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A comprehensive review of Digital Manufacturing

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ABSTRACT

Reconfigurability is an important feature of modern manufacturing system as it make smooth for the seamless introduction of new products to manufacture and the -adaption to demand of capricious society. Digital manufacturing has been considered as a highly promising part of technology for reducing product cost, development times as well as it is directing us towards the increased product quality, need of customization and faster response to the market. This review paper highlights the emergence of digital manufacturing and significant role played by information technology systems in production sector. With the Digital manufacturing and factory concept we were discussing technologies in this paper which are like computer-aided design, process planning, engineering product data management, product lifecycle management, manufacturing planning, simulation and virtual reality, process control, automation, design support, shop floor scheduling, decision making, manufacturing resources planning, logistics, enterprise resource planning, supply chain management and e-commerce system. These are the technologies discussed in the context of digital manufacturing.

Keywords: *Computer-integrated engineering, computer-aided design, computer-aided manufacturing, digital Manufacturing, information technology, manufacturing, and reconfiguration.*

INTRODUCTION

The increase in the competitiveness all over the world, dynamic and unpredictable market trends diversification of customer requirements which challenges the market of manufacturing to integrate the design, manufacturing product and support processes in order to shorten the time for product development and deal with constantly increasing difficulties in the product and manufacturing venture without compromise in quality.

The traditional approach of manufacturing dedicated production lines although still in use or practise cannot deal with changes related to the market such as increase in demand of product, product changes like

the introduction of new product in the line and the system failures like machine breakdown in cost effective or timely manner.

Digital manufacturing is an appearing area in PLM (Product Lifecycle Management) that helps to connect some phases of product lifecycle which has been evolved from manufacturing inventions such as CIM (Computer Integrated Manufacturing), flexible Manufacturing, design for manufacturability, lean manufacturing etc. The digital manufacturing is breaking the wall of manufacturing cause of recent development in the areas like 3D printing, human-machine interaction, AI (Artificial Intelligence), robotics and automation, also it is accompanying by an explosion in data and new capabilities.

The manufacturing organizations striving to integrate their business departments and functions with new systems in an enterprise database, following a unified enterprise view. The manufacturing process is optimized at initial phase only through integrating simulation techniques and manufacturing data and supporting the progress phases.

Digital manufacturing would allow for:

1. The shortening of development time and cost.
2. The integration of knowledge coming from different manufacturing process and departments.
3. The decentralised manufacturing of the increasing variety of parts and products in numerous production sites.
4. The focusing of manufacturing organizations on their core competences, working efficiently with other companies and suppliers on the basis of effective IT based cooperative engineering [33].

IT IN DIGITAL MANUFACTURING

From last few decades the use of IT in the manufacturing has allowed the various technologies to reach the stage of maturity. From the early years of the introduction of numeric control and all the way to machining centres, manufacturing cells, flexible systems, cost and increased power have been the main advantages of IT [5]. This concept was introduced in the 1980s preferring for the improvement of performance, efficiency and product quality, responsive behaviour to market differentiation, operational flexibility and time to market.

The inventory control and Material Requirement Planning (MRP) were introduced in the 1960s and 1970s resp. The MRP system was improved through integration of different processes like forecasting, scheduling and capacity planning. The result was introduction of the closed-loop MRP [6]. However, the advances in the microprocessor technology, the arrival of internet era, the standardization of software interfaces, the wide acceptance of formal techniques for software design and development and the maturity of certain software products (relational database management systems and computer- aided design (CAD) systems, for interface) covered the way for facilitating the integration among varied software applications [21].

COMPUTER-AIDED TECHNOLOGIES

CAD is counted among all the technologies that have increased productivity, allowed faster time to market for the product and affectedly reduced the time required for product development. Affordable solutions, giving a modern photorealistic graphical user interface, are now days available in the market. The CAD systems have become necessary to today's manufacturing organisations because of their strong incorporation with advanced manufacturing techniques.

Process planning activities determine the necessary manufacturing processes and

sequence in order to produce a given part economically and competitively [21]. In this direction, the computer-aided process planning (CAPP) systems have been used for the generation consistent process plans and considered as being essential components of the CIM environment [1]. Kim and Duffie [12] presented a distinct dynamic model design and have analysed the control algorithms for closed-loop process planning control that has improved response to disruptions, like rush orders and periodic instabilities in capacity. Finally, Ueda *et al* [27]. Introduced a new concurrent process planning and scheduling method of solving problems posed by situations where a process plan ad a production schedule clash, using evolutionary artificial neural networks based on emergent synthesis.

Computer-aided engineering (CAE) systems are used to reduce the level of hardware prototyping during product development and to improve the understanding of the system [7]. It supports large number of engineering research fields like fluid mechanics (computational fluid mechanics), dynamics (simulation of machines and mechanisms), mechanics of materials (FEA), thermodynamics and robotics, etc.

The concept of computer-aided manufacturing (CAM) was intuited by the development of CAD system. The introduction of computer numerical control is the big step forward to the implementation of CAM system which further brought revolution in the manufacturing systems by allowing mass production and greater flexibility along with it has also enabled the direct connect between the three-dimensional (3D) CAD model and its production.
Other systems like computer-aided quality systems are also started getting emerging and to become part of engineering functions. Product lifecycle management (PLM) and product data management (PDM) systems are allowed to perform variety of data management task consisting valuating workflow, product structure lifecycle, view and change management. PDM systems are often used to control operations, documents, files, and work processes and required to design, build, support, maintain product and distribute products.

PLM is integrated information driven system which tactics to all phases of product lifecycle from its design inspection through its manufacturing, development and maintenance to finally complete removal from service and disposal. PLM involves into reduce the prototype cost, improve product quality, reduce time to market, features for product optimization, saving through the reuse of original data, reduced waste and saving through the complete integration of engineering workflows.

Today's PDM and PLM systems are primarily focus on the administration of computer files without having much access to the actual content of the files. On other hand CAD system is used for developing the product models meanwhile geometry data organise the major part of the product defining characteristics [8]. The entire process of product development right from conception phase to manufacturing phase is done through Digital manufacturing.

During the design of a new product or process, it is important that all the knowledge and experience available (either on the product or process design) gained through time can be accessed easily and rapidly. A process models is a way of classifying standard solutions that do not need any further development so that they can be available whenever necessary within short time.

MANUFACTURING CONTROL

The future controller selection of

manufacturers will based on the factors like open industry standards, technical feasibility, cost effectiveness, multi-control discipline functionality, ease of integration and maintainability. More recently installation of RFID (Radio Frequency Identification Device) on shop floor and GSM (Global System for Mobile communication) are the new IT applications area in the industry shop floor [14].

In the automotive assembly IT is applicable to series of process such as production order control, production monitoring, sequence planning, and vehicle identification, quality management, maintenance management and material control [28].

SIMULATION

The complexity of manufacturing systems can be analysed through different simulation techniques. This helps the design engineers to eliminate most of the problems that may occur during actual implementation phase. The changes in the system configuration or in the operational policies may affect the performance of the system or organization [2].

Simulation models are sorted into dynamic, continuous, static, discrete, deterministic and stochastic. From last 4 decades simulation software packages have been providing visualization capabilities, including animation and graphical user interaction features. It provides a great advantage of studying and statistically analysing what-if scenarios, thus reducing overall time and cost required for taking decisions based on the system behaviour. It is frequently integrated with other IT systems like CAx, FEA and production planning and optimization systems.

In addition to simulation technology the virtual reality (VR) technology has enabled engineers to become submerged in virtual models and to interact with them. VR technology is now supporting the activities like factory layout, operation training, planning, testing and process control and validation.

ENTERPRISE RESOURCE PLANNING AND OPTIMIZATION

To integrate all data and processes of an organization into unfilled system the Enterprise Resource Planning (ERP) system is used. The normal ERP system takes multiple components of computer hardware and software to achieve the integration. The ERP system has been associated with quite broad range of definitions and applications over the last decades [9].

The purging of incorrect data information and laying off data, the standardization of business unit interfaces, conflict of global access and security issues and exact modelling of business processes have all become part of the list of objectives to be accomplished by an ERP system. The main worries that would affect an ERP implementation i.e. High cost of installation, maximum failure risk, huge demands on corporate time and resources and also complex and often painful business process adjustments.

The ERP system incorporates optimization capabilities for cost and time savings virtually from every production process. Indicative example includes cases from simple optimization problems, shop floor scheduling and production planning to today's complex decision making problems [3, 15]. Mnostori *et al.* [29] have proposed the scheduling system capable of real time production control. They receive the feedback from the daily production through the integration of information coming from the process, quality and production monitoring subsystems This systems is able to inspect divergences and

problems of the industrial system and to advise possible replacement for control them.

RECENT DEVELOPMENTS

Academic Research

Current developments in digital manufacturing may be sorted into two major groups. The first group has followed a bottom-up approach considering digital manufacturing and covering its concepts within a broader framework, e.g. the digital factory or organization. The development of second group has followed a top-down method considering the technologies in support of distinct feature of digital manufacturing, e.g. e-collaboration and simulation.

The digital factory includes models, methods and tools for maintainable support of factory planning operations according to the Verein Deutscher Ingenieure. It includes the methods based on linked digital models connected with the model of the product [16]. On theoretical level, the several researchers have underwritten the definition of the digital factory vision and suggested how this concept could be implemented in reality (fig. 1) [17].

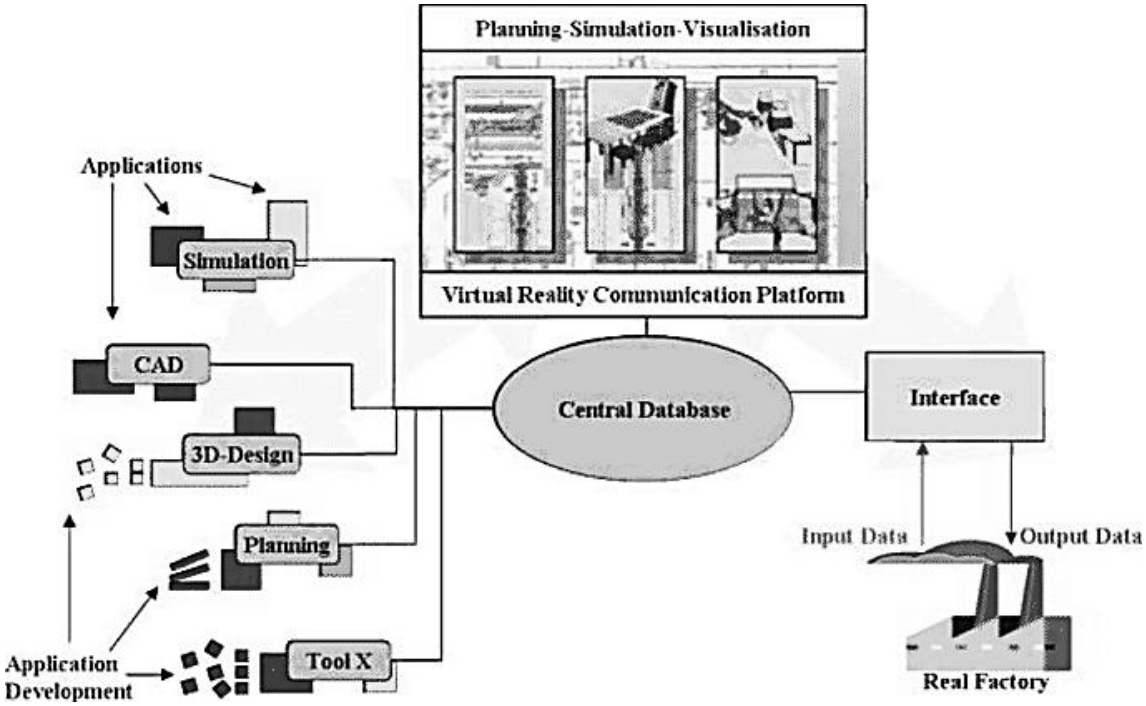

Figure 1: *The concept of the digital factory [17].*

To support the implementation of the data and models integration has been a core research activity. The overview 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 [13]. Similar activities have focused on the definition of semantic relation between the models dispersed as well as the associated database and the introduction of appropriate modelling agreements [16]. On the top of these developments a number of procedures for computer supported co-operative development engineering within a digital factory framework have been published. Some researchers have suggested that the software architectures for relationship management is the safe exchange of data [18].

Industrial Practise and Activities

In the industry, digital manufacturing

targets at the reliable and inclusive use of digital methods of planning and authentications from the product development to production and facility planning.

In the 1990s the Accessible Information Technology (AIT) programme and its progeny projects were launched by automotive and aerospace industries in Europe. Rather they have been establishing it in driving digital manufacturing advances, targeting at increasing the competition in the industries through the using of advanced information technology in design and manufacturing. On this root, the automotive industries still urges a number of appropriate developments in digital manufacturing.

In BMW, the launch of 3 Series at Leipzig has been one of the best launches ever of BMW as they achieved 50% less faults per vehicle and recorded the best process capabilities measured than the past cause of the use of simulation of production process at very early stage of design [24]. Similarly, the General Motors had started the utilization of 3 dimensional workcell simulation (iGRIP) offered by Digital Enterprise Lean Manufacturing Interactive Application (DELMIA) allowing the engineers to generate 3D simulations and translate models created in other commercially available packages. The Computer-Aided three Dimensional Interactive Application (CATIA) machining solution tools have given manufacturing experts at Daimler a chance to test virtually the 'choreography' for the production of parts ensuring that the finished product will get precise design expectations.

In Volvo, DES has been used as a tool for endless process verification in industrial system development as well as BMW and Daimler Chysler are also the users of similar applications. Ford is also using the computer simulation in the some form or other for designing and operating its engine manufacturing facilities since the mid of 1980s. The method of Digital Planning Validation (DPV) is recently gained some interest (Fig. 4) [19].

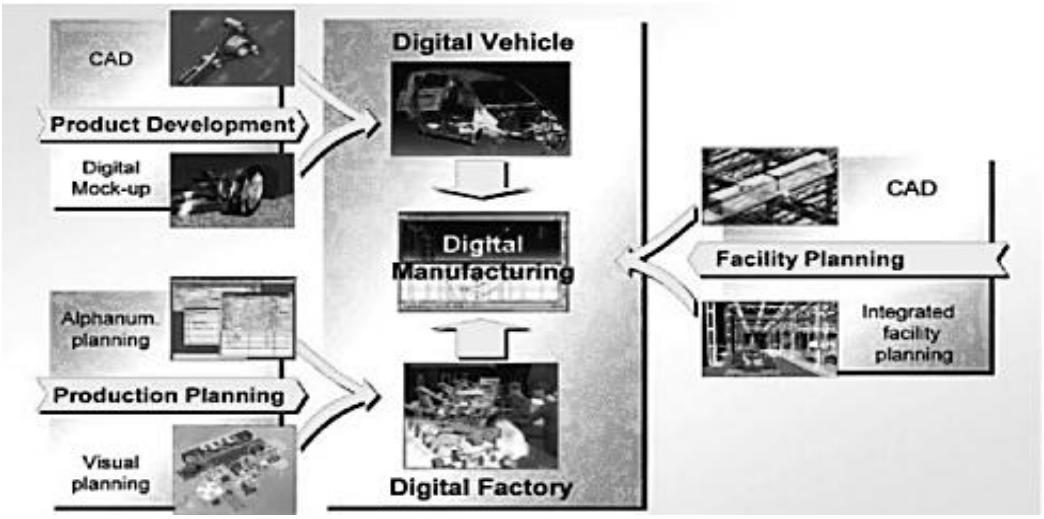

Figure 2: *Digital manufacturing links product development, production planning, and facility planning.*

To the basic of validation process running in the parallel to that of digital planning the DPV method developed by Daimler Chysler consists of both the continuous checking of digital planning result and process reviews at some points in time the

so-called process days. Through the process days the current planning states are validated through geometrical checks of the assemblies the simulation of processes or detailed examinations of layouts. DPV method is based on DMU method techniques and simulation.

The so-called virtual process is the one relevant method applied to BMW working practices for a week. This method point outs the assessment of the assembly planning by a group of people responsible for the process. On the basis of product structure visualisation scenes are created.

New methods and technologies for virtual assembly in the digital manufacturing has been investigated by Daimler Chysler, Volvo, Fiat and Ford in the context of the Eu Integrated Project 'MyCar' driven by Volvo and Laboratory for Manufacturing System and Automation, University of Patras [25]. The equipment manufacturer especially OEMs are looking for the novel approaches to achieving an improvement in the data communication and to providing a foundational IT, CAX architecture that enables the different tools to compatible seamlessly and the processes to be managed efficiently. The human simulation of manual, automated and mixed processes for improving the deliberation of human factors is another topic of major research.

DIGITAL MANUFACTURING

Outlook

The acceleration in the manufacturing process consists of two aspects: one is the speed-up of product development to reduce development lead time and the other is that of production to reduce production lead time [4].

In corresponding, the quality and manufacturing cost of the final product are determined again in both the design and production phases. This shows that there is significant need for the bridge to build between the production of development and the real production; digital manufacturing targets to play this part.

In the 1990s FAE as well as computer-aided machining quickly became affordable and usable, even on the basic level like shop floor. FAE is united with mainstream design products has meant that most testing and analysis can be conducted quickly and with trustworthy results. Now an engineer can find flaws earlier in the process of design if any and then can eliminate them quickly. The recent technology developments are making digital manufacturing real to many and many companies are using pieces of digital manufacturing without realizing it [20].

Digital manufacturing needs to be further oppressed in order to close the gap between the product definitions (configuration of components and required manufacturing processes) and the actual manufacturing production activities within enterprise [26]. Simulation and VR can now be used in order to suggestively reduce costs and time to market.

Based on the responses from factories or industries Dalton-Taggart cleared that digital manufacturing is 'the ability to describe the every aspect of the design-to-manufacturing processes digitally using tools that include digital design, office documents, PLM systems, CAD, analysis software, simulation, CAM software, and so on'.

By utilizing the digital manufacturing, manufacturing organizations target to achieve the following [26].

1. Early validation of manufacturing processes.
2. Faster production ramp-up.
3. Reduced manufacturing cost.
4. Enhanced product knowledge dissemination.
5. Increase in flexibility.
6. Shortened product development.

7. Faster time to market.
8. Reduction in errors.
9. Improved product quality.

By using the methods many industries developed benefits and those who are with capital-intensive manufacturing and those with very complex products but very low production, even single unit production. For the return in investment capital intensive manufacturers are calculated on the basis of the decrease in the time to market is 30% - 50%, due to efficient synchronised engineering, reducing the product cost by 10% - 25%, through multiple interchanges in the design for manufacturing and for assembly of design and reducing the expensive engineering changes to production tooling and product design during launch by 80% - 90%. Administrative issues including technical teams and efficient product change management organises an important challenge, which has already started to be investigated. [31].

General Motors, Boeing and Daimler-Chryslers, Lockheed Martin have publically declared that digital technologies have saved them millions of dollars in just few years. The digital simulation and planning of assembly processes are based on different enabling technologies such as immersive VR, collaborative virtual design and digital human simulation for manual assembly system and ergonomics assessments.

In digital manufacturing, the uncertainty of method knowledge in manufacturing should be eradicated totally, and the method knowledge should be transformed into perceptible knowledge namely numerical values or equations and finally into digital values.

The extending of the internet and the software technologies that rises from its provide the means for the globalization of the service offered. For the efficient work of digital manufacturing the optimization of data management is required through all the stages.

In the new manufacturing standards suggested by a manufacturer for the year 2020, digital manufacturing is defined as a key research area for the installation of the knowledgeable based factory of the future. Digital manufacturing will be a key element in the process knowledge acquisition and product helping to translate from implicit to explicit knowledge. Moreover it is actually driven by the application and standardization of the information and communication technologies and the increasing demand for the efficiency of operations in global network [32].

CONCLUSION

Modelling and simulation can be done through Digital manufacturing which integrates various elements of manufacturing like labour skills, material, machine layout, building layout, etc. Digital Manufacturing involves developing standard models, bridging the gap between product definition and production activities to be performed and converting product concept into real time model through optimization of data management.

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