Intelligent manufacturing in the context of industry 4.0: A case study of Siemens industry

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Abstract. At present, the methods by which products are designed and manufactured are advancing at a rapid pace just before our eyes. The contemporary period known as Industry 4.0 is realizing an evolution from manual to digital operations and it has great importance to manufacturers throughout the world. In the context of Industry 4.0, intelligent manufacturing is a paradigm enabled for the integration of smart sensors and controls. Traditional manufacturers are exploring intelligent manufacturing approaches (Machine Learning/Artificial Intelligence, Internet of Things, Digital Twin, etc.) to improve their competitiveness, but lack in implementing them. This paper reviews the intelligent manufacturing approaches and extends a study on how a manufacturing production plant applies its intelligence in executing these approaches to transform from discrete manufacturing to intelligent manufacturing. The case study initiates the implementation of Siemens manufacturing production plant into a model based on intelligent manufacturing, thereby transforming the whole into an intelligent manufacturing industry. A broadened path about the implementation of intelligent manufacturing in this industry is outlined. In the operation of selecting these approaches, the manufacturing plant continuously mechanizes its products, informatizes its management, and digitizes its operation.

1. Introduction

In today’s world, a very popular strategic topic known as Industry 4.0 initiated by the Germans has a great influence on designing intelligent factories where the automation of manufacturing systems are improvised and transformed by the Internet of Things (IoT), cloud computing, and cyber-physical systems [1,2]. Industry 4.0 qualifies companies to compute the performance of their plants and machines by making clever decisions via real-time communication with humans and machines to endlessly advance their productivity [3]. Industry 4.0 fuses intelligent production procedures and automation of production systems to open the way for a new era that will essentially alter the production and industry supply chains, and line frameworks.

Within the aspects of the fourth industrial revolution, the present-day challenge is to expand reconfigurable and collaborative manufacturing systems that control and support effectively few batches, high quality and low costs, and product diversity by initiating different features of adaptation, modularization, and agility [4]. Intelligent Manufacturing Systems (IMS) provides not only reconfigurability and flexibility but also this abstraction brings more than a few ideas of software intelligence definitions, which inspected attributes such as decentralization, autonomy, reliability, flexibility, learning, efficiency, and self-regeneration [5,6]. IMS can yield the best results compared to
conventional manufacturing systems as they are effective in self-learning, analyzing, and detaining complexities, which are also able to analyze and store huge amounts of data to obtain an escalated grade of the product to minimize the cost of production while reducing the time-to-market.

Intelligent manufacturing (IM), one of its solving approaches is the development of big data analytics which granted an opportunity in semiconductor manufacturing factories to improve Fault Detection & Classification (FDC) system potentialities that lessen the missed and false alarms [7, 8]. Another solving approach where IM is implemented is the Cyber-Physical Logistics Systems (CPLS) for gear manufacturing factories that have organized their procedures following the flexible production principles via this approach. The goal of the CPLS is to elevate flexible behavior through independent decisions and authorize depletion of inventories due to the self-governing solving of errors instantaneously. From research on computer simulation based on the current space of an electric train, it has been observed that the number of cycles and number of loops driven in the cycle can be reduced by 68% and 27% respectively [9]. One of the best application scenarios where IM is implemented is the symbiotic human-robot collaboration [10,11] which is specified for a fenceless environment in which profitability and effective utilization of resources can be upgraded by blending the accuracy of machines and the flexibility of humans. Some human-robot coordination, where it holds the properties of dynamic task planning, active collision advance, and adaptive robot control can be qualified by using Robotic Cyber-Physical Systems (CPS). The method is to disclose safe halfway Human-Robot Collaboration (HRC) without any fencing. Another application scenario where IM is implemented is a case company that is a seller for the flight sector, which provides completely integrated solutions for inspection storage would be the most pivotal change for a company. To create an innovative solution, utmost importance is given to check if services are being received by the market and its neighboring districts.

To achieve IM, the goal of an industry is to combine distributed manufacturing services to finish complex tasks. Nevertheless, conventional manufacturers are investigating methods to build on their competitiveness. IM key techniques appear to be the quick fix to accomplish their objectives but the absence of guidance or instructions made them difficult to execute these techniques. For that reason, this paper evaluates IM's key approaches by introducing a case study on Siemens manufacturing plant which applies its intelligence in executing these approaches thus transforming the plant into an intelligent manufacturer. The extending track of IM in the Siemens manufacturing plant is also outlined.

2. Key technologies and research areas of intelligent manufacturing
This segment evaluates a few essential techniques and their applications implemented in IM, considering the Industrial Internet of Things (IIoT), Artificial Intelligence & Machine Learning (AI & ML), Big Data Analytics, Digital Twin, and Cloud Computing as depicted in table 1.

2.1. Industrial Internet of Things (IIoT)
IIoT is referred to as the use of smart or digital technologies in industries that help in analyzing various system architectures, information processing, location, and other security problems with ease, which requires minimal human interaction and broader connectivity and computing ability with various devices [12-15]. Over the years it had witnessed a clear integration with Industry 4.0 where they had differentiated computers, machines, Internet of Things on one side, and people who do intelligent industrial operations with the help of data analytics for transforming individual and business outcomes on the other side, which in whole together contributes to the IIoT [16]. So, in short, we could say that whenever there is an involvement of IIoT under the manufacturing process or being used for industrial application, the term IIoT would be derived [17,18]. These are used in associating various industrial activities/products such as power grids, connecting to clouds from a sensor by using a network, and engines [19,20]. This finally focuses on optimizing the product, starting right from boosting its productivity, being more efficient, reducing overall costs to moving forward, and adapting to various changes in the present world.
2.2. Artificial Intelligence & Machine Learning (AI & ML)
AI is an approach where human intelligence is imitated, strengthened, or even replaced with the help of computers by applying logic, decision trees, and ML. Autonomous intelligence systems have been found out to be a vital development as there have been innovations and advancements in unmanned combat vehicles, which easily excels the advanced technologies in robotics [21,22]. To improve a particular task with time, few statistical techniques are applied, this is when ML comes into act making it a subset to AI [23]. Deep learning comes in handy which would ease the investigating and processing of large manufacturing data by providing enormous data analytic tools and focusing on the future requirements for efficient and sustainable production. To check computer communication various tests were considered and one such is the Turing test, which would tell up to what level machines could think, involving a computer, examiner, and a machine placed at unique locations. Automation is always a key factor that brings a change in manufacturing, which further contributes to intelligent technologies from design to shipment [24-26]. Nowadays, there are various openings integrated with AI such as the internet of things, cloud computing, to the latest 5G technology, which would promote decision making, additional knowledge techniques, and concentrating on real-world problems thus contributing a lot to intelligent manufacturing [27]. So, these intelligent behaviors with the help of AI and ML are integrated into the conventional manufacturing systems ranging from determining the quality of product, process, and product planning to delivery and also ensuring their competitiveness level with the present market.

2.3. Big Data Analytics (BDA)
Nowadays, with extreme growth over the internet and IoT data has become easily accessible and at the same time, it's made available everywhere in various industries which led to the crises of big data [28]. Big data derives from devices, sensors, and also including social media feeds. Since the data requirements were large, there arose a huge question if IoT could process the right data at the right time despite growing advancement in IoT, this is where Big Data Analytics comes into play which involved advanced analytic techniques to process large operations and data, especially in the manufacturing sector [29-31]. The Centre for Intelligence Maintenance Systems has developed predictive analytics known as the Watchdog Agent which has made sure that each processing of big data to be transformed into useful information [32,33]. Even the cyber-physical system integrates with knowledge from data-driven analytic algorithms and at the same time with a piece of practical knowledge, to simulate the conditions of the machine with a 5S approach that comprises Synchronization, Sensing, Synthesis, Service, and Storage. The big data analytics path is selected based on computational speed, operational-easy, cost of investment, and other various updates [34]. These analytic techniques along with cyber-physical systems are introduced, such that the manufactures would remain competitive in this predictive manufacturing process by keeping up with the emerging technologies and products more efficiently and productively.

2.4. Digital Twin (DT)
A combined system that could compute, monitor, simulate, and also check system status and control processes is termed Digital Twin (DT) [35-39]. Manufacturing systems can detect material processes, create a DT in the everyday life [40], accept real-time information from the real world for analysis in a computer simulation, and construct enlightened decisions through everyday communication and collaboration with human beings. Zheng et al. [41] strongly believed that various trends can be obtained, making it a vital analysis in the direction of IM, through drastic growth which can be seen in the field of virtual technology and data acquisition. An IM structure by Zhou et al. [42] was drafted for building up a conceptual DT manufacturing cell, through which it connects with prediction, optimization, intelligent simulation, control, and various other perceptions. DT is a real-time digital representation of a physical organization that not only ideally plots physical objects but also adjusts material objects based on the design paradigm.

2.5. Cloud Computing (CC)
Cloud computing is the delivery of accessible, computing power and data storage, which is acquired remotely by the user through a system [43-47]. Through this, cloud manufacturing was introduced, where a system-oriented manufacturing prototype was set up to reduce resource consumption along with possible utilization to the extent [48,49]. Various cloud computing implementations in IM were studied by Zhong et al. [50], along with Zhou et al. [51], from which cloud computing was selected to be the most vital and prepared technology for IM. Everything from processing software to adjusted business programs mapped out and expanded for an organization can probably achieve on a cloud system. Cloud computing has been accepted with escalating competitiveness through higher flexibility, elasticity, cost reduction, and proper resource utilization.

| Key technologies                                  | Industries/companies | Aims                                                     | Improvements                                                                 | References |
|--------------------------------------------------|----------------------|----------------------------------------------------------|-------------------------------------------------------------------------------|------------|
| Industrial Internet of Things (IIoT)             | IoT–enabled manufacturing measurement, France | Combining domains and easing the interpretation of sensor data. | Enhanced interpretation from users and improved performance                  | [20]       |
| Artificial Intelligence (AI) and Machine Learning (ML) | Transportation, China | Formulating a new entropy-AI and ML cloud-based approach | Solving the railway container station reselection problem                     | [26]       |
| Big Data Analytics (BDA)                         | Tata Motor, India    | Driving quality and reducing cost in the manufacturing process | Analytics of CRM system data and utilizes process excellence and six sigma principles | [31]       |
| Digital Twin (DT)                                | Transportation, China | Maximize the product quality and throughput              | Capacities of self-thinking, decision-making and execution                   | [42]       |
| Cloud Computing (CC)                             | Manufacturing, Iran  | Proposing a service-oriented approach                    | Adopting LAMMOD platform for distributed manufacturing agents                | [49]       |

3. Case study

3.1. Background
From a small garage in a back cortile in Berlin to a global corporation. Siemens AG, a German company, which was founded in 1966 is a global technology dominant for more than 170 years, which had excelled
in various fields like innovation, engineering, reliability, quality, and internationality. It had further progressed to become the largest industrial manufacturing company in Europe with its branch offices located abroad. Around the globe, Siemens turned out to be playing a vital role and showed active involvement by focusing on areas ranging from intelligent infrastructure for buildings and distributed energy systems; to automation and digitalization and manufacturing industries.

The integration capability and operational agility of industrial control, improving feasibility, strong information modeling, execution systems, and associated processes by combining proven and affordable system and software technology, and finally, the engineering paradigms which were all considered to be the most important objectives or goal of Siemens AG.

From mobile telephones, diagnostic imaging systems, and hearing aids to numerous other products such as ground movement radar for airfields, mass transit systems, and power generating equipment were all witnessed as the company’s development during the early 21st century. Pumps and compressors, drives for conveyor belts and rolling steel mills, heavy-duty motors, various automation equipment, and gears for the wind turbine, were some of the automation and industrial plant-associated products that Siemens had later focused on, but not limited to production machinery and raw material processing. Along with these products, Siemens was sanctioned with various projects around the world starting from its construction of 17 nuclear power plants in Germany to winning a $966.8 million contract from an oil firm situated in Saudi Aramco, being the largest tender ever received by Siemens from any company situated in Saudi for power plant components. Siemens Healthineers AG had also reported that acquiring U.S. cancer devices and also software company Varian Medical Systems with complete stock estimated at $16.4 billion was one of their major plans in August 2020.

3.2. IIoT – A framework of IoT in manufacturing

![IIOT – An industry sector classification (Boyces H., 2018, p.12)](image)

The business to business (B2B) approach being used in the current digital platforms is known as the IIoT platforms forming a flexible and open network based on the industry sector classification depicted in figure 1, keeping in mind the main objective of ease of integration over the generation of platform-based advancement. Over the years, Mindsphere has obtained a leading industrial IoT position as facility or service solutions. Ranging from edge to cloud with data collected over connected products, systems, and plants to generate better quality products, for optimization purposes as well as to innovate new
business models and for doing this Mindsphere powers the IoT solutions by bringing in various advances in the field of Analytics and AI. The first cloud-based systems on the open Internet of Things (IoT) were introduced by Siemens with Mindsphere in 2016 which could show full connectivity of physical and machine interface to the digital world. Several day-to-day challenges are being faced by industrial decision-makers such as customers demanding their unique products, tougher competitions, and rapidly changing technologies. These challenges can be solved by bringing in Siemens Mindsphere to make appropriate decisions with transparency and also to concentrate on the digitalization approach. Steps that are followed by Siemens Mindsphere in approaching a step closer to solve the real-life problems are by analyzing and predicting/preventing from unplanned assets downtime; then by monitoring and controlling solution which helps in optimizing the performance; then finally taking the digitalized transformation by meeting out the needs and requirements of every customer on their unique products and developing new business models. For creating time to appreciate industry investments and low code applications which were only made possible as Mindsphere was built on Mendix, thus introducing global IoT connectivity and categorization processes. It also plays a vital role in analyzing IoT data with information from various systems such as SLM, PLM, MES, and so on. Not only that but also well defined in the field of Closed-Loop Digital Twin by ensuring its perfectly functional while they also collect live performance data from production lines. A case study on Mindsphere has been chosen for reasons like technological integration on various fields at connected levels as well as for the open integration among third parties. Here, a detailed analysis on identifying the partnership type and its need along with the company type was discussed which led to knowledge about the development of Siemens’s ecosystem and also to organize a logical generalization on IIoT ecosystems. Initially, there were only a few boundary resources in the first two phases but with time other phases were seen to be engaging with 150 plus business resources-related actions. Siemens had also partnered with various resellers to promote its gateway and IoT. However, various partners by type such as consulting, software technology, infrastructure, design, academics, end customer to name a few were organized in phases and their total number of partnerships are calculated to find out in which field Mindsphere outshines the other. During the late phase, 2 Siemens had a planned partnership with amazon by introducing Mindsphere to be available on the AWS platform. After the release of Mindsphere 3.0, it had become popular in more than six countries. Further study on comparable IIoT systems could bring out more effectiveness in the development of IIoT ecosystems, whose results could be verified for the Mindsphere ecosystem and its visualization [52]. Another astonishing factor that had evolved during this period is the Siemens Digitalization Hub located in Singapore, which satisfies the requirements of customers in Asia and beyond. It also brings in various multi-disciplinary specialists from various fields from numerous business divisions in Siemens to innovate, learn and develop on future-ready and real-life scenarios. To digitize their business Siemens provides urban infrastructure as it gives a reliable efficiency and also integrates various cities to meet their challenges in the upcoming years; secondly, oil and gas digital center where it not only focuses on the growth of the industry but also the cost, productivity, reliability, and efficiency; then overall optimization and digitalization of the hub [53]. In continuation with that Siemens had delegated its experienced heads as the City Account Managers in the Siemens City Account initiative which suggest decision-makers in more than 60 cities to participate in various phases right from the planning phase, to develop a city that is environment friendly, improved quality of life for its residents and also on saving money. So, to fulfill all these purposes, Siemens Mindsphere comes into play, that is the cloud-based system for IoT, to digitize its infrastructure.

3.3. AI & ML – An integrated view on factory automation
When we talk about machines and processes gaining knowledge from enormous volumes of data by themselves it would be of more benefit as it would lead to greater optimization and this can be processed by the means of introducing artificial intelligence. Artificial Intelligence entirely creates advanced chances for flexibility, systematic production even if it is of highly customizable product or a complex one that would be required for small batch production. Over the past 30 years, various research and studies have been undergone in the field of AI through which a great boost in technology advancement was observed in hardware, software, and enhanced data transmission and computing power. Artificial intelligence is something where a machine would perform similar or same tasks as that assigned to human beings requiring intelligence such as learning, problem-solving and analyzing. Integrating AI with other advanced technologies in the industrial ecosystem has helped manufacturers gain a strong foothold in the Industry 4.0 revolution [54]. This application of AI in normal industrial activities started with language recognition to assist in logistics. For verified testing and predictive maintenance, Siemens has got its solutions under its portfolios. Then evolved a time where AI and Industry 4.0 came hand in hand, thus contributing to being more efficient, productive and also minimizing the energy consumptions. Mindsphere was again the laying foundation for bringing AI into the industry. Machine learning is one of the fundamentals for real intelligence on “Artificial Intelligence”, where computers are trained in such a way that irregular data patterns are understood by them through which we expect the computer to gain knowledge on these data or algorithms and perform tasks on their own. Whereas deep learning, on the other hand, focuses on deep neural networks, that is to conclude, identify connections, or make decisions it accesses data at several nodes simultaneously. This deep learning would also help in solving complex problems without any guidance by the possibility of self-learning algorithms. By implementing ML with a segment of AI we can collect up various data from sensors, robots, smart tools and then followed by visualized knowledge and further on converting this knowledge to actions as exhibited in figure 2. Though ML turns out to be a greater benefit in the customer service field still it needs to improve a lot in terms of its algorithm as it lacks transparency and less funding. The applications involving AI technology can be made more optimized and efficient by the use of ML solutions. A case study on Siemens's implementation of AI for industries, power grids, and rail systems has been taken up to show how far the impact of AI has contributed to the transformation in today’s world. For improving the reliability in the power grid by making them technologically smarter and to control various operational processes AI was used, which in turn enables the devices to restrain the disturbances present in the grid. Siemens has also come in touch with Deutsche Bahn, where it focuses on imminent conservation and modification/repair of high-speed trains, where various trends and data from the train are obtained from software and data analysts [55]. The main purpose of using AI, in this case, it helps in optimizing the control centers and it's more reliable. There are also other technologies.

Figure 2. Machine learning- A vital role in IM (Wang L., 2019, p.618).
Siemens has implemented with various other large companies and industries, one such is with Amazon in implementing Siemens Cybersecurity by using AWS Machine Learning where it can handle more than 60000 threats per second. Here they had introduced Siemens Cyber Defense Center, whose main objective is to secure its customers from malware, viruses, and various other forms of cybersecurity threats or cybercrime [56]. Later, they had also given assurance that their AI-driven cybersecurity platform was easily among the top and most needed in the world with the present increasing rate of cybercrimes. Not only that Siemens also contributes to the success story of AI to a greater extent from optimizing the emission to larger control to working on adjustable fuel valves to bring optimal state for combustion under various circumstances of weather [57]. This technology witnessed a huge impact as it had brought down labor costs, improved production speed, and a greater decline in product defects. Machine learning, Artificial Intelligence, and its integration with Industry 4.0 are seen as a greater impact in today's world as it is a powered technique where it improves various aspects of manufacturing. Starting from design to delivery Siemens focuses on every aspect through which it could find solutions to various real-life problems that have been thrown to the world.

3.4. Integrated Automation (TIA) – An intelligent portal for efficient industry planning

![Diagram of Watchdog agent - A predictive analytics on IM systems (Lee J., 2006, p.489).](image)

Industry 4.0 plays a crucial role in its development which was brought into life through Siemens’ strengths in industrial automation. This is the time when Siemens had launched its “Totally Integrated Automation” (TIA) Portal during the late 1990s which enabled the companies to coordinate for their production operation also being interrelated to hardware with software. TIA Portal had proved itself to be something greater than just an engineering framework by bringing together innovative simulation tools, transparent plant operation, and integrated engineering by focusing on increased speed, flexibility, and productivity. When it comes to increasing the flexibility, it talks about increasing the scalable simulation of the entire plant including Human-Machine Interface, having an open system to create a systematic program code and also to store TIA Portal projects in the Teamcenter, and finally, the cloud solutions where there is a networked workflow keeping in mind about maintaining the total data consistency contributing to the overall digital workflow. The main reason behind TIA being called the heart of efficient automation is that it reduces our engineering time with highly accessible applications.
such as SIMATIC S7-1500R/H CPUs; hardware diagnostics and network integration to integration of SINAMICS S210 into SIMATIC Microdrive, etc. Also, coordinated teamwork, overcoming faults, and reduction of time add up to the above are the major reasons that stand with various companies to rely on Multiuser engineering through TIA Portal. A typical case study is Audi AG, a German automobile manufacturer that initiated its production of Audi A8 where it had been observed that when Siemens TIA had been implemented there has been a drop of more than 10 percent in the engineering costs. Also utilizing TIA’s major advantage of handling efficiently and reducing downtime by assuring information being delivered to central control systems by individual control systems. One of Audi’s factories in Neckarsulm had about a 25 percent reduction in energy in 2018 which ultimately focuses on boosting productivity. Moving on to the Kuka Systems situated in Brazil is a global provider of plant and system technology. This factory concentrates on solutions for logistics as well as optimizing robot workstations by producing higher numbers of units as well as giving us a definitive robot integration [58]. Considering the aerospace industry, a huge amount of assembly space is needed for large objects like rockets and aircraft, when the traditional docking method was being used it resulted in a long manufacturing cycle, poor reliability, and low accuracy. This challenge was overcome by introducing a coordinate system developed by Siemens PLC to control Kuka robots dynamically via the KUKA-TIA-Library interface by fulfilling the needs and requirements of customization and flexibility in the aerospace industry. To obtain the above interface various applications and configuration of Kuka.PLC.mxAutomation was studied to transform programming steps of PLC to KRL language of KUKA robot, also focusing on the TIA Portal for the control of the KUKA robot [59]. Even the world’s largest automated seamless pipe-making plant, Tenaris situated in the USA depends on Siemens portfolio. They had utilized the TIA Portal code and Siemens gear in building a 3d model of the plant by testing all the components even before installation, that is, during their simulation process. By this, Tenaris was able to come across several adjustments and also stated that a huge amount of their time was saved, also increased quality and efficiency by integrating with the help of TIA Portal thus opening their plant on time. Every time a unique problem emerges TIA portal expands itself to obtain ideas and innovations from various technologies such as augmented reality, artificial intelligence, edge computing also including the latest 5G technology. Thus, the TIA portal acts as a watchdog predictive agent which marks its way by becoming perfect access to automation in a digital enterprise with space for future innovations and makes sure that each processing of big data can be transformed into valued information as displayed in figure 3.

3.5. Digital Twin – A holistic PLM software approach
Figure 4. Bausch + Ströbel’s manufacturing plant – Efficient way to create a digital twin (Source: Machine Design, March 2019).

In the current world, most complicated products and processes are outlined, tested, and adjusted in the virtual community before being manufactured in the physical world. Prototype calibration involves creating and computer-simulating software models of hereafter products, finally leading to the formation of “digital twins”. Digital twins (DT) are used all over the product lifecycle to predict, simulate, and optimize the product and manufacturing system before funding physical assets and prototypes. Overall, there are three kinds of DT – Product, Production, and Performance and are explained for case study applications. In the case of digital product twin, a typical application is a motorized equipment manufacturing plant by Siemens which used DT as part of its digital enterprise-broad initiative to improvise corporate decision-taking by converting data into practical insight. They used these potentialities to precisely predict failure modes to minimize, spontaneous downtime of apparatus while in service. The company knew the source of some of the failures but wanted to uncover extra patterns to recognize causal factors of failure. An experimental project was able to expand models to precisely predict one-third of failures in machines occurring during manufacturing time longer than 8 hours in the progress of the event and 7% of failures in machines occurring during manufacturing within 2-8 hours in the progress of the event. In the case of digital production twins, a worldwide auto manufacturer used precise models to make suitable manufacturing adjustments to meet close tolerances. This company’s managers had a circumstantial understanding of which variables were tied to issues in the quality of the product in the company’s cylinder-head production line, but insufficient information to change it. Using digital twins of the associated processes and production lines, manufacturing quality analysts can run longer than 500 production-line variables through ominous models. This solution recognizes which particular processes of the line need to be modified to ensure that products remain within their close tolerances. The solution also provides ominous insights about which manufacturing assets should be obstructively maintained to avoid hereafter problems. In the case of digital performance twin, a mining equipment manufacturer needed to find a way to authorize its engineers to initiate preventive, rather than responsive, maintenance. Break from unpredicted failure in equipment or unwanted scheduled maintenance is expensive to companies involved in mining activities. Hence, a new diagnostic optimization solution that models performance in equipment allows the equipment-suited mining manufacturer to assist its operators to spot possible problems related to maintenance before the failure
of equipment, thus preventing unwanted downtime for unneeded maintenance. The solution recognized irregularities in the collection of data from sensors on the heavy equipment that might specify impending or future problems, giving engineers time to carry out protective maintenance.

Bausch + Ströbel’s manufacturing plant in Germany is following a digital conversion plan with digital twins at their center. Bausch + Ströbel concentrates on machines for drug companies to fill and collect the most sensitive material like bottles, ampules, and syringes. Previously, the manufacturer has used commissioned wood models to design, experiment with the function and usefulness of their machines. In collaboration with Siemens, they developed a virtual portrayal of the factory in generating a digital twin platform as depicted in figure 4. It provides various benefits throughout the complete production cycle: from manufacturing planning to observational operations, analyzing faults, and increasing the innovation of systems and plants.

Hence, lengthening and integrating various digital twin views will allow companies to better govern their processes and products over their complete lifecycle, bringing value to the customers and their companies. Executing a scalable, holistic digital twin requires the cooperation of the service providers, software providers, and end customers. This transition can take place in a gradual payback framework where certain use cases are recognized and teamwork projects are built and implemented.

### 3.6. Industrial Edge - A perspective on cloud & edge computing

![Image of Schmalz Siemens Industrial Edge system](image)

**Figure 5.** Schmalz Siemens Industrial Edge system – Edge and cloud computing systems according to specific requirements (Source: Industrial Edge, the SIEMENS Edge Computing Platform [Architectural concept – Overview]).

The escalating layout of related Industry 4.0 and digitalization are influencing our personal lives yet having an even huge impact on companies. This is presenting obstacles to the transforming industry, such as small innovation cycles and the accelerating product individuality and manufacturing processes. To perfect these obstacles and remain ruthless, companies must be able to react to flexible changes as much as possible. With implementing Industrial Edge, everything is easier, more secure, and more
flexible – for ideal use of data in the field. Complete networked manufacturing and fast transforming of the created data are crucial here – and this is where cloud and edge computing comes into action. Edge Computing (EC) and Cloud Computing (CC) cite the latest model in computing that examines as well as operates a part of information utilizing the computing, storage, and resources related to networks dispensed on the pathways connecting the origin of data and the center of CC [60]. The implementation of edge and cloud computing in a manufacturing production plant, mainly integrated with actual transmission technology’s network and NFV technology, could set up an excellent network connection linking the cloud platform and the industrial field cloud as well as the platform in edge computing, achieving flexibility, provide intelligent real-time secure isolated application deployment capabilities and best-assured manufacturing plant production network with the services of edge computing [61]. A classic application of edge computing is, Siemens electronics factory in Germany which manufactures about 16 million controllers yearly for industrial automation objectives where 75% of the value chain is mechanized. Nilsen and Nyberg [62] described the Siemens Electronics plant from interviews that they use a factory execution system, which enables the complete factory to be connected. On the usage of data analytics and sensors, they allow efficient manufacturing with better quality. On implementing the high level of automation, Siemens has minimized the no. of faults in their manufacturing smart factory from 500 errors per one million actions (DPM) to 12 DPM. Siemens strengthens its Edge Management System (EMS) to reduce breaks of individual machines and complete assembly lines at the same time, which helps to deployment in speed, escalating efficiency, and eventually ROI across all applications in the factory. Formulated on this system, the teaching of brand-new algorithms can happen in the cloud going ahead, while the deployment of application at the edge platform promises industrial-grade reliability of applications, data sovereignty, and flexibility to any network issues [63]. Another typical application in edge computing is the Siemens Schmalz in Germany, which is the market head in vacuum automation and ergonomic handling systems. The mechatronic vacuum grippers from Schmalz allow robots and other industrial automation systems to hold wide-ranging of various workpieces throughout the manufacturing and logistics process. Different varieties of components such as metal, wood, plastic, or glass are tightly fixed and controlled with these vacuum grippers. To avoid unpredictable downtime due to dirty filters and the aging of gripping devices, Schmalz implemented condition monitoring solutions for both areas according to requirements shown in figure 5. This will allow Schmalz to forecast downtimes in advance to program organized maintenance activities. Schmalz strengthens for these applications a combined application lifecycle management system, which runs at the edge platform. This is most important because Schmalz is considering supplementing further applications to the system over time. Hence, manufacturing edge and cloud computing platform offers data as well as management networks which utilizes a delicate interface and approach enterprise-level guidance to distantly upgrade, supervise and preserve a huge no. of devices and approaches for distant monitoring as well as configuration. Additionally, it could desensitize with cleaning the gathered information to certify the accessibility of data thereby the careful data won’t be escaped with integrated contributed tight key authentication as well as firm booting to offer a reliable domain for production networks.

3.7. Siemens: An Intelligent Manufacturing Factory
Siemens implemented intelligent manufacturing solutions that combine manufacturing data and processes with engineering in a digital thread offering a lot of benefits to the manufacturers and engineers. It is a digitalized developed plan that surrounds everything from PCB blueprint to optimization of the factory floor in including feedback of customers into brand-new designs. The entire enterprise can collaborate with the Digital Twin of the process and production system. Innovation is risen by linking through the digital thread to effectively design, computer-simulate, adjust and verify all production processes before the creation of a physical production system. This helps to synchronize manufacturing, engineering, production, and service operations for maximizing production efficiency and smooth launches of the design. One of the fascinating projects that NAVAIR and Siemens have tackled is executing a model-based digital thread that directly assists intelligent manufacturing at the light readiness centers in the US. Naval Air Systems Command (NAVAIR) and is responsible for the sustainment and acquisition of the air assets of the Navy. The focus has been on the arrangement of data management from engineering through computer simulations and production operations. The aim is to have manufacturing operations at the air depots directly assist conservation of those air assets and ultimately come up with operational accessibility of the uptime of those air assets. In the event of NAVAIR, that digital thread is being enlarged to modern types of equipment in manufacturing at the Cherry Point Fleet Readiness Center. This guarantees that the right manufacturing operations are taking
place with detectability back through engineering and planning with an understanding of what data was used at any given point of that product lifecycle. Being able to essentially manufacture these parts more skillfully, with higher quality, has a direct impact on the accessibility and the uptime of those air assets. Another typical example of intelligent manufacturing is the case study of Naval Sea Systems Command (NAVSEA) who were outlined to manufacture and produce submarines and surface ships, but their mission has changed because the Navy no longer manufactures equipment. The current goal is to preserve equipment that has been transported to them by the primary equipment manufacturer. Siemens is leading a team that is in charge of the digital modeling of these shipyards. The models are helping PMS 555 understand what happens when a submarine or surface ships, fleet, or carrier readiness center comes into one of these Navy bases, providing insight into how the bases function.

Hence, IMS enables you to close the loop between your manufacturing process and engineering planning operations, and your actual manufacturing and quality execution operations on the production conservative floors. It guarantees that all the rich data that is gathered – any discrepancies or deficiencies, positives or negatives – feeds back into the digital threads along with the digital twin. This enables you to disrupt and innovate, not just based upon failures, but also based upon successes of how you manufacture and support your assets. A detailed layout of the Siemens IM standard system is presented in figure 6 about the IMSA construction guidelines for the development of the Siemens plant.

4. Conclusion

As growing awareness is identified to the fourth industrial revolution, IM is increasingly a major concept in the development of the present-day economy and industry. IM is examined to be a lead viewpoint in the future, both application and experimentation, as such a thing offers aid to different systems and prototypes by putting in advanced innovations to conventional prototypes in production and services. Key techniques, extensive innovative technologies, and global approaches are outlined in this research. The case study initiates the implementation on how Siemens manufacturing plant presents the IM concept, thereby transforming the whole into an intelligent manufacturing industry. In the operation of selecting these approaches, the manufacturing plant continuously mechanizes its products, informatizes its management, and digitizes its performance. We desire that the current study can inspire and inform researchers along with industrial professionals to come up with ideas in progressing the production industries. Besides, we believe the different approaches presented in this study will arouse exclusive proposals in the attempt to grasp the much-expected Industry 4.0.

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