

Chapter 5: Smart Automation Frameworks for Industry 4.0 and Beyond

5.1. Introduction to Industry 4.0

Industry 4.0 refers to the smart automation of the manufacturing industry with the help of information technology. The concept is based on the transition from traditional automation and information exchange toward cyber-physical systems, Internet of Things (IoT), real-time data, machine learning, and cloud computing.

The intelligent infrastructures forming Industry 4.0 include Cyber-Physical Production Systems (CPPS) that consist of cyber systems controlling physical machines and communicating with other machines. Every machine has its representation/model on the web, accessible in real time. Digital Twin is a CPPS variant wherein a cyber system models the production process and communicates with various machines to manage production. Collaborative Intelligent Robots (CoBot) perform physical actions for final product creation, fitting into the Industry 4.0 concept by enabling flexible and adaptable manufacturing. Big Data refers to the handling of vast amounts of data generated through the interconnection and data generation capabilities of Industry 4.0 systems.

5.1.1. Understanding the Foundations of Industry 4.0

Industry 4.0 is a term for new levels of intelligence, resource efficiency, and attention to workers' needs driven by unprecedented connectivity in asset integration. The focus is on connecting an ecosystem of players and enabling multi-dimensional optimisation across the whole value chain: Intelligence, Energy consumption, Human needs. Industry 4.0 is being made real through the digitisation of manufacturing, logistics, aviation, defence, and many other verticals. Given the connectivity of assets within Industry 4.0, new networks are becoming vulnerable to advanced cyber threats that demand new detection techniques. As Industry 4.0 evolves, increasing numbers of devices on the

production floor agree on the state of a non-centralised ledger that is immutable and almost impossible to hack.

Smart automation frameworks offer a way of partially achieving aspects of the Industry 4.0 vision. Their main features typically include leveraging modern ICT technologies such as 3D printing, robot-assisted manufacturing, customised production, automation, cloud computing, industrial Internet of Things (IoT), and Artificial Intelligence (AI) to deliver: increased levels of safety and security for workers; agile automated manufacturing processes; human-in-the-loop approaches whenever safe, necessary, and/or preferable to humans; flexible manufacturing-provisioning decisions; real-time decisions; multi-dimensional optimisation that includes attention to human needs; and truly sustainable automation that minimises energy consumption while also maximising efficiency and task/production quality.

5.2. Key Technologies in Smart Automation

The confluence of new technologies makes the Industry 4.0 conceptually feasible, although big hurdles remain in its widespread adoption in the industry. The discussion continues, and terms such as Level 3 automation, smart automation, cognitive automation, intelligent automation, and smart manufacturing are used in the literature [1-3]. Definitions vary widely, but many core ideas presented for smart manufacturing also match emerging trends that include simple automation systems based on artificial intelligence (AI), machine learning, and deep learning. These trends primarily focus on gathering a vast amount of automation data and using the data for decision-making at different levels. The discussions indicate that the industries are gradually moving toward smart automation after the current Level 2 automation, which may be considered as part of Industry 3.5, a stepping stone from Industry 3.0 to Industry 4.0.

Although key concepts of Industry 4.0 rest on data that allow full automation at the decision-making level, the term Industry 4.0 is often used to include any automation solution with increased complexity. While such an approach ensures continuity in automation systems and reduces cyclical deviations in investment, the terminology may also lead to confusion in implementation. The concept of smart automation incorporates both data-driven and simple implementations of automation at different decision-making levels. Some definitions acknowledge that human intervention will continue in certain processes. Although connected and cyber-physical systems lay the foundation for smart automation, cyber-physical systems do not ensure the incorporation of AI. AI guarantees the implementation of data-driven, smart, and automated suggestions, decision-making, and actions at the appropriate level. Without AI, automation can be implemented only at predefined levels based on explicit rule-based programming. Thus, the full concept of smart automation requires connected systems embedded with AI.

5.2.1. Internet of Things (IoT)

The Internet of Things (IoT) was born from the convergence of operational technology and information technology, connecting devices to create a network capable of collecting, sharing, and analyzing data. IoT generates vast amounts of data every minute for any imaginable application. The concept of connected machines has been around since the 1980s, with personal computers connecting through dial-up modems. However, today's IoT represents a combination of several technologies that make it powerful, including hardware, communication and connectivity protocols, software tools, and a cloud infrastructure that provides storage, computing power, analytics, and insights in near real-time.



Fig 5 . 1 : The Internet of Things (IoT): Convergence, Technologies, and Applications

IoT is an evolving industry focused on the development of technologies that connect any physical objects to the internet or a local network to communicate data and enable remote management. The goal of IoT is simple: to connect objects to develop smarter cities,

buildings, and vehicles, and ultimately to build a smart world. In the last decade, the market has witnessed the explosive growth of IoT deployments. Residential IoT, also known as smart homes, connects IoT devices for various applications such as security, entertainment, control, and automation of home appliances. Other IoT implementations include security and surveillance, asset tracking and traceability, and environmental and industrial monitoring.

5.2.2. Artificial Intelligence (AI)

Artificial intelligence (AI) is a branch of computer science concerned with building smart robots capable of performing tasks that typically require human intelligence. These tasks include learning, reasoning, sensing, acting, and imagining. According to Bettini [18], AI consists of six components: machine perception, knowledge representation, language understanding, expert systems, robotics, and machine learning. The AI system processes information received from the environment and activates an operator to perform specific actions.

Architecture of an AI System: As depicted in Fig. 2, the architecture of an AI system consists of two major components: a knowledge-oriented component that provides knowledge representation and a mechanism for solving knowledge-based problems (SOKP), and an agent-oriented component that captures the functionality of an intelligent agent and provides functions for acting and deciding. Integrating agent functionality into knowledge representation and SOKP components results in an intelligent system capable of acquiring knowledge about the problem, perceiving environmental changes, interacting with the environment, making decisions, and acting in the environment accordingly. Employing SOKP addresses high-level knowledge management issues of an intelligent agent, including learning from experience, formulating feasible plans to achieve objectives, diagnosing reasons for unexpected states, and explaining past and intended behaviors [3-5].

5.2.3. Machine Learning (ML)

At the centre of Artificial Intelligence (AI) is Machine Learning (ML), a core technological enabler that enables machines to comprehend, behave, predict, and operate like humans. ML learns new knowledge from existing datasets and builds predictive models for generating future results without being explicitly programmed. It achieves this by providing systems with the capability to explicitly learn and improve from experience or data on specific tasks. ML can be categorized into three different types, according to how machines learn knowledge and make decisions.

With no supervision, Unsupervised learning recognises patterns in unlabelled, uncategorized data to discover intrinsic structures hidden within the data itself, grouping similar data into clusters, without categorising the data. Conversely, Supervised learning uses labelled and categorized data for training, where the input data are paired with the correct output labels. Using these outputs, the algorithm finds the rules and relationships by minimising the errors in predicting the target labels for the training instances. Reinforcement Learning (RL) has also gained interest as it provides an agent the ability to interact with an uncertain environment, through an interface via state, action, and reward. Using RL, an agent learns to map situations to actions to maximise a specific cumulative reward.

With specific tasks, Domains incorporate training experience and improve the performance of ML algorithms. When the task is transferred to related/correlated environments, it is called transfer learning, enabling ML models to accelerate learning in a new task through their prior knowledge. Natural Language Processing (NLP) models address communication tasks in natural language, enabling the machine's understanding and interpretation of human language. Deep Learning (DL) is a class of representation learning methods that use multiple levels of abstraction to help the machine understand complex problems.

5.2.4. Big Data Analytics

Because of extensive digitalization, massive amounts of data are generated every day. That data can be assigned to the smart manufacturing industry. This part of big data analytics refers to the analysis of data within the manufacturing life cycle. The simple classification of data is explained below. First comes the concept of "smart data," which means meaningful data in the context of solving a specific problem. There is a clear link between data and the corresponding analysis method. Then intelligent data wrapping is considered; the aim is to merge the existing models with real data. Data sources within a company can be classified into three layers.

5.2.5. Cloud Computing

Cloud computing delivers vast computational power and storage resources via the Internet and is essential for digital manufacturing. Its key advantages are resource pooling and rapid provisioning, enabling enterprises [2,4,5] to implement a dev/test/production environment without investing heavily in their infrastructure. From the perspective of an end user, the capabilities available in the cloud, together with the responsibilities imposed on the user, are categorized in three main service models: Infrastructure-as-a-Service (IaaS), Platform-as-a-Service (PaaS), and Software-as-a-

Service (SaaS). The software available for end users or tenants is further categorized into application software, programming environments, batch queues, debugging tools, and resource management. The broader use of the term software in this context often subsumes the underlying hardware and the operating system. IaaS hides the complexity of the allocation of resources to the tenants, encouraging encapsulation of resources. PaaS, a superset of IaaS, hides the underlying infrastructure by offering programming environments to the tenants. SaaS is the broadest category of services. It provides ready-to-use, fully functional software over the network to the tenants. Digital manufacturing initiatives exchanging data using predefined formats and simple services, such as a request for quotation, do not need to resort to cloud computing. The Cloud is particularly useful when analysis is computationally intensive and needs to be carried out for many configuration points. Conventional web services may be sufficient when producing 100 simulations. In the context of Cloud computing, the term tenant is commonly used for a user while referring to different perspectives.

5.3. Frameworks for Smart Automation

In the extensive landscape of industry information systems, a multitude of frameworks supporting intelligent automation exist. The discussion commences with a dedicated framework for the smart operation of production systems and subsequently explores general framework models that underpin the smartification of enterprises and devices. These exploratory segments illuminate how similar strategies can be adopted to orchestrate other crucial facets of a smart factory, such as predisposition, production, innovation, and service provisioning. A thorough analysis of the requirements of smart production systems culminated in the Smart Production Operation Execution Model (SPOEM), a framework designed to model the smart operation of production systems. This conceptualization recognizes the core solution architecture for an Intelligent Automation Engine. Additionally, a more generalized strategy for the Smartification of Assets, Devices, and Production Systems was devised. It demonstrates how a Smartification Framework can model the smartification processes for assets, devices, production systems, and related services.

5.3.1. Reference Architectures

The wealth of literature on Industry 4.0 reference frameworks is impressive, and it continues to grow both in quantity and quality. Industry 4.0 frameworks exhibit a range of goals mainly related to development, guidance, structure, and classification. Most of the frameworks focus on Industry 4.0 development support (e.g., design or creation of products or systems), while also addressing guidance (explaining the general domain or

target) and/or structure (describing the components and their relations). Selection frameworks for Industry 4.0 proposals and synthesis frameworks for combining different initiatives on Industry 4.0 have also been proposed. Further analysis sheds light on Industry 4.0 group built in the literature: guidance group describes different perspectives of Industry 4.0 implementation; structure group identifies important components in Industry 4.0; lightweight group consists of basic proposals without specific goals; classification group classifies Industry 4.0 automation levels according to the IMS Model for Automation Levels; implementation group offers practical applications on Industry 4.0 and development group supports the development of initiatives in Industry 4.0.

5.3.2. Agile Methodologies

Agile, in general, and SCRUM, in particular, provide well-defined V&V activities from the very first iteration. V&V activities include test planning and designing test cases, requirements analysis, and design. These activities help to identify any deviation early in the development phase, which in turn reduces the cost of modification and rework. The agile testing principle states that to perform testing faster and deliver high-quality software, continuous integration should be used. Continuous integration is a methodology in which developers check in work frequently, usually at least daily. On every check-in, an automated build, test (unit and functional), and deploy is performed.

During a sprint, the sprint planning and backlog grooming identify the stories that are ready to be brought into the sprint. This corresponds to the Test Planning and Design phase in the V-Model of testing [6-8]. The code is designed and developed during the sprint corresponding to the build and code phases. Coding and Unit test implementation together correspond to the Unit Test Design phase of the V-model testing approach. Coding, unit testing, and creating functional test cases provide multiple layers of testing.

5.3.3. DevOps Practices

Security and Performance Monitoring

Security and performance monitoring play an important role in the DevOps ecosystem. Continuous monitoring ensures the security and performance of applications and infrastructure. As Systems-of-Systems (SoS) become more interconnected, their attack surface grows, necessitating constant observation of traffic and user activities to detect any malicious behavior. Various security monitoring tools have been integrated within OpenDevOps to provide real-time insights on security and performance. These tools

implement multiple layers of defense according to the position of the digital assets exposed.

Performance monitoring offers real-time visibility into infrastructure, frontend, and backend speeds, with thresholds established to alert developers when Key Performance Indicators (KPIs) are not met. Monitoring tools help avoid bottlenecks and unnecessary delays in tasks, applications, and infrastructure. Log analysis tools contribute to performance by enabling analytics to identify LSD-derived bottlenecks. These tools identify the root causes of errors and log them for developer action. Performance monitoring tools are fundamental to achieving Application Performance Management (APM).

5.3.4. Microservices Architecture

Microservices architecture in the context of Smart Automation Frameworks (SAF) for Industry 4.0 and beyond is a method of designing software applications in the form of independently deployable, modular services. These services make the automation framework configurable and maintainable for different industries, enabling its smooth operation. By configuring SAF according to industry requirements, functional or nonfunctional features can be removed or added. Moreover, a Microservices architecture narrows the scope of important decisions within the modules and services, making the automation system less vulnerable and more responsive to failures.

Using Microservices architecture ensures that the implementation of Automation Frameworks can be broken down into smaller components with specific responsibilities shared across the ecosystem. However, it is known that such an architecture tends to experience more downtime than is desirable for Industry 4.0 solutions. Downtime is expressed in some degree of loss of production, reduced production rate, or possible damage to raw material or equipment in the manufacturing process.

5.4. Implementation Strategies

Investments in Smart Automation in Industry 4.0 require a targeted analysis combining short-term advantages and long-term objectives. Since organizations must endure the innovation process and balance difficult choices, pilot projects help evaluate various approaches and technologies, thereby mitigating risks and uncertainties before a widespread rollout [1,3,9]. In Industry 4.0, with rapidly evolving systems and components, maintaining flexibility is vital. The focus should be on the rollout, ongoing requirements changes, integration and enhancement of existing solutions, and continuous feature development. While internal IT departments can minimize rollout

costs, the long-term viewpoint stresses organizational flexibility during the entire rollout and beyond.

Companies must formulate hypotheses on the proposed solution; these hypotheses are tested and validated in pilot projects before full-scale adoption. The internal examination of Hypothesis-Driven Deployment highlights the hypotheses, targets, and processes of the pilot project and rollout phases. As Hypothesis-Driven Deployment evolves iteratively based on novel hypotheses, it benefits from a conduit channeling feedback from operations, supply chain, and customers. Consequently, continuous development budgets should be ensured for the subsequent lifecycle of a Smart Automation Context. These measures enable companies to appreciate the economic benefits of Industry 4.0 and Smart Automation strategies from an economic angle.

5.4.1. Assessment and Planning

As systems become more connected and automated, business needs can quickly change. To successfully meet those changing needs, an industry can move any system gradually towards Smart Automation by addressing it as a series of projects, from a Proof of Concept (PoC) or pilot system to capable systems, and finally to a system in productive operation. At each stage, a different approach to the project will increase the chance of success and reduce the risk of failure. Start with a clearly defined question, then determine if any existing system or method already provides the answer. While it might not be a perfect solution, it could be sufficient to answer the inquiry. When existing systems or methods are not adequate, the project can progress from a PoC to a pilot with operating hardware, machines, and systems.

However, not all exploratory projects must be described as PoCs or pilots. Research projects can serve as the initial phase of development, but are typically not considered a part of company operations. Companies within the Industry 4.0 and Smart Automation domains often struggle to articulate the business case for Smart Automation. Nevertheless, the business case need not focus solely on cost aspects. Industry 4.0 projects may also serve to reduce risks, provide product diversification, improve quality, or help comply with environmental, social, or governance criteria. These benefits can be evaluated and compared to the project's financial requirements. In the case of a PoC or pilot project, the investment risk is usually relatively low, so it might be acceptable to pursue qualitative advantages without a detailed analysis of quantifiable key performance indicators or financial metrics.



Fig 5 . 2 : Smart Automation Implementation Stages and Business Case

5.4.2. Pilot Projects

The value assessment of smart automation scenarios more frequently requires qualitative analysis instead of quantitative evaluation. To fill the gap, a systematic and consistent approach guidelines need to be adopted. The guidelines start with four main building blocks of Industry 4.0—connectivity, intelligence, modularity, and safety and provide six evaluation targets—innovation incentive, cost efficiency, social and environmental impact, system-effectiveness, and future-proof.

The implementation of a defined smart automation scenario must be closely monitored and reviewed. Before starting the initial implementation, a roadmap for implementation should be defined to examine the status and results of the already implemented part at a fixed moment in time. Constant and repeated testing and status quo review ensure that the predefined goals are achieved. The proposed method identifies the most suitable framework area that should be considered for a specific use case situation. Furthermore, a framework with the highest automation potential can be found based on the proposed ranking results.

5.4.3. Scaling Up Solutions

The Evaluation phase concludes when the company identifies the key use cases and drivers and decides to proceed with full implementation. The primary objectives of the Preparation and Scaling phases include assessing the company's readiness, performing a comprehensive cost–benefit analysis, mitigating potential risks, and establishing an implementation plan. A detailed feasibility assessment ensures alignment between the

new applications and the company's production system, business model, and industrial relations. Scaling—or full implementation—entails the deployment of the applications to company-wide operations. At this stage, the company determines the need for external know-how and support to facilitate the pilot and full implementation. Pilot projects play a crucial role in managing challenges, risks, and uncertainties before embarking on full-scale deployment.

Several elements require careful consideration: it is essential to select the pilot project judiciously; to ensure the guidelines and framework accommodate intrinsic differences between pilot and full-scale implementations; and to plan for the organization's capability to scale to the full solution efficiently. A recent analysis, based on the experience of 44 pilot automation applications, identified those with the highest business potential together with the principal challenges associated with smart automation—and the strategies companies can adopt to overcome them. An established framework outlines the guidelines for planning and executing smart automation initiatives in manufacturing.

5.5. Challenges in Smart Automation

A complex network of challenges awaits industries that set out on their smart automation journey. Overcoming the main issues requires two key ingredients—focus and self-awareness. An organisation needs to make deliberate choices about where, why, and how smart automation capabilities can be best used, and then deploy them accordingly. Thanks to mistakes, failures, and lessons learned the hard way, the challenges and working principles of successful smart automation solutions are relatively well understood; however, awareness of the self that is trying to automate remains a rarely explored area.

A smart automation solution working on behalf of an organisation is eventually expected to deliver some sort of value—a fact that seems self-evident. However, what is not as trivial is the definition of such a value. Taking the task a step further, the outcome of the smart automation solution itself should be to define or predict the value that will be delivered.

5.5.1. Data Security and Privacy

The implementation of Industry 4.0 demands an extensive communication and data exchange framework. This exchange must be secured using cryptographic algorithms for confidentiality, integrity, and data origin authentication. Industry 4.0 also facilitates new production modes and business models through the transparency and traceability of

enterprise data. However, cybercrime becomes more dangerous as companies rely heavily on information technology, including automation and communications.

Blockchain technology secures transactions in Industry 4.0 by employing cryptography, distributed ledgers, and decentralization. Its implementation through smart contracts requires overcoming issues. Security-by-design principles must be applied to design and prototype new Blockchain Technology Nodes (BTNs) based on widely used technologies like the Ethereum smart contract development framework. Parse-oriented framework models must document the entire smart contract production phase through Cyber-Physical Systems (CPS). Each event in this phase, combined with aggregated features, should be encapsulated into a transaction and committed to a designated Ethereum ledger address.

5.5.2. Integration with Legacy Systems

Smart automation frameworks enable seamless integration of modern systems with legacy devices. Industrial automation is an extensively used discipline that offers products for automating processes and machines [2,8-10]. It possesses much value addition, improves the overall performance of operations, and enhances overall efficiency by reducing production time, efforts, and risk. Although trends have evolved toward digital transformation, the world still relies on old infrastructure and devices in many industries. With rising challenges and increased need, these legacy systems require upgrades that can be achieved through the support of modern IoT sensing nodes. The smart automation system consists of various IoT sensors associated with a controller that connects with machines for data collection and controller operations. These controllers are linked with a cloud server, management systems, and user interface support.

The use of IoT for such integrations ensures smoother automations and improved security. Benefits of IoT-enabled automation offered for legacy systems can satisfy the buyer with efficient automation and real-time monitoring of processes and production. Industry 4.0 provides a vision for smart factories where information and data can be collected from devices that are already connected to a network; however, the complete use of this information for decision-making is often neglected due to a lack of strong integration between legacy machines and personnel. TechTest helps companies understand how to turn their 1.0 or 2.0 factories into smart factories through their operational heritage. Conventional testing might have a significant impact on company operations, and the voluntary testing of legacy machines and devices using TechTest provides the right insight on enhancing testing processes according to upcoming Industry 4.0 initiatives.

5.5.3. Workforce Skills Gap

Industry 4.0 introduces increased complexity in manufacturing systems, entailing a skills gap in the workforce as many technical tasks transition toward cognitive processes such as design, setup, programming, and maintenance while routine tasks become automated. Integrating smartphones and smart applications into Industry 4.0 systems has the potential to mitigate this skills gap, opening new development avenues. The intersection of Industrial Internet of Things (IIoT) with Industry 4.0 services and Smart Human-Machine Interfaces (SHMIs) can foster more versatile smart operation management solutions.

Contemporary Manufacturing Execution Systems (MESs), although largely operational and resource management solutions, cover areas including product lifecycle management, production planning, and quality management. This comprehensive approach leads to extensive and complex solutions that can overwhelm the operating staff. There is an opportunity to develop simplified, self-contained smart applications focused on specific functional areas, deployable Northbound in the Automation Pyramid, and accessible by mainshop operators through their smartphones.

5.6. Future Trends in Automation

Automation represents a prerequisite for higher-quality production processes and for mastering the increasing complexity of products and the demands of customers. The future will see an increase in intelligent automation. Key areas of development include low-code–no-code platforms, industrial AI, intelligent decision support systems, and the full integration of process variables in production automation.

Low-code and no-code platforms enable customers without programming skills to configure robots, machines, and (manufacturing) devices themselves, supporting them in quickly setting up production for special orders. Industrial AI will automate the creation and validation of product control and process models. Digital twins of products and production processes will form the foundation as simulators for the AI training process. Intelligent decision support systems will assist change managers in making appropriate decisions while considering long-term perspectives, current processes, company resources, and market requirements. The integration of quality control parameters with automation of the production process will pave the way for fully automated production.

5.6.1. Edge Computing

Edge computing comprises a distributed computing paradigm, enabling data processing and analytics closer to users or data sources. This approach mitigates bandwidth demands and data processing latency, optimizing overall system performance. It is commonly employed in applications necessitating real-time data analysis or ultra-low latency, such as self-driving cars, automated traffic control, smart power grids, and remote medical analysis.

However, edge devices face three key limitations. First, in terms of physical scope, their limited computation and storage capacities constrain the geographical coverage of services they can support. Second, scalability issues may arise, as edge devices designed for specific tasks might not efficiently expand to fulfill all system requirements. Third, system complexity intensifies when scaling up with additional edge nodes, necessitating increased maintenance efforts. These limitations must be carefully considered when designing an edge computing infrastructure. Edge computing can be integrated with fog or cloud concepts, each bearing different operational roles and interrelations. The Intelligent Edge Architecture, developed for Industry 4.0 applications, capitalizes on these ideas by incorporating five distinct layers: cloud layer, fog layer, edge layer, actuators and sensors, and physical space.



Fig 5 . 3 : Edge Computing: Architecture, Benefits, and Limitations

5.6.2. Blockchain Technology

Blockchain is a distributed database shared among the nodes of a computer network. The database stores information electronically in digital format. The main features of blockchain are decentralisation, transparency, traceability, immutability, and security.

Blockchain technology can be described as a community of digital participants, with certain rights and responsibilities to verify, validate, record, and safeguard the transactions in the database. It aims to produce a consensus. Transactions are mutually agreed upon by participants, and the agreed-upon transactions are recorded in the blocks. The blocks are then linked in a chronological order, which makes the database traceable.

A block is a collection of digital transactions occurring within a specified time interval. The transactions can represent interactions among humans, machines, devices, automata, and their networks. Almost all digital transactions involve an exchange of information and service controls, often accompanied by an exchange of money too. The exchanged money is used to buy or sell a service or a product during a digital transaction. Blockchain technology can be understood as a backup for fail-safe digital transactions. It helps to protect the identity of the transacting agents, ensuring credible, traceable verification and validation. Blockchain is the backbone of cryptocurrencies, smart contracts, storing and processing sensitive information, digital voting, digital signatures, and e-governance.

5.6.3. Collaborative Robots (Cobots)

During the COVID-19 pandemic, the role of collaborative robots (cobots) in human-centric manufacturing gained further prominence. Cobots derive their widespread appeal from their ability to assist humans in a variety of manufacturing contexts. Unlike traditional industrial robots — usually caged for human safety — in Industry 5.0, the human assumes a greater role, deemed in charge of the complex, high-level, non-repetitive activities within a production system. The cobot complements humans by executing routine, laborious, repetitive activities. Moreover, the modern cobot can safely work side-by-side or cooperate directly with humans, equipped with a variety of sensors and sophisticated high-level control methods. Their flexible and adaptive nature facilitates rapid re-deployment to suit diverse goals and applications. Although traditionally limited to relatively simple tasks, cobots' sensing and AI faculties are advancing rapidly.

5.7. Economic Impact of Industry 4.0

Through Industry 4.0, the connection between automation and industry is becoming more tangible than ever. The points of the processes with the highest level of automation continue to be constantly improved and refined. More importantly, they are now connected to other processes with the help of a digital framework. This offers advantages for both the automation of a specific task and for other processes through the support of Industry 4.0. Often, together with many other benefits, the positive effect on various

economies is highlighted. However, the improving effect of automation alone on economic growth has always been a matter of controversy.

Previous research has shown that the improvement of the labor force through automation does not inherently improve the working population's wages. Rather, the economic growth due to automation is distributed unevenly and belongs mostly to the owners of industrial capital. Consequently, if the current level of automation in the economy increases further with the support of Industry 4.0, then the pace of economic growth will increase. But then, the growth of wages and employment may not follow because economic benefits will be owned primarily by the capital owners instead of the employees. Therefore, in the future, while automating specific systems with the support of Industry 4.0 and beyond, it is important to consider this potential economic effect on corresponding economies.

5.7.1. Cost-Benefit Analysis

Industry 4.0 promises the transformation of manufacturing operations into a smart industry with collaborative and smart operations. However, realizing that opportunity requires more than deploying an application. Instead, enterprises must have the right plans, processes, partners, people, tools, and technologies all aligned and acting in support of their transformation objectives.

Smart automation frameworks provide abstraction for the development lifecycle of smart applications. The concept of Smart Automation Frameworks is coined to facilitate Industry 4.0 implementation. The choice of deployment model influences the cost of developing a smart application. Based on the capital expenditure for hardware and software and operational expenditure, the cost of different deployment models is calculated. Both the cost and profit of the implementation of a smart automation system vary from industry to industry. Therefore, for any industry, a cost-benefit analysis is mandatory before implementing any solution. Projections from exploratory case studies help any organization decide on an optimal deployment model before beginning development.

5.7.2. Return on Investment (ROI)

Industry 4.0 (Smart Factories), Industry 5.0 (Human-Centric), and Industry 6.0 (Sustainable) are concepts introduced by Smart Automation Frameworks (SAFs) for planning and engineering of smart factories capable of self-configuration, self-optimization, self-diagnosis, and cognitive automation, and also with safe operation in the same environment as humans. The SAF's Cyber-Physical Systems (CPSs) contain

integrated engineered digital twins for the factory, physical assets, production system processes, and structured engineering knowledge and experience, all of which conform precisely to the physical reality. Production scheduling provides a decision support system and ensures realistic production plans. The concepts prevent time-consuming abortive actions, warranty costs, and loss of brand reputation.

Smart Automation Frameworks (SAFs) provide three ROI (Return On Investment) calculations, as follows:

- Investment Benefits – investment and operating cost savings that will be realized from implementing future factory enhancements, and also from avoidance and reduction of warranty costs
- Schedule Benefits – cost avoidance realized from the rapid provision of a realistic schedule, together with the minimum expected delay associated with meeting the schedule
- Operational Benefits – financial benefits derived from the capability of a smart factory to self-configure, self-optimize, and self-diagnose during operations. A smart factory operating configuration is a network of heterogeneous interconnected resources, including digital manufacturing flows and predictive maintenance.

5.8. Conclusion

With all the benefits Industry 4.0 has to offer, there are still many challenges to be tackled. As time goes on, the areas are becoming smarter with newer technologies, and

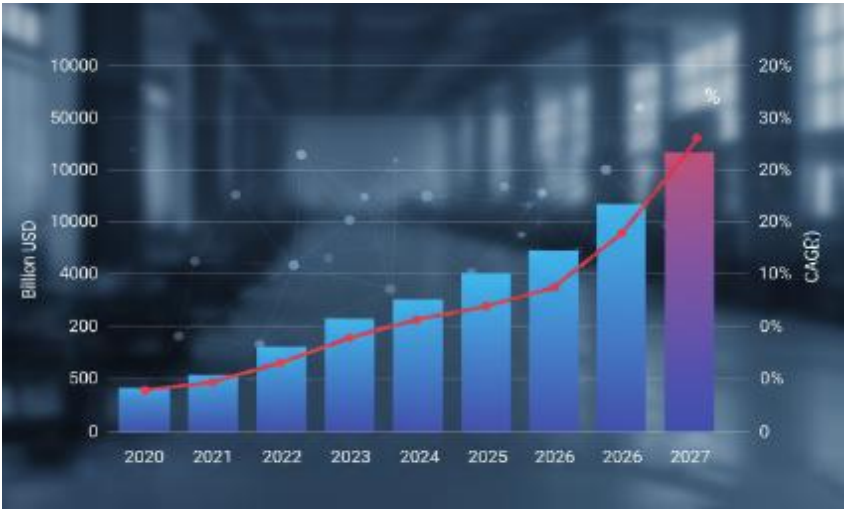


Fig 5 . 4 : Industry 4.0 Market Size

the trade-off area between these technologies can be used to solve the problems of individual technologies. In the Industry 5.0 guiding principles, the use of biological data for decision-making can be helpful. People want automation that will help them, not replace them. Subsidiarity suggests the use of human intelligence and decision-making on the higher level of automation whenever it is difficult for humans to make a decision. When the industry, therefore, tries to make the process smart in such a way that it fulfills all these demands, many new frameworks will be developed for optimization in one domain and to address trade-off optimization in others.

5.8.1. Economic Evaluation and Financial Implications

Traditionally, manufacturers have focused on the economic evaluation of combined investments in multiple machines with identical functions. Recent trends address the problem of specifying how to combine multiple machines with either an identical or different function by selecting different production capacity options. A methodology enables a manufacturer to determine the best means of satisfying a specific functional requirement when it is necessary to create functional support from two or more assets. The methodology focuses on the Generation of Production Functions from the Combination of Multiple Production Assets, considering three main objectives: minimizing the investment cost, maximizing availability, and minimizing the time required to produce a given batch of parts in a production operating budget.

Making investment decisions in manufacturing system automation is a complex task and carries a significant degree of risk for companies. Automation of manufacturing processes can directly impact terminal costs and, consequently, the selling price. Therefore, it is essential to check the automation level and the economic impact of the automation process.

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