufacturing processes and its requirements to find workstations where optimization can be done. He found bottlenecks in the running plant model and proposed efficient layout to the company. For generating model and simulations, Tecnomatix Plant Simulation is used. Along with these he discussed, features, benefits and how it can be used for optimizing material flow, efficient use of resource, improve logistics processes, role of the plant simulation in the product lifecycle system [5].

S. Julia worked with example of using Tecnomatix plant simulation has been explained in the research, it mainly focused on simulation of production and logistics process and their optimization with the use of genetic algorithms and artificial neural networks. Simulation provides a comprehensive perception of the studied process or product allow to conduct multi-criterion analysis, and to simulate different scenarios. Advanced analytic tools in Plant Simulation, such as bottleneck analyzer and charts, can be used to evaluate different production scenarios. The results ensure information necessary for quickly making good decisions at early stages of production planning. In addition, this way it is possible to optimize material flow, the use of resources and logistics at each level of planning – beginning with global production facilities, through local enterprises, up to individual lines. Important feature of program is the possibility to model and simulate processes following the paradigms of object-oriented-programming. Also listed optimizations wizard in the program. (Genetic Algorithm wizard, Layout optimizer, Neural network, Experiment manager). Simple model of production line of nail manufacturing unit is designed in program by researcher and explained each operation performed with its time. By simulating model, statistical data and bottlenecks are observed for further improvement in the production line, for improvement workstations are added to get required production [6].

H. Neradilova and F. Gabriel worked on Automated Guided Vehicle in the role of main transport system that can process all transport and handling carried at maximum efficiency and accuracy, for proper functioning it is necessary to ensure performing a range of criterion and conditions, Computer simulation method is very important in position, creating, planning and operation of automated guided vehicle, it helps to reduce the risk of various crisis situation, helps to predict possibilities of future development. Also discussed computer simulation of automated guided vehicle system for the need of digital factory, as it runs variety of complex process, there is need also to consider rules governing the transport process within the specific area, with method for addition programming for defining additional functionality and increase its capabilities within the simulation mode, also how program can be applied in two different approaches, as program can be made by users and flexibility to change its requirements for different conditions, with the help of Tecnomatix Plant Simulation. By programming one can their logic in the simulation model for studying behavior of the system, it is also powerful tool supporting development of simulation model for logistics need. Result information from the computer simulation can be used for optimization of logistics system by using genetic algorithm method [7].

F. Gregori, A. Papetti, M. Pandolfi, M. Peruzzini and M. Germani contribute to understand the scope of data digitization for efficient factories, paper aimed to propose method to acquire social related data in production plant, supported by a smart architecture within the concept of IoT factory. Human centered design (HCD) approach that aims at improving worker capabilities, health and safety, "Design for social" methodology, that embeds a social issue matrix that analyzes possible solutions to solve the main human-related criticalities has discussed, It also supports to find out best working place and optimal condition to eliminate potential hazards, to maintain production system and to control the impact of the manufacturing process even outside of the company. Also, tradition aspects must be integrated with new social items like working environment condition, worker's satisfaction, and safety, physical and ergonomics. They also discussed four steps of "design for social" methodology (Layout assessment, Virtual prototyping, Physical prototyping, Social sustainability assessment). Data is recorded from all sensors (Audio, Image, dust and smell) connected to human body and to machine to develop social decision matrix used by designers during virtual prototype definition and simulation to identify possible design solution and main criticalities from the social point of view. Family of sensors consists of sensor on human, sensor on operation, sensor in shop floor, they record body temperature and heart rate, vibration and noise, temperature, and humidity respectively for condition of plant influencing the company social sustainability, productivity. Also discussed, industrial case study, design and development of wood working machine, aimed to realize an assistive working environment that favors human-machine interaction and social-sustainability considering human need for healthy working environments and improve the global process efficiency. System was divided into three parts, machine, warehouse, principal unit, and data were recorded according to it, according to proposed method social sustainability assessments was carried out and digital framework has been exploited. Results were recorded can be implemented in corporate sustainability reports. Ultimately safe and comfort can bring sustainability to the industry when they get properly treated [8].

J. S. kumar, S. Madhukar Digital Manufacturing(DM) is a manufacturing approach, with the support of technologies such as virtual reality (VR), computer networks, rapid prototyping and database(DB), is based on customer demand so as to analyze, organize and recombine the product information, process information and resource information, to implement the product design and function simulation as well as rapid prototyping, to perform rapid production to meet customer demand and quality standards. Numeric Control (NC) machines were the reason to conceptualize the DM. 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. 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. Data and model's integration have 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 [9].

V. Jovanovic, M. Debevec discussed about three approaches and model improvement technique related to manufacturing processes. Digital Manufacturing is one of the approaches which gives the opportunity for performing an entire manufacturing process in virtual environment. So, engineers can Plan, Define, Create, Monitor and Control all manufacturing process in virtual environment. Improvements in the plant or in plan can be done simultaneously while existing manufacturing processes are in its place and there is no need of disturb. Model of Unique Type of Production is the second approach to represent model. For this approach, consideration of the all-important manufacturing resources is considered for every single manufacturing operation. Third approach is for model for

Large-Scale Production in which assembly or production cell is treated as the elementary unit of the production or manufacturing process. Results of the first two approaches are discussed as, advantage is simulation results can be quickly obtained about the estimated plan. It is proven from the testing that it takes only few minutes to perform simulation of entire production scenario. Also, no intervention for the existing production process. Possibility to test multiple scenarios and different schedule plans are practically unlimited where behavior of the production system as a function of time for an individual plan or schedule and only output of the production system is observed [10].

Author has discussed the steel surface treatment line problem with its challenges and area of improvement with the help of Tecnomatix Plant Simulation software. Listing out all process and its properties to sequence the process has done and schematic representation was prepared. Technological process for Alkaline blackening and phosphating of zinc analyzed critically to understand importance and its required time to complete. Value added in production process seen as 10.94% in alkaline blackening and 8.98% in phosphating of zinc. Unification of the phosphating of zinc and alkaline blackening was recommended for concurrent execution of operations. Total value added after simulation of concurrent line is 11.76% [10].

James C. Chen and Chun-Chien, Garment manufacturing is a traditional industry with global competition. The most critical manufacturing process is sewing, as it generally involves a great number of operations. The aim of assembly line balance planning in sewing lines is to assign tasks to the workstations, so that the machines of the workstation can perform the assigned tasks with a balanced loading. In garment industry any apparel manufacturer tries the best to finish the assembly work soon to increase on-time delivery and to increase machine/labor utilization to reduce production cost. They develop a grouping genetic algorithm (GGA) for assembly line balancing problem of sewing lines with different labor skill levels in garment industry. GGA can allocate workload among machines as evenly as possible for different labor skill levels. So, for that real data from garment factories and experimental design are used to evaluate GGA's performance. GA method has received much attention and has been applied successfully in many research fields. Within recent years, many studies have been made on the applications of GA to assembly line balancing problem of different industries. GA is also one of the most popular heuristic algorithms in the deterministic approach adopted to solve assembly line balancing problem [11].

Sangsu Choi and Bo Hyun Kim, Technology developments are ushering in the introduction of smart manufacturing (SM) systems, unmanned production lines and sustainable production. SM will minimize human intervention and allow systems to control sites intelligently. To realize such an era many global manufacturers are trying to develop different SM methods. The virtual factory is a digital-manufacturing-based SM system that predicts, solves (improves) and manages (controls) problems with overall production tasks by linking them to the actual sites in a virtual environment. This paper proposes a strategic plan and a systematic design for the efficient implementation and application of the virtual factory to real manufacturing companies. In addition, an efficient and systematic means of introducing the virtual factory is presented via diagnosis, analysis and establishment of the strategy, implementation plan and system design case with an electronic parts manufacturing company. The virtual factory is a fusion technology that combines diverse IT technologies related to manufacturing, based on digital manufacturing technology. The virtual factory is divided into infrastructure and technologies, which include the module design, process design, line design, logistics analysis, ubiquitous and virtual reality and system integration technologies Via system integration they are integrated with diverse heterogeneous systems such as enterprise resource planning (ERP), supply chain management (SCM), product lifecycle management (PLM) and manufacturing execution systems (MES). Global companies are trying to establish digital-manufacturing-based SM systems, including virtual factories, and reporting success by using relevant technologies. Extensive research related these technologies have also been published. For the successful establishment of a virtual factory, the top-down approach (with the CEO's active support) must be implemented simultaneously with the bottom-up approach (through the gradual development of detailed technologies) [12].

Noor Azlina Mohd. Salleh Salmiah kasolang, Ahmed Jaffar, the objectives of the line improvement activity are to obtain cost saving and cash flow improvement by increasing the productivity and reduction in work-in progress. DELMIA Quest Simulation has proven to be able to simulate the manufacturing process. More improvement activities can be done to measure the consistency between the simulation and the actual result for other type of process and other industry. The usage of DELMIA Quest Simulation is not available for the company due to the high cost of purchasing the software. Besides the software provider, it is recommended that there is another center that can provide services to the local automotive companies to simulate the process improvement as the university is only granted for academic license. It was also found out that in Lean Manufacturing System, takt time and yamazumi chart are very powerful tools that can be used together with cycle time in mass production [13].

David Gyulai, Adam Szaller and Zsolt Janos, layout planning is an important practical problem for manufacturing companies. In today's market conditions characterized with continuously changing product portfolio and shortening product lifecycles frequent reconfiguration is requested if the primary goal for the company is to remain competitive. The key to win customers is to widen the product portfolio and customize the products. However, this leads to the problem that the manufacturing system must be reorganized several times during its life cycle that requires solving design problems frequently. In this a novel layout planning method is introduced that can be applied efficiently to solve real industrial problems. The method applies automated simulation model building to create the different layouts. It focuses on minimizing the objective function that is specified according to the predefined key performance indicators (KPI). The solution is a hybrid optimization method in which evaluation of the layout alternatives is done by simulation and the improvement of the solution is performed by a near to optimal search algorithm. The optimization is separated from the simulation model to boost the computations. Important advantage of the solution is the efficiency consideration of stochastic parameters that improve the applicability of the results [15].

Digital manufacturing is the use of an integrated, computer-based system comprised of simulation, 3D visualization, analytics, and collaboration tools to create product and manufacturing process definitions simultaneously. Digital manufacturing evolved from manufacturing initiatives such as design for manufacturability (DFM), computer-integrated manufacturing (CIM), flexible manufacturing and lean manufacturing that highlight the need for collaborative product and process design [16].

Mateusz Kikolski discussed importance of objectives, benefits and drawback of the research project and simulation. Modeling and simulation of three scenarios has done and results were discussed. Right choice for the simulation tool will help to model exact behavior of the physical objects in to the out of the box software. Tecnomatix Plant Simulation has simple and initiative user interface. Simplicity of the model gives flexibility to modify and reiterate the simulations for better results [19].

Müller, Hörauf, Speicher, Koch, & Drieß, discussed about conventional method of production planning and scheduling with top-down approach and limitation of it without having dynamic data available of the machines, resources, and uncertainties. Conventional planning and scheduling are done with planner's assumption that all resources are available and manual planning leads to time consumptions and sub-optimal process. That is why it suffer from low quality and low range in planning data. This results into unrealistic delivery time. Whereas corporate objective is to maximize output and minimize throughput time. Use of Simulation based Online Production System (SOPS) in the trend of Industry 4.0 will help enterprises to organize their planning and scheduling by consuming near real time data and intelligence. As an essential of Production Planning, author has categorized uncertainties, as completely unknown, Suspicious about the future of the decision maker, know certainties. Also defined and discussed their importance in the realistic simulation. Approach of digital twin by combining modelling, simulation, and optimization reduces the complexity of the regarded system. Availability and transparency of the data from the shop floor is the key factor which will enable seamless digital twin experience. Technologies like, HTML, JavaScript, CSS, ChartJS and, Database Management system will help to optimize whole production system [20].

Vavríka, Gregora, & Grznára, discussed about an optimization of logistic system of one of the organization using Technomatix Plant Simulation. Due to increse in demand, growth in new product volume needs an extension of the logistic facility and insertions of new resources to handle new semi-finished product types. Creation of new logistic track and its management has done with TX Plant Simulation software. Challenge in the factory was defined and related static calculations has done to put those into simulation model. Major advantage was creation of variants of logistic track and record their results in the file. Optimum number of vehicles were decided by experiemnting defining numbers of vehicle, evaluating proposed tracks, and, simulating changes in the system [20].

Buckova, Krajcovic, & Edl, discuused optimization of the transport distance of order picking process in particular industry. Genetic algorithm played imprtant role to optimize process with ease. Simulation elimited tedious calculations. Parmutations and combinations made easy to decide best results random and optimum, to put inside simulation model [21].

3. TECHNOLOGIES IN DM

3.1 Industrial Internet of Things (IIoT)

Internet of things (IoT) is the hearth of the industry 4.0. It refers to smart network of real devices that are connected digitally between to facilitate the communication and exchange of information through internet. These smart devices may mobile phones or household appliances or cars or buildings.

3.2 Big Data

It refers to the large and complex data sets generated by IoT devices. This data comes from a wide range of cloud and enterprise applications, websites, computers, sensors, cameras and much more - all coming in different formats and protocols. In the manufacturing industry, there are many different types of data to take into consideration, including the data coming from production equipment fitted with sensors and databases from ERP(Enterprise Resource Planning), CRM(Customer Relationship Management) and MES(Manufacturing Executive System) systems. The company connects its machinery to monitor the overall production process at the core of its plant. It is achieved by embedding sensors into the factory's machines which are then used to collect data about the machines' conditions and cycle time.

3.3 Cloud Computing

Cloud computing offers a platform for users to store and process vast amounts of data on remote servers. It enables organizations to use computer resources without having to develop a computing infrastructure on premise. The term cloud computing refers to information being stored in the "cloud", accessed remotely via the Internet. In itself, cloud computing is not a solution on its own, but enables the implementation of other solutions that once required heavy computing power. The capability of cloud computing to provide scalable computing resources and storage space enables companies to capture and apply business intelligence through the use of big data analytics, helping them to consolidate and streamline manufacturing and business operations.

3.4 Advance Robotics

With recent advancements in technology, a new generation of advanced robotics is emerging, capable of performing difficult and delicate tasks. Powered by cutting-edge software and sensors, they can recognize, analyses and act upon information they receive from the environment, and even collaborate and learn from humans. One area of robotics gaining significant traction is collaborative robots ("cobots"), designed to work safely around people, freeing workers from repetitive and dangerous tasks.

3.5 Additive Manufacturing

Additive manufacturing (AM), or 3D printing, is a key technology driving Industry 4.0. AM works by using digital 3D models to create parts with a 3D printer layer by layer. 3D printing is emerging as a valuable digital manufacturing technology. Once solely a rapid prototyping technology, AM offers a huge scope of possibilities for manufacturing from tooling to mass customization across virtually all industries. It enables parts to be stored as design files in virtual inventories, so that they can be produced on-demand and closer to the point of need - a model known as distributed manufacturing. Such a decentralized approach to manufacturing can reduce transportation distances, and hence costs, as well as simplify inventory management by storing digital files instead of physical parts.

3.6 Digital Twin

The concept of a digital twin holds great promise for optimizing the performance and maintenance of industrial systems. Global research firm, Gartner, predicts that by 2021, 50% of large industrial companies will be using digital twins to monitor and control their assets and processes. A digital twin is a digital representation of a real-world product, machine, process, or system, that allows companies to better understand, analyses and optimize their processes through real-time simulation. While digital twins can be confused with simulation used in engineering, there is much more to this concept. Unlike engineering simulations, a digital twin runs an online simulation, based on data received from sensors connected to a machine or other device. As an IIoT device sends data almost in real time, a digital twin can collect this data continuously, maintaining its fidelity with the original throughout the lifespan of the product or system. This enables the digital twin to predict potential issues so that preemptive measures can be taken. For example, an operator can use a digital twin to identify why a part is malfunctioning or to predict the lifetime of a product. This continuous simulation helps to improve designs of products as well as to ensure equipment uptime. This use of digital twins has long been an important tool in demanding aerospace, heavy machinery, and automotive applications. Now, advances in computing technology, machine learning and sensors are expanding the concept of digital twinning across other industries.

3.7 Augmented/Virtual Reality

Augmented reality bridges the gap between the digital and physical worlds by superimposing virtual images or data onto a physical object. For this, the technology uses AR-capable devices, such as smartphones, tablets, and smart glasses. In the context of manufacturing, AR could enable workers to speed up the assembly process and improve decision-making. For example, AR glasses could be used to project data, such as layouts, assembly guidelines, sites of possible malfunction, or a serial number of components, on the real part, facilitating faster and easier work procedures [18].

4. BENEFITS OF DM

- Enables product, process, plant, and resource information to be associated, viewed, and taken through change processes, with a consistent and comprehensive approach to production design
- Helps you create factory models faster and ensure they are operating under optimal layout, material flow and throughput before production ramp-up
- Allows part manufacturing processes to be optimized within a managed environment to produce flexible work instructions capable of displaying 2D/3D part information, along with machining and tooling instructions
- Supports six-sigma and lean initiatives by providing a graphical environment to analyze dimensional variation
- Reduces commissioning costs through simulation by validating robotics and automation programs virtually
- Facilitates the sharing of quality data across your organization by generating complete, verifiable CAD-based machine inspection programs for coordinate measuring machines (CMMs) and numerical control (NC) machine tools

- Executes production processes with real-time access to lifecycle data

5. CONCLUSIONS

It is discussed that how industry 4.0 is influenced by digital manufacturing. Due to technological changes the way of using DM has changed dramatically over the last few years. Many of the technologies are not newer, but recent forms of integration, improvements in use, and joint use, have changed the DM field, opening several new challenges and opportunities.

Additive manufacturing, a DM technique has undergone significant development and found its applications in various sectors like automobile, aerospace, medical, materials, architecture, construction, food, etc. In aerospace industry, AM is advantageous to manufacture geometric and material complex lightweight high-performance products. Automotive industry exploited AM technologies to develop new products quickly, and efficiently thereby reducing the product development cost. Biomedical applications of AM are manifold. Manufacturing of customized implants and prosthetics, medical and diagnostic aids, tissue engineering, regenerative medicine etc. are few of them. AM technologies are also capable of printing different chemical compounds and materials with complex architectures which are difficult by traditional manufacturing. Architects took the leverage of AM in printing complex models to be presented to the customers with an aesthetic look. Construction engineering, with the help of robotic technology, is using AM to print large structures. The food industry is also using AM technologies to print chocolates, cookies, and cakes etc. Despite, a significant development in additive manufacturing technology, it still requires more insight into the microscopic and macroscopic aspects of manufacturing processes as well as systems. Additionally, novel AM systems and standard processes need to be developed with a focus on the design of complex multi material structures, materials with multifunctional properties, electrically conductive materials, bio applications using cells and biomaterials, micro and nanoengineering, energy and sustainability implications in manufacturing in order to elevate it as a middle-of-the-road technology. Also, there is a need for AM systems that can produce large parts for automobile and aerospace industries. Apart from the core industries like aerospace, military, automobile, medical, and consumer products, in the near future, AM technology will drive various other industries including dental, food, construction, architecture, fashion, toys, furniture, home accessories etc. with a digital link. With the present pace of ongoing research, new applications are likely to develop in printing customized biocompatible implants and biological tissues, edible foods, customized outfits, and jewelry, dream toys for kids, embedded electrically conductive parts enabling part simplifications etc. Therefore, digital manufacturing is widely believed as a frontier for new innovations and technology start-ups which will become the state- of- the- art technology in which a wide range of products will be developed virtually, and customized manufacturing is vogue.

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