International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 09 Issue: 04 | Apr 2022 www.irjet.net p-ISSN: 2395-0072

Digital Twin Driven Optimization of Human Cyber Physical Environment in Smart Manufacturing

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Abstract - *Digital Twin can be interpreted as a flow cycle (mirroring or twinning) between physical and virtual states, with data flowing from physical to virtual and information and processes flowing from virtual to physical. Advances in recent technologies and initiatives, such as the Internet of Things, big data, multi-physical simulations, Industry 4.0, and sensor networks, have pushed towards a data-driven and digital manufacturing future. Digital Twin's stringent criteria drive the integration of material design and ground-breaking methods to material processing. Smart manufacturing services can improve manufacturing efficiency by optimizing the whole business process and operating method. In this paper, we envision the combination of smart manufacturing services with a digital twin elaborates upon complete transformation in product design, production, and usage. High-fidelity virtual representations of physical things are created to mimic their behavior, which opens the path for the cyber-physical system to be realized. In this paper, we review an engineering design shift toward a paradigm of customers co- creating product value chain fulfillment in a human-cyber-physical environment; the traditional scope of productfulfillment must be expanded to include marketing, design, production, supply and value chains, all of which must be aligned with a learning organization's self-adaptability.*

***Key Words*: Digital Twin, Smart manufacturing, Cyber-Physical System, Internet of Things, Industry 4.0, Supply and Value chain, Digital Thread framework**

1. INTRODUCTION

Smart Manufacturing is a technology-driven method using Internet-connected machinery model to monitor the production process with an objective to find automation possibilities and utilize advanced technologies to enhance production performance. Deployments include incorporating sensors into production equipment to gather information about their operational condition and performance. Smart manufacturing, when coupled with the features of a digital twin technology, allows for intelligent sensing and simulation, resulting in more efficient and intelligent product creation. Simultaneously, it could monitor the status of goods and manufacturing equipment in real time and anticipate potential problems. Technologies like the Internet of Things (IoT), Big Data analytics,Smart Automation, the Supply Chain, Logistics, and Cloud Computing have led to a new wave of advances in the production of production technologies which are collectively referred to as Industry 4.0. Smart factories will integrate services across production and operational processes and can react to disturbances in real time to improve quality of goods and services.

We propose an engineering design shift toward a paradigm of customers co-creating product value chain fulfilment in a human-cyber-physical environment, the traditional scope of product fulfilment must be expanded to include marketing, design, production, supply and value chains, all of which must be aligned to learn organization's self-adaptability. The research methodology was based on critically analyzing the parameters influencing the digital twin driven human-cyber-physical environment as shown in Figure 1. To understand and deeply analyze this engineering design shift we review each parameter in depth, we list out the findings of previous literatures (refer to the table below) and what insights and new knowledge creation avenues we have discovered in our work on the topic.

He and Bai *et al*. [1] research examines both technology and the long-term viability of intelligent manufacturing. The relevant content of intelligent manufacturing is first examined, which includes intelligent manufacturing equipment, systems, and services. The long-term viability of intelligent manufacturing is also addressed. Following that, a digital twin and its application, as well as the development of intelligent manufacturing based on digital twin technology, with monitoring the status of goods and manufacturing equipment in real time and anticipate potential problems the supply chain mechanism can be enhanced.

Jiao *et al.* [2] research proposes that as Engineering design shifts toward a paradigm of customers co-creating product value chain fulfilment in a human-cyber-physical environment, the traditional scope of product fulfilment must be expanded to include marketing, design, production, supply and value chains, all of which must be aligned with a learning organization's self-adaptability. However, development in these sectors is driven by the requirements of specific application domains, rather than a comprehensive perspective of the global value chain network of product design, production, and fulfilment.

Roy *et al.* [3] paper also included a case study in which digital twin analyses the streaming data, diagnoses it,and presents the results on a dashboard in real time. The Digital Twin enables the user to give inputs based on the recommendation, which the twin then sends back to the machine in real time, allowing it to be controlled. The user input becomes very important when analyzing and modifying the supply chain mechanism. It also includes a data model for forecasting tool status in real time to save material waste during welding. It has the capacity of storing and displaying the results of various processing circumstances over time as a trend analysis.

Waschull *et al.* [4] examined this transition at a much more comprehensive level in their research by the creation of a framework for evaluating changes in work design as part of the transition to CPS, as well as the evaluation of the role of management decision in this process. The framework connects CPS capabilities on the machine, manufacturing line, factory, and supply chain to human information processing activities. In their articleVan der Zeeuw *et al.* [5] utilize forms of capital and Internet skills to describe several kinds of social applications of the Internet of Things (IoT). They believe that the IoT platform encourages various forms of social interactions that are often ignored when the novelty of smart "things" is the emphasis. In order to understand how individuals establish, maintain, or break social connections in a manufacturing shop floor, it's critical to look at how they utilize the IoT for supply chain design.

The recent development of the Internet of Things necessitates mechatronics developers, experts, and instructors to further evaluate the ways by which mechatronic systems and components are seen, developed, and produced. According to Kundanati and Kumari *et al.* [6] article, in particular, the usage of mechatronic smart objects as part of an IoT-based system in which the structure is determined by context is causing a greater emphasis on issues such as machine values, user communication, complexity, and context, as well as information and security issues. As a result, creative development and education and learning methods are being pursued in order to meet the difficulties that arise.

The different components of the digital twin are utilized by manufacturers in the form of services, according to Qi *et al.* [7] study, which defines and emphasizes how manufacturing services and digital twin are merged. Product design, production, use, MRO, and other processes would be drastically altered if smart manufacturing services and digital twins were combined. Through the two-way connection between the virtual and physical worlds of manufacturing, the digital twin will produce more rational manufacturing planning and accurate production control to assist achieve smart manufacturing with optimum supply and value chain standards being met.

Under the mass individualization paradigm, Leng *et al.*, [8] article proposes a digital twin-driven manufacturing cyber-physical system (MCPS) for parallel controlling of smart workshops. Various manufacturing resources may be created as a dynamic autonomous system to co-create customized goods by creating cyber-physical connections through decentralized digital twin models.

Industrial systems are becoming smart as CPS becomes more widely used in manufacturing settings. Zheng *et al.* [9] study analyses smart cities in order to enhance research on the deployment of Industry 4.0. Industry 4.0 manufacturing systems First, an Industry 4.0 conceptual framework for smart production systems is provided. Second, examples of smart design, smart machining, smart monitoring, and smart scheduling situations all being critical to the supply chain design mechanism. Based on these demonstration situations, key technologies and their potential applicability to Industry 4.0 smart manufacturing systems are examined.

Li *et al.* [10] study analyze the rapid development of core technologies in the new era of 'Internet plus AI,' which is triggering a great change in the models, means, and ecosystems of the manufacturing industry, as well as in the development of AI, based on research into the applications of artificial intelligence technology in the manufacturing industry in recent years.

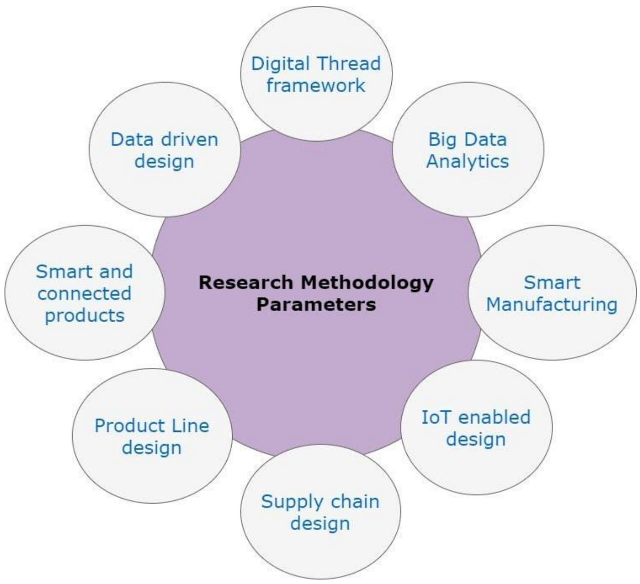

Figure 1: Research methodology parameters

2. DIGITAL TWIN AND THREAD FRAMEWORK

Digital twin is a digital representation of physical elements in a cyber-physical system. A digital twin in a manufacturing environment contains design requirements and engineering models used to define a physical object's shape, materials, components, and behavior. It also contains as-built and operating data that is particular to the physical asset that it represents. According to NASA Glaessgen and Stargel *et al.* [11] Digital Twin is a multi- physics, multiscale, probabilistic simulation of an as-built vehicle or system that utilizes the best available physical models, sensor updates, fleet history, and other factors to mimic the life of its corresponding flying twin. Michael Grieves originally introduced the idea of a digital twin at one of his PLM lectures at the University of Michigan in 2003. Digital Twin is now one of the most widely used technology. The digital twin is gaining much traction in the business because of its enormous potential for disruptive development. Grieves defines the DigitalTwin as a three-part system that includes a physical product, a virtual representation of that product, bi-directional data connections that feed data from the material to the virtual model, and information and processes from the virtual representation to the physical. Grieves portrayed this flow as a cycle (mirroring or twinning) between physical and virtual states, with data flowing from physical to virtual and information and processes flowing from virtual to physical. Advances in related technologies and initiatives, such as the Internet of Things, big data, multi- physical simulation, Industry 4.0, real-time sensors and sensor networks, data management, data processing, and a push toward a data-driven and digital manufacturing future, have all contributed to this growth. As a result, both academics and industry have been studying, creating, and attempting to implement Digital Twins or the conceptsthey represent.

One distinction between the Digital Twin and more conventional simulation and modeling activities, where analysis is often done 'off-line,' is the constant link between the real and virtual worlds. The physical-to-virtual link enables the monitoring of state changes that occur in reaction to changes in the physical environment and changes in state that occur as a result of Digital Twin interventions. Even though it is included in Grieves' original definition, the virtual-to-physical link is not usually mentioned in explanations of Digital Twins in contrast to the physical-to-virtual connection. The reason for this is unclear; theoretically, a 'Digital Twin' can be created with only a one-way physical-to-virtual connection – the state of the virtual entity will reflect the state of the physical; thus, the two can be described as 'twinned' – but it is difficult to see how the benefits of the Digital Twin can be realized without a virtual-to-physical connection.

3. BIG DATA ANALYTICS

Data is increasingly accessible and omnipresent in various sectors with an aggressive push to the Internet and IoT technologies which lead to the problem of Big Data. Sensors, devices, video/audio, networks, log files, transactional apps, the web, and social media feeds are all common sources of big data. Under these conditions, a "big data environment" has progressively emerged in the industrial industry. Although the development of IoT (e.g., smart sensors) has simplified data gathering, the issue remains as to whether this data can be effectively processed in order to deliver the appropriate information for the right purpose at the right time. The datasets in a big data environment are considerably bigger and may be too complicated for traditional data analysis tools. As a result, sophisticated analytics methods are essential for discovering hidden patterns, undiscovered connections, market trends, consumer preferences, and other valuable business information for companies and manufacturers with an excess of operational and shop-floor data.

In most sectors, including customer relationship management (CRM) data into analytics is seen as an efficient approach to improve customer engagement and satisfaction. For example, an automotive manufacturer may utilize historical orders and user comments to produce a "face-lift vehicle" that will please consumers even more than before. Furthermore, a deeper examination of different data from equipment and processes may reveal a company's productivity and competitiveness. For example, hundreds of variables must be monitored in the biopharmaceutical manufacturing cycle to ensure accuracy, quality, and output. A firm may find key factors that have the biggest effect on quality or yield variation by analyzing large data, providing common application scenarios for Big Data Analytics to explore its use in different industries. Although there are many more examples in different sectors, the bulk of the applications mentioned here are linked to manufacturing companies. Numerous examples from e-commerce businesses and financial investment institutions may be given as beginning references for manufacturers interested in using BDA and gaining substantial value from it.

Intelligent objects can identify defects and delegate tasks to other operating machines, contributing greatly to production flexibility and optimization. Smart factories can collect and analyze data in real time and make decisions immediately and at any time. Real-time capabilities are not limited to market research only but also to internal processes, such as the failure of a production line machine. Big data and analytics are the core computer technology capabilities driven by the digitization and integration of vertical and horizontal value chains as well as product and services digitization along with digital business models and client access. Industry 4.0 provides operators with comprehensive information in order to inform decision-making. It calls on information systems, by configuring digital data into sensor data, to create virtual copies of the physical world. To achieve this, raw sensor data with compatible context data must be aggregated.

4. SMART MANUFACTURING

Smart manufacturing is a large category of manufacturing that utilizes integrated computer production, high degrees of flexibility and fast design modifications, digital information technology and more flexible technical training for workers. Figure 2 illustrates the intelligent production system architecture, which covers activities, equipment, features and others that are engaged in smart three-dimensional manufacturing: life-cycle, system level and smart features. Deep integration and integration of information technology, intelligent technology, and manufacturing equipment are the intelligent manufacturing technology. Smart manufacturing technologies are based on state-of-the-art technologies such as contemporary sensor technology, network technology, automation technology and anthropomorphic intelligence. Smart manufacturing technology allows intelligent design, smart manufacturing processes, and smart production equipment via intelligent sensing, human-computer interface, decision-making and execution technology. In addition, the idea of sustainable production is increasingly being addressed, and intelligent production should be sustainable. In smart production, a physical 'thing' is linked to the industry through common cyber portals in a factory and is abstracted in cyberspace as a Digital Twin. Every digital twin in cyberspace reflects its physical state and abstracts its counterpart in the real world. The cyberspace stores and processes streaming data from physical things linked. These data are utilized in dynamic working circumstances to model, simulate and forecast the state of all physical things. The widespread application of intelligent technologies like big data processing and artificial intelligence allows the recovery of industrial intelligence at every stage of production. In local factories and cyberspace collective intelligence prepares the way for significant alterations in the areas of intra-business operation, inter- business cooperation and production model.

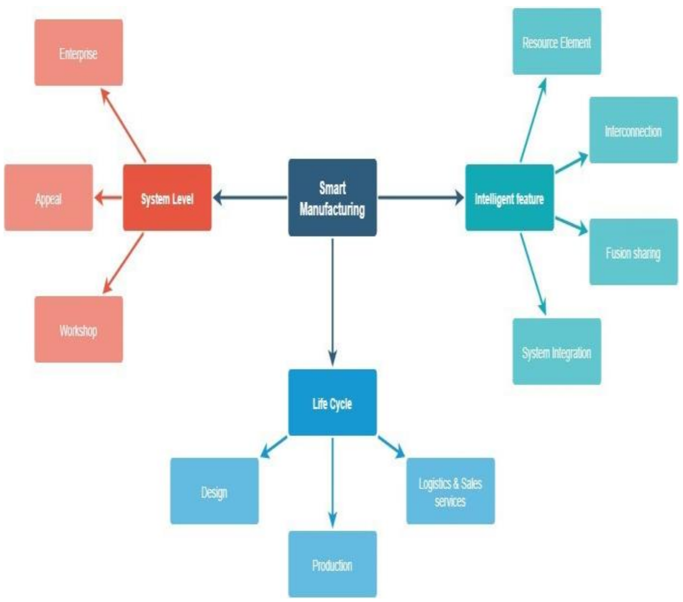

Figure 2: Smart Manufacturing System architecture

5. IoT ENABLED DESIGN

Networked technologies and IoT ubiquity make data available throughout the product life cycle effortlessly. The primary drivers of Industry 4.0 will be the need to build systems that can cooperate and adapt to enhance product quality, process dependability, system agility and the sustainability of the systems ecosystem.

The information collected from several data sources in real time is expected to assist decision making. Data mining methods applied to large data, however, are predicated on the assumption that knowledge is in some way contained in the data. Since early design iterations are based on real data, systems may be designed if incomplete or no data is available. System design and production are mostly motivated by the need for profit. Collection of IoT-enabled data through typical IoT technologies like bar coding may be integrated into different industrial resources. They are thus transformed into intelligent manufacturing objects (SMOs) which may interact and communicate intelligently to enable the acquisition and collection of real-time production data in real time.

Collection of IoT-enabled data through typical IoT technologies like RFID and bar coding may be integrated into different industrial resources. They are thus transformed into intelligent manufacturing objects (SMOs) which may interact and communicate intelligently to enable the acquisition and collection of real-time production data in real time.

6. SUPPLY CHAIN DESIGN

Digital supply chain design must be linked with the intended virtual value chain for production inside the connected company. The dynamic reconfigurability of supply networks that Industry 4.0 offers involves re- examining service-level agreements with upstream and contracting providers for efficient supplier management. Dedicated capabilities, increased risk profiling, IP protection and material dependability must all be incorporated. The design of the supply chain is strongly associated with product platforming and family design decisions. Visibility of the supply chain is essential to react to planned and unexpected events as soon as possible to improve efficiency and minimize risk. Product architecture, production planning and supply chain choices must be coordinated in accordance with Industry 4.0 digital product production threads. Demand forecasting and product planning will be enormously enhanced by big data analysis enabled by the realization of intelligent and linked products. The conception of the supply chain involves the linkage of production capacity to the logistics choices on the basis of a clear knowledge and the transposition into targeted production units of changing demand patterns. Supply networks must be reoriented in a supply network architecture which includes a digital product value chain to achieve agility and supply resilience without jeopardizing time to the market. As smarter companies take root, alignment in a holistic manner is essential, not just in manufacturing or logistics. Within the company product innovation platforms, digital supply chain activities must be designed. The linked technologies will be integratedinto new physical objects, such as goods, tools and even industrial equipment. New thinking and new IT demands product innovation platforms to define and create products, but also to manage product life cycles. The way things are produced requires new thinking.

The merger of cyber and physical products in Industry 4.0 leads to virtual structures in the value chain and supply chains that demand organisational and management tasks to be carried out through distributed manufacturing networks, logistics and distribution for relevant cross company operational processes. Cautious design of these networks and supply chains is crucial to ensuring unsafe performance. Agile collaboration networks define a horizontal integration approach which allows producers to concentrate on their skills by providing unique goods in every market. Connected design chains are created via vertical supply networks, which enable physical processes to be integrated and automated and provide more transparency. Smart supply chain design enables decentralized logistical management of manufacturing and operational excellence driven by data. The decentralized production logistics control consists of a network of self-organizing and process configuration devices enabling to decentralize the handling of materials in production control. The extensive production and logistics data collection offers a strong basis for data-driven operational excellence.

7. PRODUCT LINE DESIGN

The design of the digital product life cycle should be flexible, enable various methods to solve problems such as assembly and disassembly of parts, to allow a product to be produced in multiple ways using the same process; Consider the characteristics of the supply chain and end-user requirements to determine the optimum product portfolio for manufacturing; Manufacturing processes must be flexible and agile and must be able to respond to supply chain interruptions in real-time, either by altering the process sequence or changing the product mix and quantities to maintain high infrastructure use; Consider raw materials and product end-of-life criteria for the selection of suitable materials and methods for producing quality, environmentally friendly, cost-effective and long term goods. The developing circular economy is a movement towards a sustainable industrial system, which intentionally restores and regenerates. It replaces the end-of-life notion with restoration, moves to renewable energy and reduces the use of reusable hazardous chemicals. It attempts to reduce waste by designing materials, products, systems and business models in a better manner. But decisions taken early in the value chain often impede the transition to more circular model and material flow, as in the design phase. Eco-efficiency is not a new word in the realm of design, but efficacy is a fundamental element of circularity. To yet, however, the concept of core design has not been embraced. Future research on sustainable design of the circular economy should be focused on two new, distinct areas which distinguish circular economy from conventional, sustainable production, namely the consideration of upstream design and downstream product usage. New possibilities for the re-design of the manufacturing systems exist, for example co-design of products with end-of-life stakeholders to redirect materials via data-driven, inverse recyclability analysis, circular pathways of production through material flow analysis, modelling and simulation of dynamic systems, as well as circulatory life cycle value stream mapping and machine learning optimization Design recyclable may be a useful guideline for study into the design of multiscale material to develop items that are easy to upcycle, recycle or reproduce.

8. SMART AND CONNECTED PRODCUTS

A smart and connected product is an intelligent product/device to communicate future product conditions in real time by gathering user data and data from the physical goods. A collection of physical goods may be able to interact and cooperate directly. In addition, a physical product linked to the cloud environment may interact with an intangible Internet service. An intelligent product may be remotely monitored, operated and upgraded. The attached sensor technologies make the product aware of product and environment condition information. It is also integrated with control technology to autonomously adjust the product to internal or external instructions. In the background, intelligent and connected devices incorporated in contemporary manufacturing streams may process themselves, store data, communicate and interact within the industrial ecosystem. Today an intelligent product offers not only its identification but also its status and life cycle history. The integration of computer algorithms and machine learning capabilities will allow the products to learn and improve their results at all manufacturing stages, while giving vital maintenance and troubleshooting data for failures.

Many items that were formerly independent digital devices will be linked in future as networked intelligent gadgets. This implies that intelligent goods can communicate and provide substantial consumer advantages. Compared to a normal product, the functionality and the business model options are multiplied by a number for a linked intelligent product. Combining a number of disciplines, such as mechanics, software, electronics and, in particular, the integration of entirely new business models, should prevent it from being linked to an intelligent connected environment. It is important to connect digital and physical characteristics across the whole product life cycle. Traditional design efforts concentrate primarily on how designers and consumers may improve their interactions. Intelligent sensing and cyber-physical systems technology allow consumers to directly participate in idea development and assessment processes early and correctly determine customer requirements through feedback on products used in real time. With a view to the advantages of early customer and supplier engagement in the design phase, Industry 4.0 should be a decision-making framework for the modelling and analysis of product design interactions with the upstream customer and market concerns and product satisfaction problems in the downstream. Product development will range from conventional functionality-based goods to smart linked devices with integrated ICT components, which will offer enormous feedback on product use. The development of smart and connected goods is essential to the creation of a digital thread across design, manufacturing and consumption/use.

9. DATA DRIVEN DESIGN

Industry 4.0 companies must deal with both predictive and prescriptive analytics. Big data are important for performance optimization at all stages of development, from design to manufacturing. Performance data from the end-use environment may also result in modifications to the engineering design for future editions. Big data is also required to detect and evaluate consumer trends, which may influence directly on the making and production of engineers. The feature of large data and openness of information in Industry 4.0 strengthens a data-driven approach to continual design improvement and product forecasting in future generation. The data-led decision making process provides an example of a feedback circuit to gather, store and analyze customer and end-user data for goods with the aim of identifying new requirements or changing patterns of use and providing information back to consumers on new products. Design engineers may leverage the competitive edge of their organisation, leveraging big, multi-faceted and highly contextualized products throughout their life by discovering models, newinsights and knowledge via data-driven design. Feedback from ex-facto data should be used to examine the patterns and behavioural connections underlying real information on the use of the product. While data-driven design allows for better informed decisions to evolve better products, huge, multiplex data generated by users and products pose many challenges, in addition to unbeatable opportunities, to advance the theory, methods, tools and practice of product, system and services engineering design. This data-driven analytical method is inspired by the idea that we can better fulfil their requirements when we know how consumers use the goods. The fundamental argument is to base design choices on facts, but not hypotheses that correspond to an inverted idea of issue resolution. Thus, a data-driven analysis method is intended as a mainstream business model for businesses to reinvent their product development and proactively identify driving forces underlying product circumstances based on the analysis of the large use of information on products.

The monitoring and collection of data on product use are the foundation of the performance degradation evaluation and improvement in data-driven design. Combining product design with consumer research on the basis of a data- driven analytical strategy may influence the search area for design ideas and correctly identify the trend of customer desire for future product design. While data-based design is attractive, the fundamental effect on design theory and methodology and the optimum form of data-based analysis are yet to be completely explored. The main purpose of the existing data analytical techniques is to utilize content or experimental data produced by users to approximate excellent models for the better modelling of the design issue.

The problem is that no data on its own drives the design process directly; instead, design knowledge and computer science are obtained from data which may help designers to make educated decisions. In this way, the fundamental characterization of knowledge-based design decisions underpinning data-driven design may be shown in a data-informed design. Generating new ideas and their assessment are the most essential tools for innovation, and therefore a database analysis method helps enhance the limited capacity of designers to develop and assess numerous possible innovation alternatives. To conclude, both prescriptive and predictive analytics include data- driven analytics. Machine training is used in prescriptive analytics to assist select a course of action based on the predictions rooted in future state simulation.

10. CONCLUSION

The Digital Twin enables the user to give inputs based on the recommendation, which the twin then sends back to the machine in real time, allowing it to be controlled. The user input becomes very important when analyzing and modifying the supply chain mechanism. It also includes a data model for forecasting tool status in real time to save material waste during welding. It has the capacity of storing and displaying the results of various processing circumstances over time as a trend analysis.

In this paper, we first examine the relevant literature of intelligent manufacturing, which includes intelligent manufacturing equipment, systems, and services. The long-term viability of intelligent manufacturing is also addressed. Following that, a digital twin and its application, as well as the development of intelligent manufacturing based on digital twin technology, with monitoring the status of goods and manufacturing equipment in real time and anticipate potential problems the supply chain mechanism can be enhanced. The research shows how big data analysis might be utilized to offer knowledge recommendation services. In addition, the environment in which big data research is conducted to offer customized services, the findings of different analytical methods, and a discussion of comparable studies using big data and cloud platforms were examined.

Product design, production, and other processes would be drastically altered if smart manufacturing services anddigital twins were combined. Through the two-way connection between the virtual and physical worlds of manufacturing, the digital twin will produce more rational manufacturing planning and accurate production control to assist achieve smart manufacturing with optimum supply and value chain standards being met. Framework—Develop a plan for the

Digital Twins data and information system in order to guarantee its modularity and usability. Data sources—Evaluate data availability and determine how to get critical data that isn't currently accessible. Prioritize—define the areas where the Digital Twins may be used in the future. Start small and implement it on a small basis at first. Integrate—ascertain that the existing digital infrastructure can beintegrated into the Digital Twins to ensure that current resources are used appropriately. Collect data—determine which sensors are required for the Digital Twins to operate.

The industry 4.0 expansion for the holistic administration requires enabling technology. Digital twins in the supply chain are one of these technologies. This new idea unifies the organization's physical and virtual locations. The number of applications in the industrial sector, health care, and public policy is now on the rise. Then we look at how job qualities are affected by Cyber-Physical System's prospective automation or augmentation of various tasks. In this sense, automation refers to the transfer of control and decision making from people to CPS, while augmentation refers to the use of technology to improve human productivity or capacity. We anticipate that the transition to CPS, as well as the consequent automation and task augmentation, will shift the bulk of human labour to occupations with high degrees of job complexity, autonomy, and skill variety.

Better models, frameworks, metrics, and optimization techniques must be considered as a consequence. Despite the fact that many academics have recently addressed these needs, there is still much space for improvement in order to assist companies in becoming more sustainable. The framework contains two more key enablers that arerequired to stimulate and accelerate the manufacturing sustainability process. In fact, by integrating ethics and accountability with technology and education, the sectors' development in the area of sustainability may be substantially accelerated.

Systems for sharing, storing, and using data in the field must accompany the engineering of each designed system, with all resulting data being managed to guarantee accurate data retention for the duration of the usage cycle. Additionally, this "data-driven analytical approach" is based on the notion that the way a consumer uses a product may assist in knowing their pleasure with that product and learning what motivates them to utilize it. It is difficult for designers to know how to get information about customers' expectations for the product since the customers have to have information about the product in order to tell the designers about their expectations for it. Iterative and incremental design are ideal for long-lifecycle goods, but don't fit rapid-advancing technology. Key questions to be addressed are:

- What is the best way to combine people with digital twin of industrial production systems and processes, such as teaching robots to work together with humans on assembly lines, or maybe even how to includethem to the design process?
- How can the design process of intelligently produced goods be immediately impacted and enhanced by analyzing large quantities of data from prototypes and/or released products automatically collected in different ecosystems of other linked intelligent products in the near term?
- How is real-time data being incorporated into design and manufacturing?
- How can product redesign improve products into becoming "service systems" that offer value to the user experience?
- How may platforms be structured to capture value via consumer subscriptions to use products they do not own outright, in which the user does not pay for ownership of the product but for its availability?
- How can demand and supply chains with product families be coordinated and the design of product platforms be conducted in an integrated way with the design and logistics of production processes?
- How can platform strategies be expanded to include customer platforms, branding platforms, product platforms, process platforms and logistical platforms across a whole series of products?

APPENDIX - GLOSSARY

Digital Twin	A digital twin is a digital representation of physical elements in a cyber-physicalsystem. A digital twin in a manufacturing environment contains design requirements and engineering models used to define a physical object's shape, materials, components, and behavior. It also contains as-built and operating data that is particularto the physical asset that it represents.
Cybernetics	Cybernetic is the study of "system thinking", deals with ideas like control, communication, learning, cognition, adaptability, emergence, and efficiency, all of which are required for comprehending complex systems.
Smart Manufacturing	Smart manufacturing is a technology-driven method that monitors the manufacturing process using Internet-connected equipment. Smart manufacturing aims to discover possibilities for automating processes and to enhance manufacturing performance via data analytics.
Industry 4.0	The complete transformation of the whole industrial production sector via the integration of digital technologies and the internet with traditional industry.
Design Automation	Design automation is a knowledge-based engineering method that logically integratesdifferent engineering ideas with real-time application analysis during product development.
Product Architecture	Explains how the product's functional components are organized; the key is in how these components, or units, work together. This is critical to manufacturing, distributing, and supporting new goods and linking to the system design and system engineering concepts.
Product Design	The creation of goods that serve particular requirements and resolve user issues in agiven market is defined as the design process of envisioning, developing, and iteratingthe product. Product designers use empathy and understanding of their prospects' routines, behaviors, frustrations, needs, and desires to create genuine solutions for realpeople.
Product Line	A product line consists of several goods offered by the same business under the samebrand name. Many brands have many product lines under them, each with the aim of appealing to customers and allowing them to differentiate the products.
Supply Chain Design	Find the appropriate balance between inventory, transportation, and production cost, business uses the process of supply chain design. To handle supply and demand unpredictability, stock things well, and know how to manage what is stocked. Additionally, it manages resources well in a constantly changing setting.

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