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Industry 4.0 and Automation in Manufacturing: An Extensive Overview

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A B S T R A C T

Considering relevant research literature can aid researchers in gaining comprehensive understanding of the field of study. Industry 4.0 focuses on the digitalization of industry and its potential to improve production performance. However, empirical case studies show that incorporating digital technologies into production does not always lead to higher productivity. The study also suggests that digitization is a systemic endeavor, with its specific contribution being overstated. Because of this, it is crucial to go over pertinent study literature before starting data gathering or any other significant research project. The goal of the study project is to evaluate Industry 4.0's significance for the industrial industry. This is why an assessment of pertinent research literature, including books, articles, and journals, has been done to determine how industry 4.0 would affect the manufacturing sector. Furthermore, the literature analysis has aided in comprehending the advantages and constraints of implementing Industry 4.0 within industrial establishments. In this chapter, the main conclusions from the studied literature have been succinctly summarized.

Keywords: Industry 4.0, Automation, Intelligent Process Automation, Manufacturing, Productivity

1. Introduction

Automation has revolutionized the manufacturing industry, making it more efficient, productive, and profitable. With the advent of Industry 4.0, the integration of advanced technologies such as artificial intelligence (AI), the Internet of Things (IoT), and big data has further transformed the manufacturing landscape. While automation has brought numerous benefits, it has also raised concerns about job displacement, skills gap, and economic inequality. This essay will explore the impact of automation on the manufacturing industry, the future of manufacturing automation in Industry 4.0, and the social and economic implications of automation in manufacturing.

The impact of automation on the manufacturing industry cannot be overstated. Automation has increased productivity and efficiency by reducing the time and resources required to produce goods. For example, automated assembly lines can produce goods faster and with fewer errors than manual labor. Automation has also improved quality control by reducing the likelihood of human error. By minimizing errors, manufacturers can reduce waste and improve the quality of their products, which can lead to increased customer satisfaction and loyalty. Additionally, automation has reduced labor costs, allowing manufacturers to increase profitability. By automating repetitive and low-skilled tasks, manufacturers can focus on higher value-added activities, such as innovation and research.

Industry 4.0 is a new era of automation in production that incorporates big data, IoT, AI, and other cutting-edge technology. This integration has led to increased customization and flexibility in production processes. For example, manufacturers can use real-time data analysis to make decentralized decisions about production processes, which can lead to more efficient and effective operations. Additionally, manufacturers can use AI to optimize production processes, leading to reduced waste and increased productivity. These technologies have also enabled the development of smart factories, which use IoT to connect machines and systems, allowing for greater automation and efficiency.

While automation has brought numerous benefits to the manufacturing industry, it has also raised concerns about job displacement, skills gap, and economic inequality. As machines replace human labor, many workers may find themselves without jobs, leading to unemployment and economic insecurity. Additionally, the skills required to work in an automated manufacturing environment may be different from those required in traditional manufacturing, leading to a skills gap and the need for retraining. Finally, automation may exacerbate economic inequality, as those with the skills and resources to adapt to an automated manufacturing environment may benefit at the expense of those who do not.

Automation has revolutionized the productivity, efficiency, and profitability of the manufacturing industry. Through integration of advanced technologies in Industry 4.0, the future of manufacturing automation looks even more promising. Since the social and economic implications of automation cannot be ignored it is important to consider the impact on workers and society as a whole as we move towards a more automated manufacturing environment. By addressing these concerns, we can ensure that the benefits of automation are shared by all.

2. Automation in Manufacturing towards Industry 4.0

Automation in manufacturing has undergone a significant transformation with the advent of Industry 4.0, also known as the fourth industrial revolution. This revolution is marked by the integration of smart technologies and the internet of things (IoT) into various facets of manufacturing processes, paving the way for increased efficiency, productivity, and flexibility in manufacturing operations globally. The adoption of automation in the manufacturing sector is crucial for companies to stay competitive in today's dynamic business landscape. The marriage of IT and manufacturing operations, or "Manufacturing 4.0" or "Industry 4.0," is the development of digital technologies in the manufacturing sector. It reflects a "holistic shift from centralized to decentralized manufacturing," according to Mark Holleran, the former CEO of Xplore Technologies, and calls for adjustments to procedures, talent, company structures, and technology. "Technology is bringing about the next industrial revolution with its improved robotics and artificial intelligence, cloud computing, Internet of Things, smart sensors, data gathering and analytics, and digital manufacturing.'' according to Holleran.

Industry 4.0 represents a paradigm shift in manufacturing, wherein automation plays a pivotal role in optimizing production processes and enhancing overall performance. Automation technologies such as robotics, artificial intelligence, big data analytics, and machine learning are revolutionizing traditional manufacturing operations. These technologies enable machines and systems to communicate, collaborate, and make intelligent decisions in real time, leading to improved accuracy, speed, and cost-effectiveness. One of the key benefits of automation in manufacturing is the streamlining of production processes. By automating repetitive and time-consuming tasks, manufacturers can increase throughput, reduce cycle times, and minimize errors in production. Automation also allows for a high degree of customization and personalization in manufacturing, enabling companies to meet the diverse needs and preferences of customers efficiently. Furthermore, automation contributes to the enhancement of workplace safety by minimizing the exposure of workers to hazardous environments and tasks. Robots and automated systems can handle dangerous operations with precision and consistency, reducing the risk of workplace accidents and injuries. Additionally, automation leads to a more skilled and efficient workforce as employees can focus on higher-value tasks that require creativity, problem-solving, and decision-making skills.

In the context of Industry 4.0, automation is not limited to the shop floor but extends to the entire manufacturing ecosystem. Through the integration of cyber-physical systems, data analytics, and cloud computing, manufacturers can achieve real-time visibility and control over their operations. This interconnectedness enables predictive maintenance, demand-driven production, and supply chain optimization, resulting in increased agility and responsiveness to market fluctuations. While the benefits of automation in manufacturing are undeniable, companies must overcome certain challenges to successfully implement Industry 4.0 technologies. These challenges include the initial investment costs, the need for upskilling employees to operate and maintain automated systems, and concerns regarding data security and privacy. However, the long-term advantages of automation, such as improved productivity, quality, and competitiveness, far outweigh these challenges.

In conclusion, automation in manufacturing towards Industry 4.0 represents a transformative journey towards a more efficient, agile, and sustainable manufacturing industry. By embracing automation technologies and harnessing the power of digitalization, companies can unlock new opportunities for growth and innovation. As we navigate the complexities of the fourth industrial revolution, the role of automation in manufacturing will continue to evolve, driving progress and prosperity across industries and economies worldwide.

3. Concept of Industry 4.0

The concept of the "smart factory," which unites cyber-physical systems to connect the virtual and physical worlds and eventually combines commercial and technical processes, best embodies the idea of Industry 4.0[1]. The industrial manufacturing life cycle is geared toward the growing individualism of customer needs and includes the following: the concept and the order for product development and production, product distribution and recycling, and all associated services. Humans, objects, and systems are all interconnected, which results in dynamic, self-organized, real-time optimized inter-company value creation systems. These systems are assessed and improved based on parameters like costs, resource efficiency, and availability.The foundation of industry 4.0 includes nine technology pillars. These developments create a link between the digital and physical realms and enable intelligent, self-governing systems [2].

Figure 1 Technologies Related to Industry 4.0

Big data and analytics enable the collection and thorough examination of data from assets, equipment, IoT-enabled devices, and customers with the objective to support real-time decision making, optimize production quality, conserve energy, and boost equipment maintenance. Data sources can range from consumer input and industry trends that guide R&D and design to weather and traffic applications that facilitate more efficient logistics. Real-time analytics driven by AI and machine learning are applied to the data, and the insights gained are used to enhance automation and decision-making across all levels in the manufacturing and supply chain management domains.

Horizontal and vertical integration is a fundamental framework[4] of Industry 4.0. With horizontal integration, processes are closely linked at the "field level"—on the factory floor, throughout several production sites, and throughout the supply chain. An organization's levels are connected when there is vertical integration, allowing data to move freely from the shop floor to the top floor and back down again. The development of cross-company, universal data-integration networks and the ability to create entirely computerized value chains will lead to a much more cohesive integration between businesses, departments, functions, and capabilities.

In Industry 4.0, additive manufacturing or 3D printing techniques will also be widely used for manufacturing small quantities of customized goods with construction benefits like intricate, lightweight designs. Decentralized additive manufacturing systems with high performance will cut down on both stock on hand and transportation distances. 3D printing lowers costs and eliminates the requirement for off-site/offshore production by allowing parts and products to be held as design files in virtual inventories and manufactured on demand as needed. The scope of 3D printing is expanding every year, incorporating more and more, base materials like metals, ceramics, high-performance polymers, and even biomolecules.

Industry 4.0 is so heavily reliant on the Internet of Things (IoT), or more precisely the Industrial Internet of Things, that the two phrases are frequently used synonymously. In Industry 4.0, sensors and RFID tags are used by the majority of physical objects, including robots, machinery, equipment, and products, to transmit real-time information about their location, performance, and state. With the use of technology, businesses can streamline supply chains, create and adapt goods quickly, avoid equipment failure, monitor customer preferences, track inventory and products, and much more.

Augmented-reality-based systems can serve a wide range of functions, such choosing parts in a warehouse and transmitting repair instructions to mobile devices. When using an augmented reality (AR) system, workers can view real-time IoT data, digitalized parts, maintenance or assembly instructions, training materials, and more while still focusing on a tangible object, such as a product or piece of equipment, by using smart glasses or mobile devices[4]. Although AR is still in its infancy, it already has a significant impact on technician safety and training, maintenance, and quality assurance.

Simulations will leverage real-time data to create a virtual model of the physical world that may contain people, machines, and other objects. This reduces machine setup times and improves quality by enabling workers to test and fine-tune the machine settings for the following product in line in the virtual world before the actual changeover. This fundamental element of Industry 4.0 enables companies to analyze, comprehend, and enhance the functionality and upkeep of industrial systems and goods. A digital twin, for instance, can be used by an asset operator to pinpoint a specific broken component, anticipate future problems, and increase uptime.

Modern cloud computing offers enterprises the ability to innovate while serving as the basis for the majority of cutting-edge technologies, including AI, machine learning, and IoT integration. Cloud-based data powers Industry 4.0 technology, and Industry 4.0's cyber-physical systems rely on the cloud for real-time communication and coordination.

More autonomous, adaptable, and cooperative robots are emerging. These robots can do intricate and challenging jobs because they are outfitted with advanced software, artificial intelligence (AI), sensors, and machine vision. They can also recognize, analyze, and respond to information they gather from their environment. They will eventually communicate with one another, collaborate safely with people, and pick up knowledge from them.

Effective cybersecurity is critical considering Industry 4.0's expanded accordance and use of Big Data. Businesses may minimize the risk of data breaches and production delays throughout their networks by automating threat detection, prevention, and response through the use of Zero Trust architecture and cutting-edge technologies like block-chain and machine intelligence

4. Need of Automation in Manufacturing Quantifying the Impact : Case Study of Germany

4.1. Increased productivity: A large portion of the monotonous labor that was formerly performed by human operators has been eliminated through automation, analytics, and machine-learning algorithms. This entails faster, improved production that is done continuously, with system maintenance and monitoring mostly handled by human operators.

4.2. Enhanced competitiveness: In earlier times, outsourcing to low-wage countries was essential for manufacturers hoping to stay in front of the competition. Richer nations may now, however, compete again because of technological advancements.

4.3. Enhanced profits and revenue: Industry 4.0 allows for things like predictive and preventative maintenance and upgrades, in addition to producing a more effective and high-quality production process.

4.4. To lower labor expenses: The tendency in the industrialized nations of the world has been and now is rising labor costs. As a result, increasing investment in automation to replace manual tasks has become economically justified. Human labor is being replaced more often by machines in order to lower the cost per unit of production.

4.5. To lessen the impact of labor scarcity: Many developed countries are experiencing a general labor shortage, which has prompted the development of automated operations as a worker replacement.

4.6. To cut down on or do away with standard manual and administrative work: One may make the case that automating repetitive, monotonous, taxing, and perhaps annoying tasks has social benefits. The goal of automating such duties is to raise the standard of working conditions overall.

4.7. To raise worker safety standards: The task is made safer by automating a certain function and moving the employee from active involvement in the process to a supervisory role. With the passage of the Occupational Safety and Health Act (OSHA) in 1970, worker safety and physical health have gained national attention. Automating processes has benefited from this.

4.8. To raise the caliber of the products: In addition to producing more at a faster rate than manual labor, automation improves consistency and adherence to quality standards throughout the manufacturing process. One of automation's main advantages is a lower percent fault rate.

4.9. To shorten the lead time for manufacturing: Automation helps to shorten the time between a customer's order and the delivery of the goods, giving the manufacturer a competitive edge for upcoming orders.Work-in-process inventory is decreased by the manufacturer by cutting the manufacturing lead time.[15]

4.10. Smooth traceability and recordkeeping: Large-scale data collection and analysis also lead to improved record preservation and search capabilities. This affects everything from client retention to governing regulatory compliance. The automatic closed-feedback loop is an essential attribute of Industry 4.0, unlike traditional relationships, where feedback on products and services takes time to gather.

4.11. Augmented manufacturing process: Enhanced cooperation throughout the supply chain is rendered possible by better analytics, shared data, and connectivity. This may eventually result in higher productivity, increased efficiency, and more innovation in the manufacturing sector. Greater interaction between manufacturers, suppliers, and other stakeholders along the value chain will be facilitated by "machine-to-machine communications and integrated system".

5. Quantifying the Impact : Case Study of Germany

The fourth wave of technological innovation is expected to deliver benefits in four sectors, according to our analysis of Germany's manufacturing forecast [20], which will help establish a quantitative picture of Industry 4.0's potential international impact:

5.1 Productivity:

Industry 4.0 will be adopted by more businesses over the course of the next five to ten years, increasing productivity by €90 billion to €150 billion in all German manufacturing sectors. 15 to 25 percent will be the range of productivity improvements on conversion expenses, which do not include the cost of materials. There will be a 5–8% increase in productivity after accounting for the cost of the supplies. The improvements will differ based on the industry. Manufacturers producing industrial components, for instance, could see some of the largest gains in productivity (20 to 30 percent), while automakers could see rises of 10 to 20 percent(Exhibit 3).

5.2. Revenue Growth:

Revenue growth will also be fueled by Industry 4.0. The need for more specialized products and improved machinery from manufacturers and new data applications from consumers will result in an extra €30 billion in revenue growth annually, or nearly 1% of Germany's GDP.

5.3 .Employment:

Our study of Industry 4.0's effects on German manufacturing revealed that, over the next 10 years, the growth it fosters will result in a 6% rise in employment. (Exhibit 4). Furthermore, there could be an even greater increase in demand for workers in the mechanical engineering sector—by as much as 10% during the same time frame. Still, new abilities will be needed. In the near future, some of the frequently unskilled workers who carry out routine, easy jobs will be replaced by the trend toward increased automation. The need for workers with expertise in software development and IT technologies, such as mechatronics specialists with software skills, will rise in tandem with the expanding usage of software, connectivity, and analytics. This shift in competency is one of the main obstacles.

5.4. Producers:

The whole value chain of manufacturers, from design to after-sales support, will be impacted by the next wave of manufacturing: Integrated IT systems will optimize production operations along the value chain. Consequently, completely automated, integrated production lines will take the place of today's isolated manufacturing cells. Producers and suppliers will work together to digitally develop and commission products, production processes, and production automation in a single integrated process. There will be very few physical prototypes made. Small batch sizes can be produced economically and with greater flexibility because to advancements in manufacturing methods. This flexibility will come from smart items, robots, and machines that can communicate with one another and decide on their own. Equipment that can learn and optimize itself—for example, by adjusting its own parameters when it detects specific characteristics of the raw material—will improve manufacturing operations.

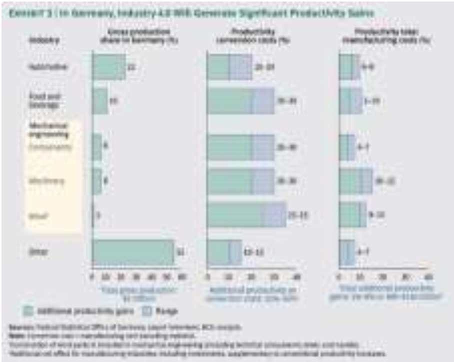

Fig. 2 Exhibit 3[20]

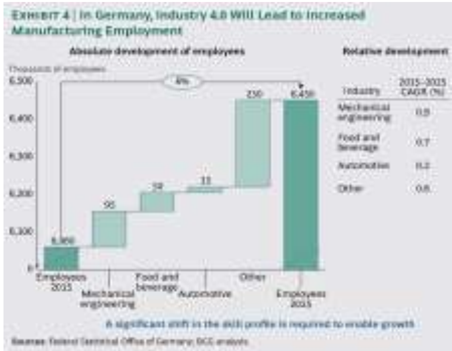

Fig 3. Exhibit 4[20]

Industry 4.0 towards sustainability in manufacturing

- **Collaborative Design Platforms**: Industry 4.0 facilitates the development of collaborative design platforms that allow stakeholders, R&D teams, and product designers from around your organization to view and add to design insights and data. This transparent methodology promotes interdisciplinary cooperation, concept dissemination, and information sharing, resulting in better-informed design choices and expedited creation of inventive, customer-focused solutions.
- **Predictive maintenance**: Manufacturing companies may track the condition of their equipment in real time by combining data analytics with Internet of Things sensors. By identifying possible problems before they arise, predictive maintenance algorithms enable you to put preventive procedures in place that can save downtime by up to 50% and increase asset lifespan by up to 40%.
- **Optimization of the supply chain**: Industry 4.0 enables full transparency throughout your overseas supply chain. Real-time data from suppliers, inventory levels, production plans, customer demand, internal teams, and much more may be used to improve the fulfillment of orders, balance supply and demand, optimize logistics, and boost overall efficiency of your supply chain and manufacturing process as a whole.
- **Agile methods for manufacturing**: Real-time customer insights and feedback can be collected and analyzed from sources like social media, online reviews, and customer care conversations with the help of artificial intelligence (AI) and advanced analytics. Using this data, your R&D teams and product designers can pinpoint customer preferences, problems, and new trends. Your teams will be able to accelerate the development of goods that better meet consumer needs, increase customer satisfaction and loyalty, and spur innovation by incorporating this feedback into the design process.
- **Quality Control and Defect Detection**: By utilizing machine learning algorithms and IoT devices, you may gather data in real-time from every production line. You can stay on the cutting edge of the quality of the product by keeping a vigilant eye on the manufacturing and production process. This allows you to see abnormalities, pinpoint quality problems, and move swiftly to address them.
- **Practicing the circular economy**: Industry 4.0 encourages the adoption of circular economies, emphasizing waste minimization and material reuse, refurbishing, and recycling to the fullest. You may optimize the recovery of valuable resources, track product life cycles, and conduct the reverse logistics for product returns by leveraging IoT networks and Big Data analytics. Additionally, AI-powered advanced analytics may assist your product designers in creating things that are built to last from the very beginning.
- **Carbon Footprint Monitoring and Optimization**: Industry 4.0 technologies make it easier to gather and evaluate data in real-time on energy use, emissions from transportation, and other aspects that affect an organization's carbon footprint. You may accomplish your increasingly ambitious sustainability targets by reducing your overall carbon footprint, identifying areas for improvement, and developing plans to do so by precisely measuring and monitoring emissions.
- **Robotic Process Automation**: Robotic Process Automation (RPA) is a software that mimics human work and replaces it with automated processes. RPAs can read emails, open attachments, move files, follow programmed rules, extract data, integrate information with ERPs, CRMs, and HR systems, and have applications in various industries such as insurance, capital markets, banking, finance, accounting, and business administration. RPAs increase profitability and throughput by automating recurrent and repeatable processes. However, RPA has weaknesses, such as requiring detailed process mining, clearly defined input-output rules, and rigorous technological infrastructure. RPAs are also limited in enhancing decision-making in complex processes and judgment-related tasks, making them suitable for Intelligent Process Automation (IPA). These weaknesses open the door for new paradigms, methodologies, and use cases, such as Intelligent Process Automation (IPA), which can address these issues and improve work quality.

- **Intelligent Process Automation**: Intelligent Process Automation (IPA) is a preconfigured software instance that combines business rules, experience-based context determination logic, and decision criteria to initiate and execute multiple interrelated human and automated processes in a dynamic context. IPA differs from conventional automation in its ability to imitate human activities and reproduce human decision making at crucial stages. It extends traditional RPA functionalities with new emerging technologies, such as self-learning capabilities, data mining process discovery, optimization models, AI-screen recognition, speech algorithms, image recognition, machine learning, and natural language processing.

IPA plays an important role when input data sources are unstructured, the RPA cannot adapt to changing conditions, cannot deal with any data, cannot turn data into insights, or cannot enhance decision-making- and judgment-related tasks. Combining RPA automation capabilities with AI skills can improve operations and customer interactions, optimize efficiency, gain deep process insights, and create new business models. IPA consists of six core technologies: RPA, machine learning, natural language processing, artificial vision, deep learning, and mathematical programming. When combining RPA automation with AI, care must be taken with the methodology and process to successfully implement the project. Key considerations include process mining, the core AI technology used, the robust design of the system, and the computing architecture used.

Table 1. RPA vs. IPA (adapted from [19])

Feature	Simple RPA	Cognitive RPA or IPA
Type of tasks	Routine tasks	Non-routine tasks
Capability of robot	Follow instructions	Come to conclusions
Application focus	Broader	Narrower
Market offerings	Maturing	Emerging
Implementation and ongoing costs	Lower	Higher
Implementation timeframe	Weeks	Months

Framework to Implement IPA in Industries

The framework for implementing IPA in industries is presented in Figure 4 and then, in the following subsections, each of the components is described.

Fig 4. Framework to implement IPA in manufacturing industries [5]

i) **Create an IPA Implementation Roadmap** : An Intelligent Automation (IPA) roadmap should consider the entire process, including the use of AI, and ensure a holistic view of the added value. Process mining is crucial for project design and technology implementation[16]. Governance is essential, and conflicts should be resolved quickly. A cost-benefit analysis is necessary, as complex IPA implementations can be costly. Simple solutions with fast development life cycles are better. Tracking benefits, KPIs, and measures is essential[17]. The impact of IPA extends beyond task automation and data use, and changes in management impact functions, roles, and teams. A meticulous planning, coordinated action, and rigor are required for successful implementation.

ii) **From Process Discovery to Process Mining**: Process blueprints are formed through surveys, workshops, and observations of business activities and employees. Process mining, a new paradigm, uses simulation, AI, self-learning algorithms, and data science to extract knowledge and process structure. It improves efficiency and speed in automation by building an as-is process model and identifying bottlenecks, variations, and root causes of inefficiencies[18]. This approach can lead to 54% faster automation implementation and 44% increase in value when combined with process mining. Process mining is essential for understanding current processes, identifying inefficiencies, identifying crucial parts, implementing IA, monitoring automation rates, and other KPIs. However, it may be costly if implemented without sufficient understanding of business processes.

iii) **AI Analysis and RPA Estimation** Process blueprints are formed through surveys, workshops, and observations of business activities and employees. Process mining, a new paradigm, uses simulation, AI, self-learning algorithms, and data science to extract knowledge and process structure. It improves efficiency and speed in automation by building an as-is process model and identifying bottlenecks, variations, and root causes of inefficiencies. This approach can lead to 54% faster automation implementation and 44% increase in value when combined with process mining. Process mining is essential for understanding current processes, identifying inefficiencies, identifying crucial parts, implementing IA, monitoring automation rates, and other KPIs. However, it may be costly if implemented without sufficient understanding of business processes.

iv) **Define a Suitable Solution Architecture** Implementing intelligent automation (IPA) projects requires a holistic architecture that covers key components. Organizations should evaluate their capabilities to integrate new systems with the enterprise ecosystem. The IT area should establish a performance monitoring mechanism to manage and monitor projects. Cloud infrastructure is ideal for scalability and interoperability. A suitable architecture should include optimal databases for data storage, ETLs for integration with other data sources, and efficient data repository technology for AI algorithms. Choosing a cloud provider according to the company's IT scheme is crucial for integration and sustainability. Co-creation between business and IT teams is essential for project success. Below in Figure 5, a typical architecture to develop IPAs under a holistic scheme is shown[5].

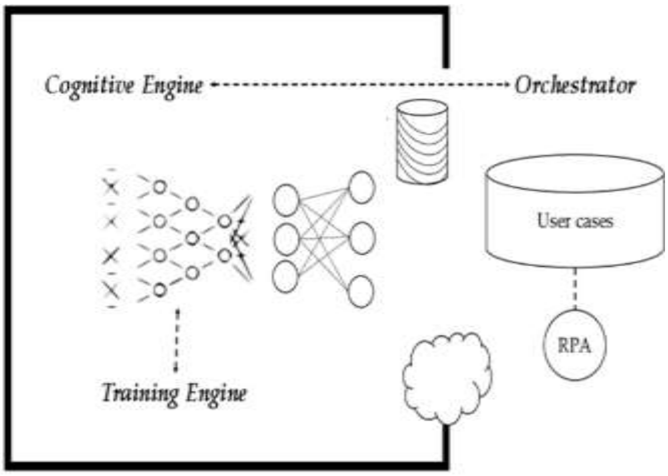

Fig 5. IPA common Architecture example

Starting with RPA and then adding AI capability is crucial for successful implementation of Intelligent Process Automation (IPA). Connected, knowledgeable, and organized data is necessary for cognitive and AI techniques. The first set of processes for AI implementation should be "low-hanging fruits" with minimal inconveniences and transition efforts. Common IPA applications include algorithms, prediction technologies, planning algorithms, and large bottlenecks. Machine learning algorithms can also provide human validation in cases where human validation is needed. Tools like natural language processing, deep learning, and computer vision can be used to evolve RPAs.

Application in the Manufacturing Industry

This chapter discusses the potential of artificial intelligence (AI) in the manufacturing industry, specifically in automating production orders for fabric finishing plants. It outlines the steps involved in developing an AI algorithm for optimizing fabric roll allocation and cutting, highlighting the benefits of this automation.

Fig 6. Sequence of instructions to apply the proposed technology in the manufacturing industry

i) IPA Objective The IPA: aims to automate fabric stamping, purchase order creation, receiving and processing information via email, creating the order in SAP, and generating a PDF response.

ii) Description of the IPA Process: The process involves a customer email with fabric purchasing requirements, which is validated and activated by an orchestrator. The robot logs into SAP and creates orders, ensuring fabric waste minimization and compliance with business rules. An AI algorithm is integrated into the Robotic Process Automation (RPA) to optimize decision-making and pick up fabric rolls. The robot controls exceptions and input/output interactions, and creates a purchase order in SAP. The process ends with a PDF file sent to the organization manager and supplier.

iii) IPA Process Mining: Table 2 shows the description of the process mining carried out in the IPA.

iv) AI Integration Capability: The AI component in the automation system optimizes batches and meets business conditions, such as consumption of the same batch, picking from the same warehouse or external supplier, and ensuring rolls have at least 50 m. It also handles tolerances for orders, ranging from 0 to 600 m, 6% to 1000 m, and 2% to 1000 m. The integration of AI software and RPA with well-defined business rules enhances the automation experience, allowing software to make optimal decisions. Table 3 shows a process breakdown from a technical perspective, specifying process steps performed by the RPA and AI software.

Table 2. IPA Case—Process steps.

Steps	Process Description of the IPA Case
1	The RPA software checks if there are unread emails in the mailbox.
2	If there are new unread emails, the request type is identified by the email subject. If the issue does not exist or is not within the standards, a notification email is sent back requesting the email information to be corrected.
3	After the subject is correctly identified, the RPA software verifies that the email attachment is in a xlsx format.
4	Mandatory parameters are verified. If the file contains invalid parameters, the RPA sends the information rows with problems back to the sender.
5	If all parameters contained in the file are correct, the requested orders are sorted and prioritized by date.
6	Key process information from the file is sent to the RPA orchestrator: material, delivery cycle, value, brand, quality, the quantity of fabric required, ID of the fabric supplier, minimum quantity to take, and priority of the order, among others.
7	If there are no unread emails, the RPA checks for pending orders in the orchestrator's queue.
8	The RPA logs into SAP.
9	The RPA searches for the transaction code.
10	Material numbers and order due dates are entered into the system.
11	The RPA verifies the existence of the required material in SAP. If it does not exist in SAP or the due date is a non-working day, then an email is sent informing of the error, and this task is marked as failed.
12	Value, required quantity, brand, and quality of the raw material are entered into the system.
13	The RPA verifies if the data was entered correctly.
14	Fabric supplier ID, order number, arrival warehouse, brand, and fabric quality information are entered.
15	Fabric batches are assigned according to business rules and restrictions, assuring that available fabric meets the minimum required quantity in the order.
16	The AI software is invoked to find the set of batches that together meet the amount of required fabric and minimize waste the most.
17	The output of the AI software is put into an Excel file that contains the information of the batches to be taken and the quantities for each one.
18	Specified fabric batches and quantities are selected in SAP.
19	The order is saved, and the order number is extracted.
20	The order is generated, and a PDF is saved.
21	The supplier email is extracted.
22	An email is sent to the supplier and buyer with the order and the generated PDF.
23	The RPA software checks if there are unread emails in the mailbox.
24	If there are new unread emails, the request type is identified by the email subject. If the issue does not exist or is not under the standards, a notification email is sent back, requesting email information to be corrected.
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29	If there are no unread emails, the RPA checks for pending orders in the orchestrator's queue.

Table 3. IPA Case design.

Steps	Explanation
1	The RPA software generates a query to the company's WMS system, which stores inventory information, and exports it to a SQL database, appending detailed requirement information to the data dump.
2	The RPA software calls the AI software using the server console where the system is housed.
3	The AI software reads the SQL database generated in step 1.
4	The AI software creates a global query, considering demand and inventory rolls available that contain over 30 m of fabric. If the inventory is more extensive than demand, the AI software starts execution. Otherwise, it stops and sends an error email to the RPA software console, finishing execution.
5	The AI software then sorts existing fabric categories in the different business units of the company. Each business unit stores a different fabric quality. To optimize the inventory and reduce waste, they need to be consumed in a specific order (First A, then B, and C).
6	The AI software takes a subset of the fabric of category A.
7	The AI software executes three possible scenarios, defined in the business requirements as rules to optimize waste and keep the fabric batches homogeneous.
8	First scenario: AI software finds the identical quantity within one single batch. A heuristic algorithm is applied to minimize the difference between a total requirement and the combination of rolls of the same batch that gets close to the requirement with a delta that ranges from −10 m to +50 m. If it does not find a solution for the first scenario, it moves to the second one. Second scenario: the AI software must decide how much fabric to take from each roll within every batch. In this case, the delta does not apply to the requirement established by the business. Therefore, the AI software needs to virtually "cut" a fabric amount from a roll of any batch. In this case, the AI algorithm decides the right amount and selects from multiple rolls the right one to minimize the fabric waste after the cutting process. For this scenario, the AI software needs to leave more than 50 m of fabric in the roll after the cut to be utilized in further requirements and not treated as waste. The amount of fabric (of a single category) required is not within a single roll, so the AI software needs to pick from different rolls until the requirement is met or the closest amount to the requirement is found, always keeping the business deltas.
9	The AI software generates a JSON file containing the execution message according to the scenario.
10	The AI software sends a message to the RPA software with the execution results through the RPA software console.
11	The RPA decides what to do next according to the message received. It can stop the execution and communicate errors or continue with reserving the fabric in the system by choosing the amount of fabric that the AI software indicated in the message.

v) Results and Benefits:

The implementation of AI software in the IPA process significantly reduced order processing time, saved two employees' time, and reduced fabric waste by 30%, thereby generating economic benefits.

Data and Statistics

According to McKinsey's recent research with the World Economic Forum puts the value creation potential of manufacturers and suppliers implementing Industry 4.0 in their operations at USD 3.7 trillion in 2025. [21] A case study by the National Bureau of Economic Research (2018) revealed that the adoption of Industry 4.0 technologies can lead to a 10% increase in productivity in the manufacturing sector. [22] A report by the Boston Consulting Group (2019) suggests that Industry 4.0 technologies can improve overall equipment effectiveness by up to 15%. A study by PwC (2018) estimates that the implementation of Industry 4.0 technologies can result in cost savings of up to 30% in the manufacturing sector. [23] According to a report by the International Federation of Robotics (2020), the use of industrial robots in manufacturing can reduce labor costs by up to 60%. A report by the World Economic Forum (2018) predicts that the adoption of Industry 4.0 technologies will create 133 million new jobs globally by 2022, while also displacing 75 million existing jobs. [24] The same report suggests that by 2022, 54% of all employees will require reskilling due to the impact of Industry 4.0 technologies. A case study by the National Bureau of Economic Research (2018) demonstrates that automated systems can adapt to changes in production requirements more quickly than manual processes, allowing for greater flexibility in meeting customer demands. [25] A report by PwC (2019) highlights that manufacturers adopting Industry 4.0 technologies are 2.2 times more likely to report increased responsiveness to customer needs.

These statistics provide insights into the adoption of automation and Industry 4.0 technologies in the manufacturing sector, their impact on productivity, cost savings, employment, and flexibility.

Industry development 4.0

The conversation around the development of Industry 4.0 brings together a wide range of interest areas. For a coherent technical, syntactic, and semantic interoperability, communication and automation technologies, production standards, and approaches to factory and process automation must be appropriately connected to one another. RAMI 4.0, which was showcased at the 2015 Hannover Fair (shown in fig. 7), is presently among the most noteworthy findings in the field of Industry 4.0 research. It offers a structured framework wherein the fundamental attributes of Industry 4.0 for production systems can be modified.

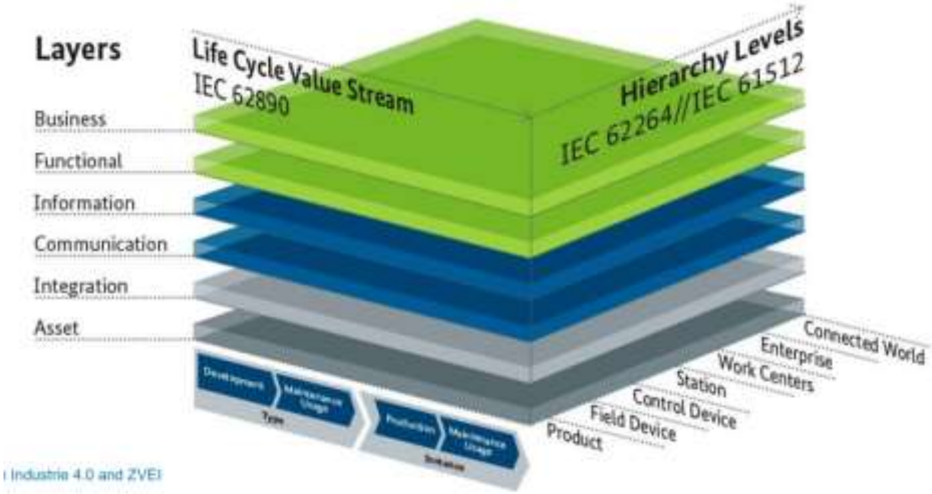

Fig 7. RAMI 4.0 Hierarchy levels and Life Cycle Value Stream.[13]

The three axes that make up the model are as follows:

1. The six levels that make up the Architecture axis ("Layers") provide details on the asset role and the IT structure of a production system.
2. The asset's lifetime and value-added process are shown by the "Life Cycle and Value Stream" axis.
3. An overview of the hierarchical levels of a manufacturing system is provided by the "Hierarchy Levels" axis.

Adopting RAMI 4.0 presents a significant technological challenge in terms of automation: creating workable solutions that support the functions of each layer and their interactions. Therefore this work mainly focuses on the vertical architecture axes. The physical world—machines, portions of machines, axes, etc.—is represented by the Asset layer in the Architecture axes, along with a link between the asset and its virtual representation at higher layers.

The shift from the real world to the information world takes place at the Integration level. Therefore, this layer includes features and process-related capabilities, such as technical element descriptions and human-machine interfaces (HMI), that enable the asset to be used for its intended purpose. Every pertinent real-world occurrence that is reported to the Integration level sets off an event in the virtual world.

A unified data format is used in standardized Industry 4.0 compliant communication within the Communication layer. Stated differently, it delineates how the asset is linked to data and operations of other assets. All of the data that the asset's technical functionality uses, generates, or modifies is described in the Information layer. This level involves the persistent and consistent integration of several data sources. The Functional layer offers a platform for the horizontal integration of various functions of all assets by containing formal, digital descriptions of the technical functions of the asset in relation to its position in the production system. The Business layer, which is the last but not the least, is a higher strategic enterprise view. This entails mapping business models and the ensuing business processes, assuring the integrity of functions in the value-added chain, orchestrating services in the functional layer, etc. But particular solutions like enterprise resource planning (ERP), which are found on the functional layer, have nothing to do with the function of the business layer [13].

Conclusion

The study examines pertinent literature in order to assess the effects of applying Industry 4.0. Based on the aforementioned arguments, it can be inferred that Industry 4.0 has the potential to boost manufacturing organizations' productivity and competitiveness. But the biggest obstacles to Industry 4.0 adoption are its costly installation, maintenance, and training expenses. Nonetheless, it will be simpler for businesses to successfully adopt Industry 4.0 if they can convince staff members of the advantages of digital technology and that they can use them with ease.

References

[1] Willliam M. D. 2014. Industrie 4.0 Smart Manufacturing For The Future. Berlin: Germany Trade & Invest

[2] Michael, R. Markus, L. and et al. 2015. Industry 4.0: The Future of Productivity and Growth in Manufacturing Industries. Boston Consulting Group

[3]Bahrin, M., Othman, M.F., Azli, N.H., & Talib, M.F. (2016). INDUSTRY 4.0: A REVIEW ON INDUSTRIAL AUTOMATION AND ROBOTIC.

[4]. Industry 4.0: The Future of Manufacturing | SAP. (n.d.).

[5]Liévano-Martínez, F.A., Fernández-Ledesma, J.D., Burgos, D., Branch-Bedoya, J.W., & Jiménez-Builes, J.A. (2022). Intelligent Process Automation: An Application in Manufacturing Industry. Sustainability.

[6]Bahtat, Chaymae & El Barkany, Abdellah & Jabri, Abdelouahhab. (2023). Reconfigurable Manufacturing Systems: From Automation Through Industry 4.0. 34. 1-22. 10.22068/ijiepr.34.2.2.

[7]Hoover, William & Guerra-Zubiaga, David & Banta, Jeremy & Wandene, Kevin & Key, Kaleb & Gonzalez-Badillo, Germanico. (2023). Industry 4.0 Trends in Intelligent Manufacturing Automation Exploring Machine Learning. 10.1115/IMECE2022-96092.

[8]Antonazzo, L., Stroud, D., & Weinel, M. (2023). Smart manufacturing and tasks automation in the steel industry: Reflecting on routine work and skills in Industry 4.0. Economic and Industrial Democracy, 0(0). https://doi.org/10.1177/0143831X231201002

[9]Smolka, D., & Papulová, Z. (2022). Implementation of Automation and Industry 4.0 Technologies in Automotive Manufacturing Companies. Human Interaction and Emerging Technologies (IHIET 2022): Artificial Intelligence and Future Applications.

[10]Zuzana Papulová, Andrea Gažová, Ľubomír Šufliarský,Implementation of Automation Technologies of Industry 4.0 in Automotive Manufacturing Companies, Procedia Computer Science, Volume 200,2022, Pages 1488-1497,ISSN 1877-0509, https://doi.org/10.1016/j.procs.2022.01.350.

[11]Zadjali, S.A. & Ullah, A. (2021). Impact of Industry 4.0 in Manufacturing Sector. International Journal of Management Science and Business Administration, 7(6), 25-33.

[12]Djerdj Horvat, Henning Kroll, Angela Jäger, Researching the Effects of Automation and Digitalization on Manufacturing Companies' Productivity in the Early Stage of Industry 4.0, Procedia Manufacturing, Volume 39,

2019, Pages 886-893, ISSN 2351-9789, https://doi.org/10.1016/j.promfg.2020.01.401.

[13] Christian Brecher,

Aleksandra Muller, Yannick Dassen, Simon Storms(2021).Automation technology as a key component of the Industry 4.0 production development path, pp 2288-2289.

[14]Sharma, M., Kamble, S., Mani, V., Sehrawat, R., Belhadi, A. and Sharma, V., 2021. Industry 4.0 adoption for sustainability in multi-tier manufacturing supply chain in emerging economies. Journal of Cleaner Production, 281, p.125013

[15]David O'Sullivan,2009.Industrial Automation.Universidade do Minho

[16]Fettke, P.; Loos, P. "Strukturieren, Strukturieren, Strukturieren" in the Era of Robotic Process Automation. In The Art of Structuring; Springer International Publishing: New York, NY, USA, 2019; pp. 191–201.

[17]Ivanˇci´c, L.; Suša Vugec, D.; Bosilj Vukši´c, V. Robotic Process Automation: Systematic Literature Review. Lect. Notes Bus. Inf. Process. 2019, 361, 280–295

[18]Van der Aalst, W.M.P.; Bichler, M.; Heinzl, A. Robotic Process Automation. In Business and Information Systems Engineering; Gabler Verlag: Wiesbaden, Germany, 2018; Volume, 60, pp. 269–272.

[19]Fettke, P.; Loos, P. "Strukturieren, Strukturieren, Strukturieren" in the Era of Robotic Process Automation. In The Art of Structuring; Springer International Publishing: New York, NY, USA, 2019; pp. 191–201.

[20]Rüßmann, M., Lorenz, M., Gerbert, P.D., Waldner, M., Justus, J., Engel, P., & Harnisch, M.J. (2016). Industry 4.0The Future of Productivity and Growth in Manufacturing Industries April 09.

[21] Industry 4.0 Capturing value at scale in discrete manufacturing. (2025). In McKinsey Report.http://dln.jaipuria.ac.in:8080/jspui/bitstream/123456789/1331/1/Industry-4-0-Capturing-value-at-scale-in-discrete-manufacturing-vF.pdf

[22] Rojko,K.,Erman,N. & Jelovac,D.(2020).Impacts of the Transformation to Industry 4.0 in the Manufacturing Sector: The Case of the U.S.. Organizacija,53(4) 287-305. https://doi.org/10.2478/orga-2020-0019.

[23] Çınar ZM, Zeeshan Q, Korhan O. A Framework for Industry 4.0 Readiness and Maturity of Smart Manufacturing Enterprises: A Case Study. *Sustainability*. 2021; 13(12):6659. https://doi.org/10.3390/su13126659.

[24] IFR International Federation of Robotics. (n.d.). IFR presents World Robotics Report 2020. https://ifr.org/ifr-press-releases/news/record-2.7-million-robots-work-in-factories-around-the-globe.

[25] Acemoglu, D., Restrepo, P., David Autor, Toulouse Network on Information Technology, Google, Microsoft, IBM, & Sloan Foundation. (2018). *ARTIFICIAL INTELLIGENCE, AUTOMATION AND WORK* (Ajay Agarwal, Avi Goldfarb, & Joshua Gans, Eds.; No. 24196). https://www.nber.org/system/files/working_papers/w24196/w24196.pdf.