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Advanced virtual manufacturing systems: A review

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Abstract

Advanced virtual manufacturing systems refer to highly sophisticated computer-based systems which simulate and optimize manufacturing processes in a virtual environment. Recently, many researchers have presented research works in different areas of simulation and analysis of manufacturing process in virtual environments such as cloud manufacturing, virtual training systems, virtual inspection systems, virtual process planning, flexible manufacturing systems, virtual manufacturing networks, virtual monitoring systems, virtual manufacturing for optimized production process, virtual machining systems and virtual commissioning systems. The advantages of virtual manufacturing systems include improving the quality of the produced components, decreasing the quantity of waste materials and accelerate product and process design using virtual simulation and modification. As a result, accuracy as well as efficiency in process of part manufacturing can be increased by applying the virtual environments to manufacturing operations. Moreover, digital marketing by using virtual manufacturing systems can increase the added value in the process of part production. To analyze and modify the processes of part production, recent achievements in virtual manufacturing systems are reviewed and presented in the study. The applications of virtual manufacturing systems in creating manufacturing processes are discussed, and future research works are also proposed. It has been discovered that reviewing and evaluating recent achievements in the published papers can promote the process of manufacturing engineering using virtual simulation and modification.

Keywords: Virtual manufacturing; Flexible manufacturing systems; Efficiency; Part production; Monitoring system

1. Introduction

In order to introduce new and more effective production techniques, modern methods of part manufacture such as virtual manufacturing are

presented. ¹. Manufacturing technology systems are recently developed by using virtual simulation and analysis in order to reduce cost and time of part production ². Advanced Virtual Manufacturing Systems (AVMS) is a concept that involves the integration of virtual reality, artificial intelligence, and advanced manufacturing technologies to create efficient and flexible production systems. By simulating the manufacturing process in a virtual environment, engineers can optimize the production line and find potential problems before the real

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manufacturing processes are implemented. It uses computer-aided design (CAD) and computer-aided manufacturing (CAM) software to generate digital models of products and manufacturing processes. These models can be used to simulate the production process, identify potential issues, and test different scenarios to optimize the production process. Increasing the quality of the produced parts, reducing number of physical prototype models and optimizing the designing time of product and processes are some advantages of the virtual manufacturing systems ³. Also, it has the potential to revolutionize the manufacturing industry by improving production efficiency, reducing costs, and minimizing waste. It also provides a platform for engineers to innovate and experiment with new manufacturing processes and technologies without the need for expensive physical prototypes. Moreover, by minimizing material waste and tooling costs, virtual simulation and analytical capabilities can reduce production costs ⁴. Design, assembly, part prototyping, production scheduling, Computer Aided Process Planning (CAPP), energy management in process of manufacturing operation, material handling systems and digital marketing are some applications of virtual manufacturing processes in different industries in order to remain competitive in challenging conditions of marketing⁵. Advantages of virtual manufacturing systems in process of part production are shown in the Fig.1.



Fig. 1. Advantages of virtual manufacturing systems in process of part production.

A review paper in virtual manufacturing systems is presented by Bharath and Patil ⁶ in order to describe its origin, types, benefits, different virtual manufacturing systems, applications and future challenges. Usage of virtual reality in the manufacturing sector is reviewed by Choi et al. ⁷ to discuss trends in past and present research works and application for virtual manufacturing systems. The idea of applying the computer simulation and analysis to the manufacturing process is appeared in 1970s by Miron Krueger and then it is developed by Jaron Lanier in 1989 ⁶. The terms "virtual world" and "virtual environment" first appeared around 1990 in a variety of fields, including aerospace, construction equipment, and automobiles ⁶. Applications of virtual manufacturing systems are recently developed in different industries in order to analyze and modify the manufacturing processes and operations without the

need of shop floor testing. As a consequence, the developed methodology can provide less amount of time and money in part manufacturing. Moreover, digital marketing by using virtual manufacturing can increase the added value in the process of part production.

To evaluate and enhance CNC machining in virtual environments, Soori et al. proposed virtual machining approaches ⁸⁻¹¹. In order to enhance accuracy in 5-axis CNC milling operations, dimensional, geometrical, tool deflection and thermal errors are compensated by Soori and Arezoo ¹². To examine and improve efficiency in the process of component manufacture using welding processes, Soori et al. ¹³ proposed an overview of recent advancements in friction stir welding techniques. Soori and Asamel ¹⁴ studied the implementation of virtual machining methods to reduce deflection error and residual stress throughout milling operations of turbine blades. To assess and reduce the cutting temperature in milling of difficult-to-cut components, Soori and Asmael ¹⁵ proposed virtualized machining systems. To improve surface quality throughout turbine blade five-axis milling operations, Soori et al. ¹⁶ presented an improved method of virtual machining. To reduce deflection error while machining impeller blades using a five-axis machine tools, Soori and Asmael ¹⁷ proposed method of virtual milling. To examine and improve the strategies of machining parameter optimization, Soori and Asmael ¹⁸ a review from published works is presented. In order to enhance productivity in process of component production, Dastres et al. ¹⁹ presented a review of RFID-based wireless manufacturing systems. To improve productivity and added value in component production processes, Soori et al. ²⁰ studied artificial intelligence and machine learning in CNC machine tools. To evaluate and eliminate residual stress, Soori and Arezoo ²¹ provided a review in residual stress generation during machining operation. Soori and Arezoo ²² obtained optimal machining parameters utilizing the Taguchi optimization method to minimize residual stress and surface integrity in grinding operations. To increase cutting tool life during machining operations, numerous tool wear prediction systems were examined by Soori and Arezoo ²³. To transform the component production process more efficient, Soori and Asmael ²⁴ analyzed computer assisted process planning. To modify data warehouse operations using decision-supporting systems, Dastres and Soori ²⁵ studied improvements in web-based decision assistance systems. To develop the application of artificial neural networks, Dastres and Soori ²⁶ presented a survey of current artificial neural network applications and innovation. Dastres and Soori ²⁷ suggested integrating ICT with environmental protection to decrease the influence of technological advancement on natural disasters.

Dastres and Soori²⁸ presented the secure socket layer to improve security of network and data online. To develop the decision support systems approaches, Dastres and Soori²⁵ analyze the recent development in web-based assistance with decision making systems. Dastres and Soori²⁹ proposed an analysis of the latest developments in network risk in order to enhance network security measures. Dastres and Soori³⁰ analyze image processing and analysis systems to expand the possibilities of image processing systems in many applications. In order to analyze and enhance the effects of artificial intelligent, machine learning and deep learning in advanced robotics, recent achievements in published papers are reviewed by Soori et. al.³¹

In order to analyze the effects of cutting parameter to the tool life and cutting temperature in milling operations, application of virtual machining system is developed by Soori and Arezoo³². Application of virtual machining systems in turning operations is investigated by Soori and Arezoo³³ in order to analyze the impacts of coolant on the cutting temperature, surface roughness and tool wear in turning operations of Ti6Al4V Alloy. In order to analyze and modify composite materials and structures, recent achievements from published papers are reviewed by Soori³⁴. In the context of smart factories, IoT enables the creation of a digital twin of the physical factory, where real-time data from sensors, machines, and other devices can be collected and analyzed in order to optimize production processes, reduce downtime, and improve quality control³⁵. IoT plays a crucial role in creating smart factories in Industry 4.0. It enables factories to be more efficient, productive, and safe by leveraging real-time data and AI algorithms³⁶.

In this paper, a review of advanced virtual manufacturing systems is presented in order to study and analyze the recent achievements in virtual manufacturing systems. Different applications of virtual manufacturing systems in developing the production process are categorized and presented in order to analyze and discuss different achievements in published papers. Based on the review, the identification of gaps in the research filed is presented and future trends and challenges of the virtual manufacturing systems are also introduced. The research work provides a useful reference for both scholars and manufacturing centres seeking classified research works in the recent development of virtual manufacturing system in order to increase accuracy as well as efficiency in process of part manufacturing. Both academia and industry will need to have a classified references related to the virtual manufacturing systems to develop the process of part production using previous achievements in different field of research works in the production engineering. As a result, to develop the research field, new ideas for future research works in virtual manufacturing

systems are presented.

2. Virtual process planning, production scheduling and materials processing

To connect computer-aided design (CAD) and computer-aided manufacturing (CAM) systems, manufacturing engineers recently created virtual computer-aided process planning (CAPP) solutions³⁷. Production scheduling in advanced virtual manufacturing systems involves the use of scheduling software to optimize the use of resources and minimize delays and downtime. This can involve scheduling the use of machines, personnel, and materials to ensure maximum efficiency and productivity. Materials processing in advanced virtual manufacturing systems involves the use of simulation software to optimize the use of materials during the manufacturing process. This can involve identifying the most efficient way to cut or shape materials to minimize waste and reduce production costs.

CAPP is a technology-driven approach that assists engineers in developing efficient manufacturing processes. CAPP automates the process planning activities by utilizing the capabilities of CAD and CAM systems³⁸. To create non-linear process plans by applying event-driven function blocks, a machine tool analysis using Cloud-based adaptive process planning is investigated by Mourtzis et al.³⁹ The conditions of uncertainty in projects of part productions is analyzed by Huang et al.⁴⁰ to calculate the project's start time, completion time, transportation time, as well as cost using virtual manufacturing systems. In order to present an advanced tool path generation system in virtual environments, the hybrid manufacturing systems to solve different challenges of part production is studied by Urbanic et al.⁴¹ To create virtual process planning techniques for hybrid manufacturing processes, Urbanic et al.⁴² examined the 2.5 multi-axis machining process. To improve the effectiveness of the world's manufacturing systems, digital manufacturing systems is investigated by Lee et al.⁴³

Material flow development, manufacturing networks and factory layout designing, manufacturing systems control is developed by Mourtzis et al.⁴⁴ to discuss future trends in development of manufacturing industries. To develop process of gear manufacturing using virtual environments, vehicle gears and manufacturing resources using feature-based modeling are analyzed by Hu et al.⁴⁵ The virtual factory layout is analyzed and developed by Lee et al.⁴⁶ in order to enhance performances of advanced virtual manufacturing in different industries.

Hybrid modeling in virtual environments as an approach to cope with complex enterprise-wide systems is reviewed by Jahangirian et al.⁴⁷ In order to cope with new challenges in complex conditions of

component production process decision making. Virtual manufacturing systems using data mining algorithms is proposed by Stockton et al.⁴⁸ to improve precision in turning operations. To improve part

production efficiency, virtual manufacturing systems platform is investigated by Dobrescu et al.⁴⁹ An advanced method for robust scheduling using digital twins is shown in the Fig.2⁵⁰.

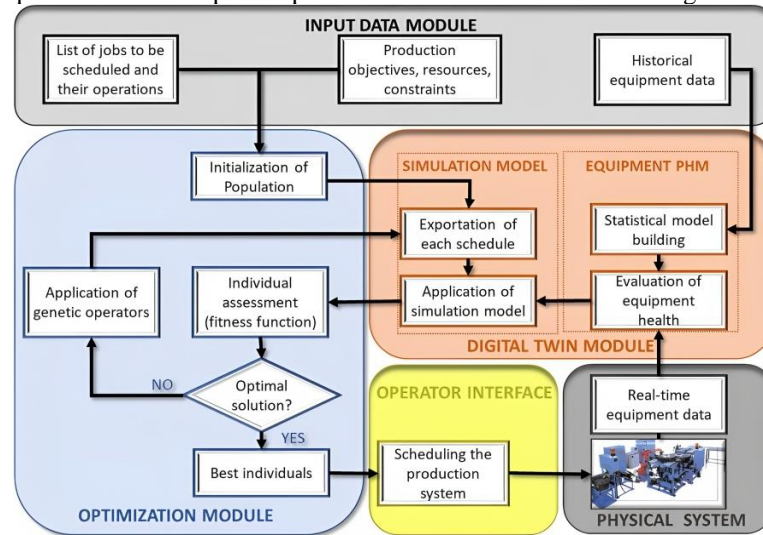


Fig. 2. An advanced method for robust scheduling using digital twins⁵⁰.

3. Virtual assembly systems

Virtual assembly systems are digital models of manufacturing processes that allow engineers and designers to test and optimize assembly processes before physical prototypes are created. These systems simulate the assembly of various components, from simple parts to complex products, such as cars or airplanes. Assembly methods and strategies used in the component production process can be studied and modified in virtual environments to increase added value in manufacturing systems⁵¹. Using virtual assembly systems, engineers can visualize the assembly process, identify potential problems, and optimize the assembly sequence and process flow. They can also test different assembly methods, tools, and techniques, and evaluate the performance and quality of the assembled product. Virtual assembly systems use computer-aided design (CAD) and computer-aided manufacturing (CAM) software, as well as simulation and visualization tools, to create a digital replica of the assembly process. These systems can also incorporate virtual reality (VR) and augmented reality (AR) technologies to create an immersive and interactive experience. virtual assembly systems are an important application of advanced virtual manufacturing systems that enable manufacturers to simulate and optimize assembly processes, reduce costs, improve product quality, and accelerate time-to-market.

Virtual assembly systems include advantages such as lower costs, better product quality, and quicker time to market. By identifying and resolving assembly problems in the digital realm, manufacturers can avoid costly physical prototypes and reduce the time and expense associated with iterative testing and debugging.

To select the best model of assembly in the process of part production, the new method of the process planning in the assembly process is investigated by Yang et al.⁵² To assemble together digital versions of actual models through simulating realistic environment behaviour, applications of virtual reality system in part assembly process is presented by Seth et al.⁵³ CAD model based virtual assembly simulation is investigated by Leu et al.⁵⁴ to reduce the problems and challenges of the assembly operations in process of part production. To obtain the consumption rates, work-in-process, real-time production rate and probabilities of machine starvation and blockage, different assembly systems with Bernoulli machines and finite buffers during transients are studied by Jia et al.⁵⁵ To decrease the energy and cost of part manufacturing, assembly operator training and process planning via virtual systems is developed by Wang and Yang⁵⁶.

4. Virtual inspection and quality control systems

Virtual inspection and quality control systems play a crucial role in modern manufacturing processes. These systems leverage advanced technologies to monitor, analyze, and ensure the quality of products without physical intervention. Virtual inspection systems use advanced imaging technology in order to inspect products and identify defects. This technology can include 3D scanning, laser scanning, and x-ray imaging. The images generated by these systems are analyzed using advanced algorithms and software to detect defects, measure dimensions, and ensure that products meet quality standards. Quality control systems are also a critical component of advanced virtual manufacturing systems. They are designed to ensure that products meet the required quality

standards by tracking the production process and identifying problems. This allows manufacturers to make adjustments and corrections to the production process before defects become too costly to be fixed. virtual inspection and quality control systems are essential for ensuring that products meet quality standards in advanced virtual manufacturing systems. They rely on advanced imaging technology, software algorithms, and machine learning to detect defects, measure dimensions, and track the production process to ensure consistent quality.

Accuracy of part production can be virtually analyzed in order to be increased using virtual inspection systems⁵⁷. As a results, machine tool errors as well as part position errors can be detected and

compensated to increase accuracy of machined parts⁵⁸. To detect and compensate the dimensional errors in manufacturing of airfoil components, a virtual inspection systems is developed by Makem et al.⁵⁹ To increase accuracy by decreasing the human worker errors, the virtual inspection systems is applied to the process of inspection and maintenance in the aviation industries by Eschen et al.⁶⁰ In order to decrease the manufacturing cost and ensure product quality and reliability, virtual inspection system is investigated by Mar et al.⁶¹ Workpiece positioning errors and machine tool geometric errors are analyzed by Martin et al.⁶² to increase precision in process of part manufacturing. Fig.3 displays a digital twins paradigm for examination of laser-welded blank⁶³.

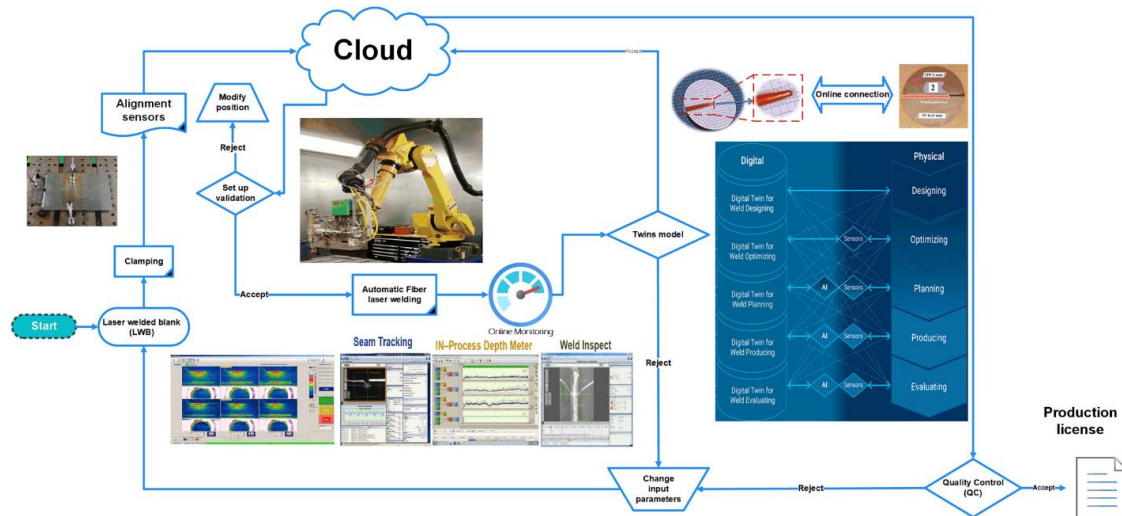


Fig. 3. Digital twins paradigm for examination of laser-welded blank⁶³.

5. Virtual material handling systems

Virtual material handling systems (VMHS) refer to the use of computer simulations and virtual reality (VR) technologies to design, analyze, and optimize the movement of materials within a manufacturing facility. These systems can help engineers and planners to efficiently plan and streamline material flow, improve productivity, reduce costs, and enhance safety in process of part production⁶⁴. VMHS are a type of advanced virtual manufacturing system which simulate the movement of materials and products within a manufacturing facility. They use computer-aided design (CAD) software to create a 3D virtual model of the facility and its equipment, including conveyors, cranes, and robotic arms. VMHS can simulate the flow of materials through a manufacturing facility, including the movement of raw materials, work-in-progress, and finished products. By using a virtual model, manufacturers can test and optimize their material handling processes before implementing them in the real world. This can help to reduce costs, increase efficiency, and minimize the risk of errors or accidents.

Some of the key features of VMHS include:

1. Simulation of equipment and

processes: VMHS can simulate a variety of material handling equipment and processes, including conveyors, cranes, lifts, and robotic arms.

2. Optimization of material flow: By simulating the movement of materials through a facility, VMHS can identify bottlenecks and inefficiencies in the material handling process. This information can be used to optimize the layout of the facility and the placement of equipment to improve material flow.

3. Visualization of material handling: VMHS provides a visual representation of material handling processes, allowing manufacturers to see how materials move through the facility and identify potential issues.

4. Training and education: VMHS can be used to train and educate employees on material handling processes and equipment. This can help to improve safety and reduce the risk of accidents in the real world.

To minimize the total cost of the expected work-in-process on the conveyor systems, automated

conveyors in material handling systems is investigated by Hong et al.⁶⁵ To generate new function version of control units in automated material handling systems, programmable material handling is investigated by Seidel et al.⁶⁶ An analytical model for advanced material handling system is developed by Nazzal et al.⁶⁷ in order to decrease delays as a result of congestion at intersection points during material movement of part manufacturing. Lin and Huang⁶⁸ described a simulation-based evolution methodology for an automated material handling technology in a semiconductor fabrication facility to reduce the cost of the material handling system in the component manufacturing process. Overall, VMHS are a useful tool for companies which want to optimize their facilities' operations and material handling procedures.

6. Flexible manufacturing and smart manufacturing systems

Flexible manufacturing is a concept in manufacturing engineering that refers to the ability of a manufacturing system to quickly and efficiently adapt to changes in product specifications, production volumes, and process requirements. They are capable of producing a wide variety of products without the need for major reconfiguration of the manufacturing equipment. FMS typically include a combination of computer-controlled machines, material handling systems, and software which can be programmed to handle different product designs and production volumes. FMS are often used in high-volume manufacturing environments where efficiency,

consistency, and speed are critical. Smart manufacturing systems, on the other hand, leverage advanced technologies such as artificial intelligence, machine learning, the Internet of Things (IoT), and data analytics to optimize manufacturing processes and improve quality, efficiency, and productivity. These systems are characterized by their ability to collect and analyze vast amounts of data in real-time to enable better decision-making, predictive maintenance, and optimization of production workflows. Smart manufacturing systems are often used in complex manufacturing environments where variability, customization, and quality control are critical. New challenges of different manufacturing systems should be analyzed and managed in order to increase efficiency in process of part production⁶⁹. Flexible manufacturing systems are a crucial tool for solving challenges and present innovative solutions in competitive conditions of marketing⁷⁰. In order to increase productivity in part manufacturing, sustainability in manufacturing process is presented by Herrmann et al.⁷¹ To solve the problems of the production process using optimized conditions, digital manufacturing systems are examined by Choi et al.⁷² To analyze and develop the different solution methods, a review study on intelligent methods for creating dynamic and reliable layouts in flexible manufacturing systems is proposed by Moslemipour et al.⁷³

Evaluation of a digital twin-based virtual factory for the advanced smart manufacturing systems is presented by Yildiz et al.⁷⁴ to provide dynamics and complex smart manufacturing systems. Virtual factory based on digital twins is depicted in Fig.4⁷⁴.

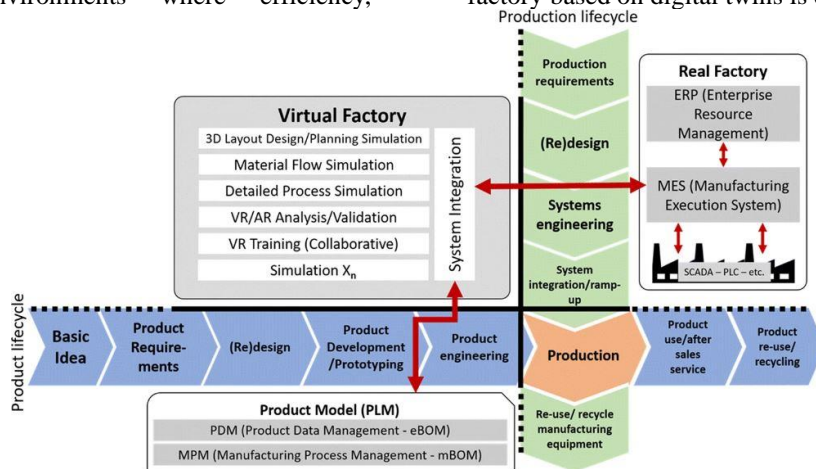


Fig. 4. Virtual factory based on digital twins⁷⁴.

Optimized designs of part manufacturing systems to decrease the cost and time of part production in flexible manufacturing systems is reviewed by Renzi et al.⁷⁵ In order to increase efficiency in flexible manufacturing systems, a developed genetic algorithm is applied to the scheduling objective under changing production demand conditions is presented by Kesen et al.⁷⁶ To minimize energy and material

usage in smart manufacturing systems, new generation of the dynamic performances in part production scheduling in developed by Davis et al.⁷⁷ Edge computing approach incorporated into a multi-agent-based collaborative virtual manufacturing enterprise is investigated by Zhang et al.⁷⁸ to reduce energy usage and increase production performance.

7. Virtual manufacturing networks

Virtual manufacturing networks (VMNs) are collaborative networks of geographically dispersed manufacturing entities that come together to share resources, knowledge, and capabilities in order to design, manufacture, and distribute products. These networks are enabled by advances in communication technologies and digitalization, which have made it possible for manufacturers to collaborate in real-time, share data, and coordinate their activities despite being physically distant from one another. In a VMN, manufacturing firms collaborate in a variety of ways, such as sharing resources like manufacturing equipment or personnel, jointly developing products and processes, and pooling their expertise and capabilities to address complex manufacturing challenges. By collaborating in this way, firms can improve their agility, responsiveness, and competitiveness, while also reducing costs and risks. VMNs are particularly beneficial for small and medium-sized enterprises (SMEs), as they allow these firms to access resources and capabilities that they might not be able to afford on their own. By participating in a VMN, SMEs can leverage the strengths of other firms in the network, allowing them to compete on a more level playing field with larger firms. To discuss the benefits of various production systems in different industries, web-based manufacturing networks can be presented⁶⁴. Thus, new generation of developed manufacturing systems can be presented using the virtual manufacturing networks to boost level of part production process⁷⁹. A developed Web-based virtual machine tool using mathematical modeling, hardware interactions and STEP-NC-based methodologies is presented by Kadir et al.⁸⁰ to address the actual behavior of machine tools and the machining process with a more scientific perspective.

The formation of manufacturing networks, structure, strategy, evolution and dynamics behavior of developed manufacturing networks is presented by Monroy and Arto⁸¹ to develop applications of virtual manufacturing networks in part production. To enhance the networking abilities in the manufacturing systems, a new manufacturing paradigm using cloud manufacturing is presented by Zhang et al.⁸² To classify the previous research works and suggest new ideas in the virtual manufacturing systems, a review in concept of cloud manufacturing systems and manufacturing networks is presented by Ren et al.⁸³ Overall, VMNs provide a potential strategy for manufacturing in the digital era, allowing businesses to collaborate and develop in novel ways and presenting new prospects for growth and competitiveness.

8. Virtual monitoring systems

In manufacturing, virtual monitoring systems can

be used to monitor production lines and equipment, track inventory levels, and optimize supply chain operations. In energy, virtual monitoring systems can be used to monitor power plants, track energy consumption, and manage renewable energy sources. And in transportation, virtual monitoring systems can be used to track vehicles, monitor fuel consumption, and optimize routing and scheduling. Virtual monitoring systems typically rely on a combination of sensors, communication networks, and analytics software to collect and process data in real-time. This data is often displayed on a dashboard or other user interface that allows operators to quickly identify issues and make informed decisions. The part production process can be virtually monitored in order to be analyzed. Therefore, decision making strategies as well quality control of part production process can be developed using the virtual monitoring systems⁸⁴. To reduce the failure rate of the cutting tools used in machining processes, fusion based virtual tool wear sensing systems based on artificial intelligence is investigated by Wang et al.⁸⁵ The process of machining operations using sensors is monitored by Teti et al.⁸⁶ to increase capabilities of monitoring systems in accuracy enhancement of produced parts. In order to introduce new sensors and monitoring methods for emergent additive manufacturing processes, the process of additive manufacturing is analyzed by Everton et al.⁸⁷ Application of the virtual reality systems in the monitoring and analysis of shop-floors production process is investigated by Fast-Berglund et al.⁸⁸ to increase the effects of virtual reality systems in part efficiency enhancement of part manufacturing.

On line monitoring system of machining operation is developed by Altintas and Aslan⁸⁹ to obtain the power, torque, cutting forces, chip load and other process states in machining operation. To improve productivity by adjusting production process using the predicted values of virtual metrology system, a virtual metrology system is developed by Kang et al.⁹⁰ To decrease the collision rate in the moving area of the robot arms, monitoring system of the industrial robots is presented by Ferraro et al.⁹¹

9. Virtual commissioning systems

Virtual commissioning systems are computer-based simulation tools in order to test and validate the functionality of a manufacturing system or machine before it is physically built or installed. Advanced virtual manufacturing systems use virtual commissioning systems in order to simulate and analyze the entire manufacturing process, including the production line, machines, and control systems. The benefits of virtual commissioning systems are numerous. They can significantly reduce the time and cost required to commission and debug a manufacturing system or machine. By identifying and

resolving potential issues in a virtual environment, manufacturers can avoid costly delays and downtime during the actual commissioning process. Additionally, by enabling engineers to test and fine-tune the control algorithms and settings in a virtual environment, virtual commissioning systems can aid in improving the performance of a production system. To use a virtual commissioning system, engineers create a digital twin of the manufacturing system or machine using 3D modeling software. The digital twin includes a detailed model of the physical components, such as motors, sensors, and control systems, as well as the software that controls their operation. The virtual commissioning system then simulates the operation of the manufacturing system or machine under a range of operating conditions, allowing engineers to identify and correct any potential issues. The automated manufacturing systems can be developed by applying the different applications of virtual commissioning systems to the part production process such as Computer Aided Process Planning (CAPP) as well as virtual machining systems⁹². As a result, virtual environments could be used to design and assess the component production process. The application of virtual commissioning for automated manufacturing systems is analyzed by Lee and Park⁹³ to reduce the amount of time spent troubleshooting and making corrections in the following real production systems. The application of virtual commissioning in training process is shown in the Fig.5⁹⁴.

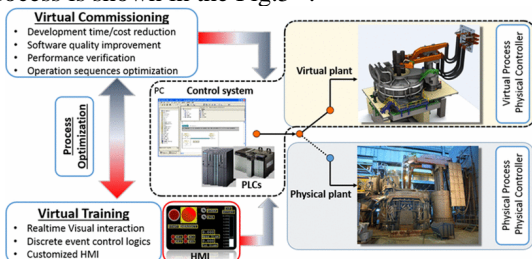


Fig. 5. Application of virtual commissioning in training process⁹⁴.

To develop virtual manufacturing systems, a flexible framework in virtual manufacturing enterprises using virtual commissioning is developed by Knoke et al.⁹⁵ To increase efficiency in large-scale assembly systems, application of industrial robots in the virtual commissioning systems is investigated by Makris et al.⁹⁶ To increase capabilities of the virtual commissioning systems, a new design techniques of manufacturing system for virtual commissioning is developed by Ko et al.⁹⁷ The automated generation of manufacturing systems is developed by Puntel-Schmidt and Fay⁹⁸ to enhance productivity in part production process using virtual commissioning systems. Overall, virtual commissioning systems are a powerful tool for manufacturers looking to improve the efficiency and

reliability of their manufacturing systems. By simulating the manufacturing process in a virtual environment, manufacturers can reduce costs, optimize performance, and ensure that their systems are ready to operate at peak efficiency from day one.

10. Virtual training systems

Virtual training systems are becoming increasingly popular in manufacturing due to the many benefits they offer. These systems use advanced technologies such as virtual reality (VR) and augmented reality (AR) to create a simulated environment that allows workers to learn and practice their skills without the risks and costs associated with traditional training methods.

Here are some of the ways virtual training systems are being used in manufacturing:

1. Skill development: Virtual training systems allow workers to learn and develop new skills in a safe, controlled environment. This can include anything from operating complex machinery to performing intricate assembly tasks.

2. Safety training: One of the biggest advantages of virtual training systems is that they can provide workers with realistic safety training without putting them in harm's way. Workers can learn how to identify and avoid hazards, respond to emergencies, and practice proper safety procedures.

3. Quality control: Virtual training systems can be used to teach workers how to identify defects and other quality issues. This can help improve overall product quality and reduce waste and rework.

4. Equipment maintenance: Virtual training systems can also be used to train workers on how to perform equipment maintenance and repairs. This can help reduce downtime and increase overall equipment reliability.

Experiences of operators in different sections of manufacturing systems can be increased by using virtual training systems⁹⁹. Real challenges and problems of part production process can be simulated in virtual environments in order to be managed by novice operators. As a result, the operators can be trained in virtual environments without the demand of education in workshops to make component production systems less expensive. To enhance accuracy in part production process, the application of the virtual training system in the PLC programming is developed by Riera et al.¹⁰⁰ The manufacturing systems is simulated in virtual environments by Manesh et al.¹⁰¹ in order to be used in virtual training applications. The virtual training system is developed by Xia et al.¹⁰² to develop the assembly system of the

sophisticated parts using virtual training and education. As a result, errors and problems of assembly process for complex parts can be analysed and decreased. Future generation of automotive manufacturing industries using virtual training systems are studied by Gorecky et al.¹⁰³ in order to increase efficiency in car production process. To enhance workers experiences and decrease cost and time of staff training in assembly process of car

production, application of virtual training system is presented by Stork et al.¹⁰⁴ A industrial assembly training system using virtual reality is created by Abidi et al.¹⁰⁵ to provide lesser time in actual product assembly process in terms of improving part production's performance. Virtual training and modification system of cutting tool paths during milling operations is shown in the Fig.6¹⁰⁶.

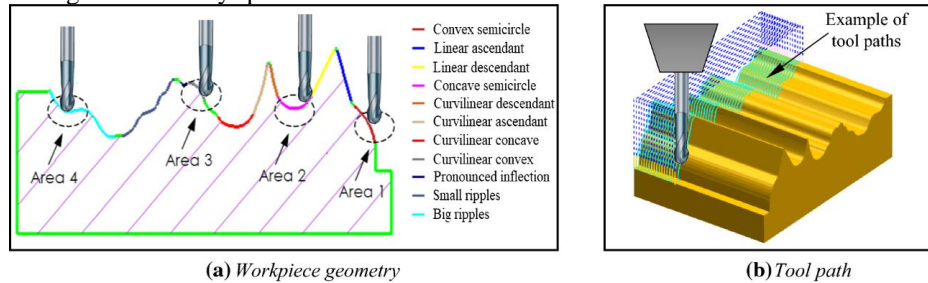


Fig. 6. Virtual training and modification system of cutting tool paths during milling operations¹⁰⁶.

Overall, virtual training systems can be a valuable tool for improving worker skills, productivity, and safety in manufacturing environments.

11. Virtual machining systems

Virtual machining systems (VMS) are computer programs or simulators that allow engineers, designers, and machinists to create, test, and optimize machine tool paths and machining processes in a virtual environment. VMS can be used for a wide range of applications, including milling, turning, drilling, and grinding. VMS software typically allows users to create 3D models of their parts, define machining operations, and simulate the machining process to verify the accuracy and efficiency of the tool paths. VMS also provides a platform for optimizing machining parameters such as cutting speed, feed rate, and tool selection. The benefits of VMS include reduced machining time, improved accuracy, and reduced material waste. VMS can also help machinists avoid collisions between the tool and the workpiece, as well as between the tool and the machine itself. Virtual machining solutions are presented to simulate and examine the manufactured parts in virtual settings. Using virtual machining technologies, the generated parts can be examined and adjusted¹⁰⁷. As a result, accuracy as well as efficiency in produced parts can be increased. To optimize the process parameters and increase efficiency of part manufacturing in the aerospace industries, the virtual machining system is applied by Wiederkehr and Siebrecht¹⁰⁸.

to produce real machined components in virtual settings while taking into account the geometrical and dimensional flaws of a three axis CNC milling machine, virtual machining system is developed by Soori et al.¹⁰. Also, dimensional, geometrical and tool deflection errors in three-axis CNC milling machines is considered by Soori et al.⁹ to manufacture actual

machined components in virtual worlds. CNC systems' processing of motion commands using virtual machining system is shown in Fig.7¹⁰⁹.

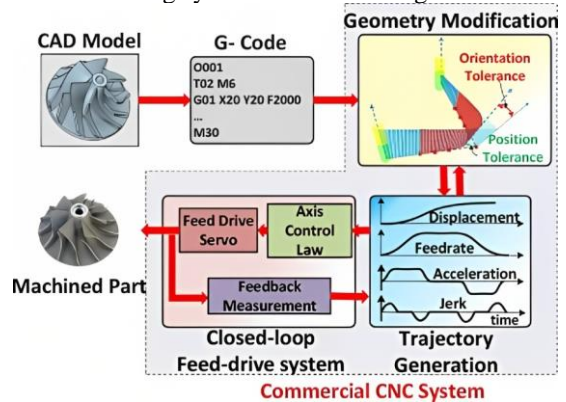


Fig. 7. CNC systems' processing of motion commands using virtual machining system¹⁰⁹.

To monitor and minimize tool deflection error in 3-axis CNC milling operations, application of virtual machining system is presented by Soori et al.¹¹ To analyze accuracy of tool deflection error modeling in prediction of milled surfaces, a developed virtual machining system is presented by Soori et al.⁸. The study compares several tool deflection error estimation techniques to demonstrate the precision and dependability of the techniques in milled surface prediction. Overall, VMS is a powerful tool for optimizing machining processes and improving productivity in manufacturing operations.

12. Virtual manufacturing for production optimization

Virtual manufacturing for production optimization is a methodology that utilizes computer-based tools and simulations to optimize the production processes in manufacturing industries. It involves creating a virtual representation of the manufacturing

environment, including the equipment, processes, and resources, and using this digital model to analyze, predict, and optimize various aspects of production. As a result, part manufacture can obtain additional added values¹¹⁰. One of the primary benefits of virtual manufacturing is that it enables manufacturers to reduce the time and cost associated with physical testing and prototyping. By simulating the manufacturing process in a virtual environment, manufacturers can identify potential problems and test different solutions before committing to costly physical prototyping and testing. Another benefit of virtual manufacturing is that it allows manufacturers to optimize their production processes to increase efficiency and reduce waste. By simulating different production scenarios and identifying potential bottlenecks, manufacturers can develop more efficient production plans that minimize waste and improve overall productivity. In addition to optimizing production processes, virtual manufacturing can also be used to improve product design and performances. By simulating the manufacturing process and testing different design iterations, manufacturers can identify design flaws and optimize product designs for manufacturability, reducing the risk of production delays and quality issues. Optimized manufacturing process parameters using virtual prototyping and digital manufacturing tools is obtained by Andrisano et al.¹¹¹ in order to optimize the component production process. The optimized condition of the part production using milling and turning machining operation is investigated by Monica¹¹² to decrease time and cost of accurate production. Optimized conditions of the clamping positions in milling operations is investigated by Rehage et al.¹¹³ to develop process of part production using virtual machine tools.

Application of virtual manufacturing in additive manufacturing process is presented by Liu et al.¹¹⁴ in order to enhance accuracy in produced parts. To increase the ability of designing of the workstations in manufacturing cells, a general framework for the manufacturing workstation design optimization is developed by del Rio Vilas et al.¹¹⁵ Application of digital twin and virtual simulation in optimization process of machining operations is shown in the Fig.8¹¹⁶.

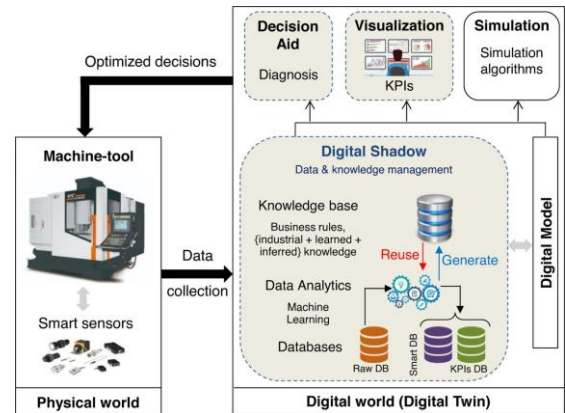


Fig. 8. Application of digital twin and virtual simulation in optimization process of machining operations¹¹⁶.

Overall, virtual manufacturing is a powerful tool for optimizing production processes and improving product design in order enhance productivity in part manufacturing. It offers significant advantages in optimizing production processes, reducing costs, improving product quality, and enhancing overall efficiency in manufacturing industries.

13. Cloud manufacturing systems

Cloud manufacturing systems refer to the use of cloud computing technologies to manage and optimize the manufacturing process. Cloud manufacturing systems typically involve the integration of various technologies, such as big data analytics, artificial intelligence (AI), and the Internet of Things (IoT), to enable manufacturers to streamline their production operations and improve their overall efficiency. One of the key advantages of cloud manufacturing systems is that they allow manufacturers to access and use a wide range of resources, tools, and services over the internet, without having to invest in expensive hardware or software. This enables manufacturers to scale their operations up or down as needed, and to take advantage of new technologies as they become available. Cloud manufacturing systems can also help manufacturers to collect and analyze data from their production processes, which can be used to identify patterns, optimize workflows, and improve overall quality control. For example, data analytics tools can be used to monitor the performance of individual machines and to predict when maintenance or repairs will be needed, which can help to reduce downtime and improve efficiency.

The application of cloud manufacturing systems in advanced component production can share the advantages of various part manufacturing procedures in the networks¹¹⁷. As a result, new generation of the part production process can be presented by accumulating the advantages of different manufacturing systems in different industries. Application of the cloud manufacturing services in

small and medium-sized production plan is studied by Huang et al.¹¹⁸ to share the advantages of different production scheduling systems. In order to develop applications of the cloud manufacturing systems in the virtual manufacturing, an advanced web based cloud manufacturing model is investigated by Tao et al.¹¹⁹ To design new manufacturing plan using cloud manufacturing system, operating Paradigm, functional requirements, and architecture design in the cloud manufacturing platform is investigated by Ren et al.¹²⁰ In cloud-based design and production environment, intelligent virtual manufacturing cells are presented by Ostrosi and Fougères¹²¹ in order to develop the designing and manufacturing processes.

To develop the part production process using virtual manufacturing systems, manufacturing service management in cloud manufacturing is applied by Tao et al.¹²² In order to develop the virtual manufacturing systems cloud manufacturing, cloud computing and other relevant manufacturing technologies is studied and developed by Ren et al.¹²³ Cloud manufacturing systems are examined in terms of fuzzy decision-making theory by Cao et al.¹²⁴ to increase efficiency in process of part production. The model of future intelligent manufacturing enterprises is presented in Fig.9¹²⁵.

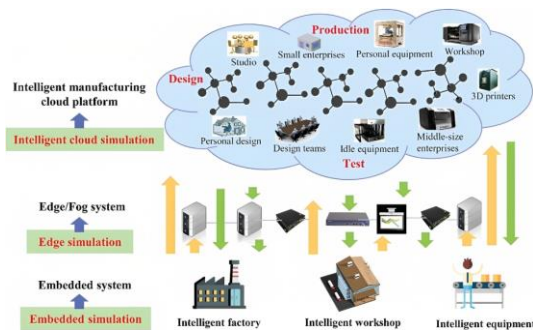


Fig. 9. Future framework of intelligent manufacturing¹²⁵.

Overall, cloud manufacturing systems can offer significant benefits to manufacturers, including increased flexibility, improved productivity, and greater agility in responding to changing market conditions. However, they also require careful planning and implementation to ensure that they are integrated effectively into existing production processes and workflows.

14. Conclusions and future research works

In this paper, virtual manufacturing systems and applications are reviewed to study the recent achievements from published papers. Virtual process planning, production scheduling and materials processing are developed to analyze effective parameters in process of manufacturing process³⁹⁻⁴⁸.

As a consequence, part production processes can become more efficient. Virtual machining assembly systems⁵²⁻⁵⁶ are developed to modify the process of part assembly in virtual environments. Virtual inspection and quality control systems can be used to evaluate accuracy of simulated manufacturing process in virtual environments⁵⁹⁻⁶². By examining the simulated manufacturing process in virtual worlds, accuracy of generated products as well as efficiency of production process can be improved. To develop the process of part handling in manufacturing operations, virtual material handling systems⁶⁵⁻⁶⁸ are presented to increase efficiency of material management in process of part production process. Flexible manufacturing systems and smart manufacturing systems in future are presented in order to develop future plans of virtual manufacturing systems^{71-73,75-77}. Virtual manufacturing networks are developed in order to be connected in the web of data⁸⁰⁻⁸³. As a result, advantages and capabilities of different virtual manufacturing systems can be shared and increased. Virtual monitoring systems are studied to develop sensing techniques based on production data^{85-87,89-91}. Virtual commissioning systems are developed to examine and modify the simulated manufacturing process in virtual environments^{93,95-98}.

Virtual training systems are presented in different research works in order to enhance skills of workers without physical training¹⁰⁰⁻¹⁰⁴. So, the operators can be trained by the system without the need of physical production operations to decrease the cost of operator training. To increase accuracy as well as efficiency of part production, virtual machining systems are presented by simulating real machining operations in digital environments^{8-11,108}. Moreover, production processes can be optimized using different optimization techniques to improve part production efficiency using virtual manufacturing systems¹¹¹⁻¹¹⁵. Cloud manufacturing systems are presented to develop concept and applications of the systems in virtual manufacturing^{118-120,122-124}.

The impacts of virtual manufacturing systems in productivity enhancement of part production are discussed in different research works. By integrating virtual worlds into production processes, these systems can benefit from flexibility, adaptability, and analytical capability. Using optimization techniques to acquire improved manufacturing variation parameters can boost the efficiency of part manufacture. Virtual machining systems, virtual monitoring systems, and virtual inspection systems can be used in the simulated component manufacturing process in a virtual environment to enhance accuracy in manufactured parts. By adopting virtual manufacturing systems, the time and expense of material handling as well as assembly processes in the component production process may be evaluated and reduced. In order to lower the cost of employee

education, machine tool operators can be trained using virtual simulations of industrial processes. It can be utilized to improve the manufacturing cells' capabilities in order to meet the need for innovation in the highly competitive world of product marketing. Also, virtual manufacturing is a powerful tool for reducing the risk connected with producing new goods in terms of modifying the production engineering. Virtual manufacturing networks and cloud manufacturing systems can be applied to the simulated manufacturing systems in virtual environments to share the benefits of the various manufacturing systems in different industrial applications. Advanced virtual manufacturing systems can help manufacturers to improve efficiency, reduce waste, and optimize their manufacturing processes to meet changing market demands.

In virtual environments, free form surfaces of workpieces may be simulated and studied. To increase the precision of item manufacture, surface machining tactics can be evaluated and adjusted. In terms of collision detection techniques, the machining tactics are subject to analysis and modification in virtual settings. Thus, when free form surfaces are being machined using 5-axis CNC machine tools, machining mistakes can be reduced by adopting modified versions of machining techniques. To offer an improved Computer Assisted Process Planning, machining scientists' experiences and expertise can be evaluated and updated using mathematical principles to identify the optimal machining techniques in the production of complex components (CAPP). The development of knowledge-based CAPP systems in fuzzy settings can improve performance of machining operation in virtual manufacturing systems. Flexible virtual manufacturing systems can be used to handle the resource balance in multi-criteria decision-making situations. In order to deal with product difficulties in production process of complicated parts, the supply chain management systems based on virtual manufacturing systems can also be applied.

Virtual monitoring systems can be connected together via network to share the advantages of different manufacturing operations of part production process. In order to improve the efficiency of the component production process, complicated manufacturing networks offer an efficient solution for the rising scale and expanding scope of manufacturing services. By supplying the mapping connections between services and demands at time points of component production schedules, virtual manufacturing systems enable analysis and modification of supply demand matching and scheduling of manufacturing services. Internet of things, big data and Cloud Techniques-Based analysis systems are also some applications of virtual simulation in future trend of virtual manufacturing systems. Advanced virtual manufacturing systems can

also incorporate machine learning and artificial intelligence algorithms to improve the accuracy and efficiency of virtual inspection and quality control systems. These technologies can help manufacturers identify patterns in defect data and make predictive maintenance decisions to improve product quality. Advanced virtual manufacturing systems can be developed by using virtual commissioning and incorporating data from real-world manufacturing systems in terms of accuracy enhancement of simulation process. By combining data from sensors and other sources, these systems can create highly detailed models of the manufacturing process and identify potential issues before they occur.

By employing virtual manufacturing networks for component production, cloud manufacturing processes can offer the capabilities of service monitoring systems. To improve the efficiency of the component production process, energy-consumption evaluation, analysis, and optimization systems might be built. To cut down on the time and expense of the product assembly process, developed assembly systems can be evaluated and controlled utilizing virtual manufacturing systems. In order to achieve the optimum topology of complicated components with free form surfaces, the additive manufacturing methodology can be developed utilizing a virtual manufacturing system. So, by utilizing virtual manufacturing systems during the component production process, more added values may be created. In order to reduce environmental pollution brought on by industrial engineering, green manufacturing systems can be constructed utilizing virtual manufacturing systems. By applying virtual environments into the component production process, waste materials in manufacturing processes can also be examined and reduced. These are ideas for potential future research works in the field of developing virtual manufacturing systems.

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