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Chapter 11: Accelerating the adoption of industry 4.0 with intelligent manufacturing and IoT-integrated systems

11.1. Introduction

Industry 4.0 (I4.0) is a term first introduced in 2011 at the Hanover Fair and selectively adopted by other countries to promote various programs to modernize their manufacturing industries around integrated vertical and horizontal services. Germany's program to implement a smart factory included the following goals for the factories converting to Industry 4.0, including the development of Cyber-Physical Systems, Internet of Things, reusable, self-configurable units, Artificial Intelligence/machine learning, big data, and a functional ecosystem for SMEs. Other I4.0 initiatives include various programs from China, the US, Korea, Singapore, and Japan, for example, the National Network for Manufacturing Innovation. Since those initial discussions, I4.0 comprises the deep penetration of automation in all sectors of manufacturing, creating intelligent operations that are digitally connected and integrated horizontally (between enterprises and suppliers) and vertically (between all levels of operations in the enterprise, linked to the supply chain and the market). The time span from autonomous robots, 3D printing, and automation to a digital supply chain with augmented reality, artificial Intelligence, blockchain, big data analytics, IIoT, modeling, simulation, and high-level integration has gone from a few decades to deep concerns and pains about labor replacement and what do digital workers do, especially since the pandemic of 2020. Discussions include a rework of the social contracts that allow these changes to happen, so we do not end up with the work of the lower-skilled (Gilchrist, 2016; Kang et al., 2016; Liao et al., 2017).

But how do we accelerate the pace of adoption? The obvious answer is that it’s in the tools that we develop and the way we integrate them, especially with cloud-based tools that we are all getting used to through our phones and tablet interfaces; the development of cloud computing that allows SMEs to access tools previously relegated to multi-national companies. But it’s also that Industry 4.0 is not just about industrialization and manufacturing, but that there is a transformation going on in every major service sector as well: those tools are platforms and ecosystems supported by milestones that show how to move forward (Xu et al., 2018; Wan et al., 2020).

11.1.1. Overview of the Industry 4.0 Paradigm

This paper presents a review of the issues, trends, challenges, and opportunities behind the concept, applications, and relevance of Industry 4.0, Intelligent Manufacturing and IoT-Integrated Systems, Intelligent Cybersecurity for Industry 4.0 Systems, I4 Enabled Organizations, and Networks of Intelligent Cyber-Physical Systems, and Organizations as Applied to Production, Logistics, and the Management of Supply Chains. The contribution and relevance of this research field may help meet the challenges behind the adoption of Intelligent Cyber-Physical Integrated Manufacturing Systems, address the limitations and obstacles in the way of the Cyber-Physical Integrated Systems' development and deployment, and promote the advancement of Cyber-Physical Integrated Manufacturing Systems' intelligentization towards the future.

Fig 11 . 1 : Industry 4.0 and Intelligent Manufacturing Systems

Industry 4.0 is widely recognized as the Fourth Industrial Revolution, the next-generation digital factory, denoting the trend of ongoing automation and data exchange in manufacturing technologies and processes aided by Smart and Intelligent Cyber-Physical Industry Systems. Some other labels, such as Cyber-Physical Integrated Manufacturing Systems, Intelligent Cyber-Physical Integrated Manufacturing Systems, Intelligent Cyber-Physical Systems, Intelligent Cyber-Physical Distributed Manufacturing Systems, Interconnected and Intelligent Cyber-Physical Systems, are also commonly used to reference the same automation trend and applicable technologies. The rise of Intelligent Cyber-Physical Integrated Systems is being driven by the implementation of Smart and Intelligent Devices connected over networks, enabling the creation of systems of systems and use cases for Smart Cities, Smart Buildings, Smart Mobility, Smart and Integrated Supply Chains, Cyber-Physical Integrated Logistics and Manufacturing Systems.

11.2. Understanding Industry 4.0

1. Definition and Key Features

Industry 4.0 is a distinct paradigm of the intentional and controlled digital transformation and smartization of industrial systems. The vision of Industry 4.0 is that of a new generation of internet-connected smart manufacturing systems integrated with other intelligent systems deployed across the economy. These smart systems are capable of adapting to different and changing conditions in real-time and at different levels - including self-optimizing, self-dispatching, self-reconfiguring, and self-healing - as a result of their enhancements with high levels of embedded and external real-time intelligence.

The main distinctive feature of Industry 4.0 is the unprecedented integration and correlation of autonomous decisions and actions performed by interconnected industrial systems, people, and things in relation to global operational goals. This level of correlation is possible due to the combination of three enabling elements of Industry 4.0: the availability of Big Data and advanced data analytics, the Internet of Things and Services, and the maturity of intelligent, autonomous, and cooperative systems. The intelligent connected systems vision is based on a unique perspective of Industry 4.0, as it views smart systems and their intelligent integration on a global scale as key components of the new industrial paradigm.

2. Historical Context and Evolution

The term Fourth Industrial Revolution was popularized by emphasizing the impact of digital technologies on the business model of a broader number of industries, moving from manufacturing to other industries as well as into government and services activities and processes. While earlier Industrial Revolutions were characterized by the evolution of production technologies, the Fourth is anchored in fast and unprecedented changes of the relations among companies and between companies and citizens.

11.2.1. Definition and Key Features

Industry 4.0 refers to a fourth industrial revolution that is attained thanks to its advanced technology infrastructure, based on a digital, cybernetic, and intelligent representation of the factory, the logistics, and the supply chain, with the digital twin as the principal new computational instrument. It is expected that with this new technological infrastructure, beside the adequate management, companies will reach the next level of operational excellence with a much deeper integration between the physical and the digital worlds result of the use of the Internet of Things, Big Data Analytics, Artificial Intelligence, and Cyber-Physical Systems. Through this technological integration, the typical industry-related KPIs, e.g., lead time, throughput time, utilization, OEE, flexibility, and delivery, will be achieved at a performance level never attained previously, driving the digital transformation of the industry, that will directly impact the sustainable development of the society.

The Industry 4.0 paradigm is defined from the union of a set of technological and organizational advancements. Some of the key enabling technologies of Industry 4.0 are: an advanced automation, with Cyber-Physical Systems being the mechanical components able of processing real-time data through the use of Sensory Systems, becoming more intelligent and able to partially or completely replace human workers; the Internet of Things, being the network connecting all these Cyber-Physical Systems, able of sharing data for real-time awareness and decision making; Digital Twin, the digital representation of things, people, machines, systems, processes, and products employed to simulate, predict, and control their behavior; Big Data, that allows tremendous amount of data in a distributed way; Artificial Intelligence, that drives the intelligence and automation of systems through Machine Learning algorithms; Collaborative Work, that ables the use of Cyber-Physical Systems to share information and collaborate with human workers in manufacturing, logistics, and supply chain operations, operations that are carried out by human workers and machines together.

11.2.2. Historical Context and Evolution

The advent of the Fourth Industrial Revolution (Industry 4.0) follows on from three key prior developments. The development of steam power made it possible to mechanize some tasks, thereby driving the original Industrial Revolution. The Second Industrial Revolution, at the end of the 19th Century, built on the foundation of mechanization by introducing electricity and the new forms of communication it enabled, leading to the mass production of goods within factories. Further development of communications technology in particular during the last half of the 20th Century ushered in a Third Industrial Revolution based on the principles of industrial automation, information technology and data exchange: cyber-physical systems have been widely adopted within factories for this purpose, especially for tasks requiring precision and speed.

Industry 4.0 builds on the foundations of the Third Industrial Revolution but goes much further. Businesses are going beyond the implementation of automation in small well-defined sectors of production, to consider the entire product life cycle. Greater human involvement is envisioned during the design, production, configuration, use, and decommissioning phases in order to better meet customers requirements and to reduce costs. More sophisticated cyber-physical systems are proposed, integrated across functions and vertically integrated from the factory floor to the enterprise decision makers, using the principles of the Internet of Things. Greater benefits are predicted to result from this approach in sectors as diverse as process and discrete manufacturing, healthcare, energy, and basic materials.

11.3. Intelligent Manufacturing

Recent decades have seen huge improvements in technologies surrounding factories and manufacturing, capable of enabling incrementally enhanced digitalization, connectivity, speed and intelligent enhance capabilities to many increasingly complex and varied products. Intelligent manufacturing leverages such capabilities through the generation of connected, adaptive, autonomous and smart factories. Intelligent manufacturing is broader than the majority of frameworks in that it focuses on the use of advanced technology to achieve significant economic, environmental and societal value at the system-wide level. It covers all aspects of manufacturing organizations, from their strategic vision at the top, through their leadership, employees, customers, partners and suppliers, to their specific goals for Factory Operations, Digital Technology, Enterprise and Market domain capabilities, and Environmental Sustainability. Moreover, it also deals with the enabling technologies like Artificial Intelligence, Internet of Things, Big Data, Robotic Process Automation, Cloud Computing, Cyber-Physical Systems, Additive Manufacturing, and Augmented Reality.

However, from our experience in working with factories of all shapes and sizes, which represent a collective shared economic wealth in the trillions of dollars, involving nearly 20 million employees in the United States and 400 million worldwide, we are concerned that the term of intelligent manufacturing initiation would face a challenging path toward the realization of full potential. Thorough clearly warranted and well-studied development framework would be required in order to make this transition enabling factors drive sustainable competitive advantage while also serving the economic, environmental, and societal priorities and concerns on top of many organizations. In this sense, intelligent factories are a leap in terms of expectations relative to today’s smart factories.

11.3.1. Concept and Importance

In the façade of economic recession, social challenges and sustainability, Industry 4.0 integrated with Industrial Internet of Things has become a hot issue in both academia and industry. As a core enabling technology of Industry 4.0, intelligent manufacturing, which pursues a paradigm shift from traditional manufacturing to new manufacturing with functional intensity, sustainability, and human-centered element, has been profoundly advanced in recent years. With a growing shortage of skilled labor, declining productivity and cost increase, how to accelerate the adoption of intelligent manufacturing is an urgent issue for both government and industry. This chapter aims to deliver a comprehensive understanding for IIoT integrated intelligent manufacturing by first clarifying the concept and importance of intelligent manufacturing and providing a parallel comparison with traditional manufacturing, some noteworthy surveying endeavors, challenges and obstacles in the path of intelligent manufacturing adoption.

Intelligent manufacturing has gained increasing attention in both academia and industry, especially since it was highlighted in various national manufacturing strategies and funding programs. The concept of intelligent manufacturing is different from "smart manufacturing." Smart manufacturing is referred to the establishment of a manufacturing model to develop a cyber-physical system with intelligence. Intelligent manufacturing focuses on the shift of manufacturing paradigm to meet the social and economic objectives in a more integrated way. With low-cost sensors and near-zero-cost communication, IIoT enabled intelligent manufacturing is able to functionalize any physical object in manufacturing, such as machines, products, and people, creating a networked manufacturing environment. The exploration of how sensors and connectivity can facilitate the secure and collaborative communication and interaction between both physical and virtual spaces in an integrated manner is recently being investigated by several researchers.

11.3.2. Technological Innovations

The recent trends witnessed in regard to the technological advancement seeking innovations such as Industry 4.0 demand are reinforced by investments in advanced manufacturing technology, smart factories, intelligent network systems, advanced human–robot collaboration, manufacturing IoT-enabled systems, big-data analytics, real-time monitoring, augmented reality, and nanotechnology-based design, which are capable of improving product quality, industrial productivity, workforce efficiency and safety, and environmental performances or sustainability. These key technical factors and hard issues in I4.0 represent a significant leap forward that could represent a cornerstone for the vision of next-generation advanced manufacturing. The contribution of the emerging digital technologies and the vision of the new advanced manufacturing paradigm, intelligent manufacturing, in particular, are strategically important for developing next-gen innovative I4.0 systems. Digital transformation initiatives are made possible by the emergence of major tech trends and technological enablers that represent the pillars at the base of I4.0, such as cloud computing and storage, robotics and automation, artificial intelligence and machine learning, digital twins, big-data analytics and streaming analytic, IoT and Cyber-physical system, security, distributed ledgers, AR, VR and graphics, social media, and 5G. Accordingly, tech trends along with the enablers can accelerate the digital transformation of business actors through the fast-paced adoption of I4.0 and digital manufacturing technologies, as well as Industry 4.0 solutions.

Technological innovations allow the digital transformation of manufacturing firms by enhancing the functionalities and capabilities of their plants and production systems. Consequently, the advanced sensors, control technologies, and intelligent software applications allowing the pervasive networking and monitoring of intra- and extra-firm manufacturing flows enable the fulfillment of increasing levels of complexity in terms of product features and performances. Intelligent manufacturing also allows an improvement in the manufacturing performance, through the introduction of a new generation of optimization methods and of advanced monitoring, simulation, and analytics models.

11.3.3. Case Studies of Intelligent Manufacturing

Throughout the chapters of this work, we discuss innovative solutions towards intelligent manufacturing, following the strategic initiative of "Smart, Connected Processes", which is a solution for the manufacturing industry, exploring specific technological innovations to enable intelligent manufacturing, particularly in terms of data-driven decisions. In this section, we present several case studies related to companies that have already developed intelligent manufacturing solutions and implemented them besides the theorized models. Such examples involve some third-party solutions and implementation partners.

In this sense, we present an example with a global specialist in energy management and automation boasting 159,000 employees in over 100 countries that achieved its greatest growth in Europe. The company has deployed about 3,700 connected products, including variable speed drives, circuit breakers, and soft-starter motors, at 73 factories worldwide, which account for around 65% of production. The company has also consolidated its core ERP, IoT platform, and energy management systems into one centralized platform.

Another manufacturer of agricultural, construction, and forestry machinery and diesel engines has implemented its Intelligent Solutions Group technology to promote intelligent manufacturing with the provision of sensors in telematic devices for making smart decisions. The company currently employs 57,515 people, 60% more than it did a decade ago. It produces a broad range of equipment to serve customers engaged in agriculture and turf-related tasks, which includes equipment for ground preparation, planting, cultivating, harvesting, and other farming activities, providing connectivity through telematic devices as well as sensors to offer equipment monitoring suitable for businessmen engaged in agricultural and turf-related tasks. The company also manufactures providing finance associated with its sales of equipment and the sales of replacement parts, as well as extended warranties.

11.4. The Role of IoT in Industry 4.0

1. IoT Fundamentals

The term Internet of Things (IoT) describes an infrastructure connecting physical objects that are uniquely identifiable and capable of sensing, and interacting with their internal states and external environments, to the Internet and/or to each other. Data can then be made available to various applications that use the data to analyze events that are happening to those objects in near real time, allowing enterprises to predict and respond to changes in those events that may affect their core business. While the concept sought primarily to make it easier for consumer-oriented applications to operate efficiently, the vision of the IoT as an integrated part of the Internet delivery architecture is being referred as the Industrial Internet and its extension that refers specifically to the industrial sector as the Industrial Internet of Things (IIoT). The potential economic value of IoT- and IIoT-enabled applications for Industry 4.0 is massive.

2. Integration with Manufacturing Systems

Intelligent manufacturing systems will seamlessly integrate IoT-enabled assets with manufacturing and operational processes, create responsive linkages between the business side of organizations and their manufacturing and supply chain operations processes, and form complementary relationships between suppliers, partners, and customers enabled by the IoT and their intelligent manufacturing systems. Because of the vast range of products, processes, and business models that comprise the manufacturing sector in advanced economies and around the world, there will not be a silver bullet that provides the common underpinning for all IoT-enabled applications within bilingual intelligent manufacturing and IoT-integrated systems. The applications will fall along a spectrum ranging from special-purpose applications that provide incremental improvements in efficiency and productivity, time-to-market, and asset utilization at specific points in specially-defined manufacturing processes to comprehensive applications that draw, integrate, analyze, and act upon massive amounts of data from potentially thousands of sensors embedded in and networks built around systems that encompass entire organizations.

11.4.1. IoT Fundamentals

The Internet of Things (IoT) refers to the connectivity of devices and systems through communication technologies, enabling interactive exchanges of data and services using shared protocols and the internet. Offering local processing and data storage, the edge level of the IoT enacts artificial intelligence, machine learning, and advanced decision-making capabilities through intelligent manufacturing systems. As a transformative catalyst for cross-domain optimization through business model innovation, the IoT has been hailed as an enabler of four Industrial Revolution by offering horizontal and vertical integration of the manufacturing sector via cyber-physical systems. The basic features of the Industry 4.0 IoT include service-centricity, game-changer sensing and connectivity, cloud-level computing, big data and analytics, and intelligent response and automation. Bridging the virtual world of the internet and the physical world of the manufacturing and service processes, the Industry 4.0 IoT offers a cyber-physical continuum for the interoperable, collaborative, generalized, transparent, flexible, and economically viable designs of smart factories. Establishing interoperability, end-to-end transparency, decentralized decision-making, cyber-physical behavior, and resilience for intelligent manufacturing, the Industry 4.0 IoT enhances customer experience and expectation, product and service customization, operational efficiency, agility and flexibility, product quality, resiliency, and safety across the manufacturing value chain. With a promising set of market and technological realities, it is validated through a matrix of business readiness, technology level, return on investment, and scale intensity. Based on standardized and modularized infrastructure, manufacturing service networks and platforms offer an economy of scale for rapid growth across industries and sectors. With far-reaching implications for the design, structure, logistics, products, processes, services, safety, sustainability, and strategy of manufacturing, Industry 4.0 IoT is a complex socio-technical ecosystem involving a wide range of stakeholders across the innovation value chain. As both a disruptive and necessity facilitator for the transformation of manufacturing, it needs the holistic and integrated systems view.

11.4.2. Integration with Manufacturing Systems

The IoT is a key enabling technology for Industry 4.0, bringing in new capabilities for intelligence that transform the way manufacturing industries operate. While IoT concepts originally emerged from applications in other diverse domains, such as smart buildings and cities, automotive, and healthcare, their impact in Industry 4.0 is becoming crucial. The IoT is transforming manufacturing systems into smart factories, by enhancing operational visibility, enabling real-time interaction between cyber and physical domains, and closing the loop with built-in smart production capabilities. These enhancements to smart factories are being achieved through advanced monitoring and management of products, assets, and processes.

However, the concept of IoT within the manufacturing context is not a triviality that simply refers to product, machine, or other element connectivity. An important difference lies in the level of intelligence and the purpose of such connectivity. The IoT within the manufacturing context is about embedding enough intelligence so that devices, such as machines, instruments, and in-process products can seamlessly and autonomously communicate information, take actions, and make decisions when interacting with one another towards achieving a common goal: efficient operation of the smart factory. It is the level of intelligence enabled by the proper integration of IoT devices and systems together with other relevant general-purpose technologies, such as advanced instrumentation, collaborative robotics, and artificial intelligence that defines the value proposition of an IoT Integrated System for manufacturing.

11.4.3. Data Management and Analytics

Data management and analytics enable IoT-enabled systems to leverage the data that they gather. IoT devices and systems collect a variety of manufacturing and business-relevant data through a combination of sensors, on-board processing and filtering, and routing of larger data sets to the cloud and/or edge. The major types of data include sensor data on machine and machine environmental conditions, and business data regarding the activities of the business units that are linked with the operation of the machines, such as material flows, throughput levels, and qualification parameters. To be truly useful for intelligent manufacturing, machine data need to be aligned and reconciled with the data coming from the business-unit and enterprise-level systems. Further, because the system and business data are often unstructured and contain noise and outliers, they require various filtering and preprocessing techniques before they can be analyzed for diagnostic, predictive, and prescriptive purposes.

While focused mostly on data interpretation in a business context, the discussion also alludes to the techniques and processes used to produce the data needed for accurate intelligent manufacturing. These data usually include actual machine performance parameters as well as process parameters, along with unit costs or times for units being processed. They emphasize the importance of high data quality from the IoT systems in order to support efficient management.

11.5. Challenges in Adoption

As Industry 4.0 technologies start growing in importance for manufacturing organizations it is important to be aware of the potential roadblocks in adoption so that these can be mitigated against. While Industry 4.0 Systems have the potential to bring considerable benefits and advantages, organizations should have a clear understanding of these roadblocks and prepare and execute strategies to overcome them – especially in the early days of using these technologies when the payback times may be longer than with traditional manufacturing systems. Therefore, in this section we describe some of the challenges in adopting Intelligent Manufacturing Systems that have been mentioned by various organizations.

Industry 4.0 technologies are rapidly maturing which leads to fairly short technology adoption lifecycles. However, some Industry 4.0 technologies are not yet at the "Crossing the Chasm" phase which means that some technologies have limited market maturity. Many companies have also expressed concerns about technology readiness and reliability of IT and product modules needed for the implementation. Specifically, companies are worried about data management and storage, as well as the cybersecurity aspects of systems and associated modules that use Cloud Computing – major requirements for Industry 4.0. The training of employees to gather and process data is also a critical concern in Industry 4.0. Employees may be resistant to adoption of Industry 4.0 Systems, particularly job losses related to automation.

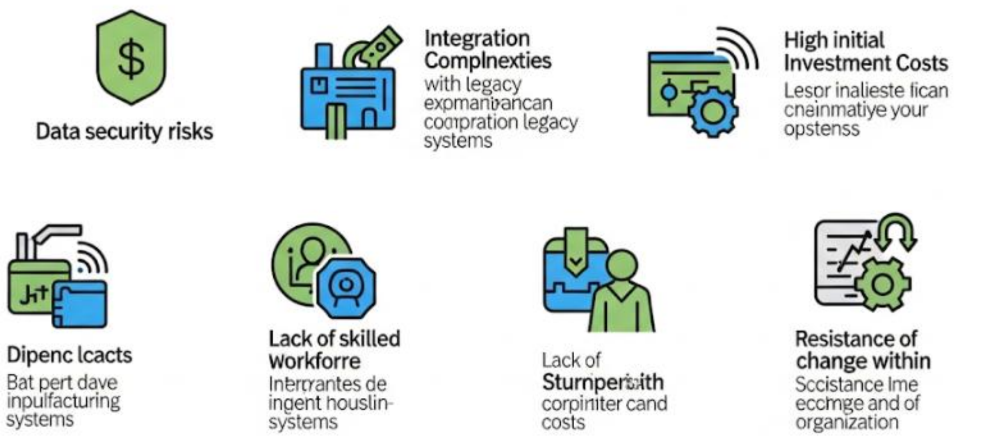

Fig 11 . 2 : Challenges in Adopting Intelligent Manufacturing Systems

A significant part of the current manufacturing workforce in many companies consists of aging workers. Additional concerns have also been expressed about how to introduce new technology-driven manufacturing processes while at the same time nurturing and maintaining the knowledge and skills resource of legacy workers. There are natural concerns from companies of whether they will get the expected return on investment from their Industry 4.0 investments. Industry 4.0 investments can be considerable and time-consuming, and many manufacturers are often reluctant to experiment or make changes to their systems until they see real benefits being gained from those who have gone before them.

11.5.1. Technological Barriers

The recent development and interest in cyber-physical systems, such as IoT technology, promote interconnectivity, intelligence and automation in the manufacturing system. These developments and trends change the technological focus of manufacturing approaches. The primary focus area is helping manufacturers identify and eliminate current roadblocks. Industry-leaders identified workforce development, security and privacy, industry standards, and existing information technology and architecture as major challenges facing first adopters. For the successful deployment of Intelligent Manufacturing with IoT-integrated systems, potential application developers, operating companies and service providers of the Target Market need to overcome these technological challenges.

An initial challenge that confronts the advancement of machine learning in IoT-integrated systems is the lack of ML expertise. This challenge is urgent considering the staggering demand and supply gap for top analytics talent. The gap extends to the rest of IoT, for which the demand for more than 4 million workers over the next decade potentially greatly exceeds the current pool of experts, and potential increases in education capacity. Second, cybersecurity risk overwhelms many firms attempting to innovate with IoT now at dangerous levels in some sectors and far exceed any previous historical cybersecurity risk levels. Cybersecurity for IoT is considered especially concerning, in part because justice and security acquisition budgets may fail to keep up with the growing vulnerability caused by massive IoT investments for smart cities, transportation, utilities, and buildings. Indeed, IoT security is so nascent that properly securing cities, utilities, and transportation may require new principles, new firms, and possibly even new business models. This accelerates the magnitude of the focus on expanding education capacity – namely, training programs aimed at embedding security considerations, and the best practices included in IoT frameworks, across the lifecycle development within organizations that seek to adopt IoT.

11.5.2. Cultural Resistance

A considerable factor in the limitation of technology acceptance is indeed cultural resistance to change, especially in an industrial domain. The drive for continuous improvement and to increase competitiveness has been the stronghold characteristics and culture in manufacturing for decades. Nonetheless, the infusion and push for Industry 4.0 and digital transformation initiatives comprise an imperative shift from simple and local improvements to systemic changes and impact. Transformation to intelligent enterprise cannot succeed only with investments in technologies. The traditional view about people as a factor in production systems needs to make a change to people being the core part of intelligent manufacturing. This point cannot be overemphasized. Returning to insights into human motivation, self-actualization and esteem need emerges as paramount importance for the successful implementation of transformation principles. People have to feel that they are part of the intelligent manufacturing initiative and that their contributions through their proximity to products and services are highly valuable. Moreover, they have to perceive that they as educated and trained workers can assume and embrace roles that create synergies and amplify the contributions of machines and systems.

Such value perception can only be fulfilled when the intelligent manufacturing environment is conceived as symbiotic, while symbiotic in our perspective implies a true collaborative partnership at the same standing and equal rank. It is therefore of high import to involve people and workers already during the design and setup processes of intelligent factories and systems. In this community service endeavor, they must perceive their unique value that cannot be substituted by technology. Only once these conditions have been met, will it be feasible and achievable to capitalize on the transformation to intelligent enterprise and Industry 4.0 as such.

11.5.3. Financial Constraints

Adoption of new technologies requires financial resources. SMEs invest a relatively low percentage of their revenues in R&D activities. This constrains their ability to either internally finance their investments in the new technologies or attract the required external financial resources from banks and capital markets. This situation diminishes the potential for performance-enhancement potential and makes the sector less attractive for capital markets. Investments on advanced technologies are normally viewed by financial institutions as being risky, and with a long payback period. Financial institutions are therefore reluctant to provide financing for SMEs to invest in the new capabilities the transformations require. The still relatively low relevant experience that the financial markets have with Industry 4.0 technologies and their advantages or disadvantages over traditional industrial modernization solutions, for instance, de facto preclude access to low-cost capital for relevant transformations. The available capital to support the much-needed investments in advanced production technologies could therefore become an important limiting factor to the necessary transformation, and if transformation does not occur, it could weaken the SMEs over time even more.

The situation is further complicated by the fact that the potential technological advantages for long-term competitive advantages that using advanced technologies could create is, at least in theory, still questioned by a number of influential scholars and managers. Modern advanced technologies could, and many argue that in fact will, lead to more homogenization and convergence of products and services, turning them into commodities. This does, of course, not happen overnight, and it certainly depends on a very large number jointly determined factors. This uncertainty does, however, further add to the risks perceived by financial institutions.

11.6. Strategies for Accelerating Adoption

The strategies discussed in this section offer some insights, but they are not exhaustive. Adopting I4.0 practices and technologies is still a new endeavor for many manufacturers, and research and experiences will no doubt deliver more ways to accelerate adoption. Further, different approaches to similar strategies may be needed for different types of manufacturers, with I4.0 adoption impacts varying greatly by region, country, industry sector, and type of manufacturing firm. For example, there may be more attention needed on ways to accelerate the adoption of I4.0 principles and technologies by manufacturers that are small, vulnerable, or lagging behind in competitiveness. Similarly, government support may need to be directed toward regions and countries with lower productivity, investment rates, GDP per capita, or higher income inequality. Efforts to support or build on industry clusters may receive more attention in some regions. Or there may be a need to place certain types of constraints on productivity and automation technologies by specific labor markets.

Education and Training. The need for educational programs has consistently been cited by both organizations working to accelerate I4.0 adoption and researches as one of the most important initial priorities. Input from which specific programs and skills are most needed for what specific types of manufacturers and what types of skills are only beginning to come available. Programs offered by organizations, universities, consulting firms, vendors, and so forth will no doubt start to fill this gap, with a particular need for adoption support directed toward small to mid-sized manufacturers.

11.6.1. Education and Training

Contents

Industry 4.0 and the Technology Revolution 3.2. Intelligent Manufacturing 3.3. IoT-Integrated Systems 4.1. The Challenge of Lacking Readiness 4.2. Education and Training 5.1. Education 5.2. Partnership 5.3. Government Involvement 6. Strategies for Accelerating Adoption 6.1. Education and Training 6.2. Collaboration and Partnerships 6.3. Government Policies and Support 7. Conclusions

Introduction

Adoption and implementation of I4.0 are important undertakings yet challenging. The discussion in previous sections has highlighted the challenge of lacking readiness with respect to organizational capability by companies in making I4.0 advances, and considering this lack of readiness, there is a need to develop clear pathways for practitioners and managers in realizing I4.0 and optimizing I4.0 benefits. The foundational step for such a clear pathway is a well-planned I4.0 technology education and training framework. The education and training for higher education institutions serving the needs of the industry will position graduates entering the talent pool for I4.0 as being educated during their college years in the fundamental content associated with the I4.0 technologies. In addition, there is also a critical need to create training pathways and programs for existing workforce in specific I4.0 technologies, and who may be in roles and sectors most impacted by technology changes.

11.6.2. Collaboration and Partnerships

Innovation Ecosystems of Companies and Universities. Collaborations with organizations researching advanced technologies that boost performance and reduce costs should be established by companies. Partnerships also lead to infrastructure development. Government support should encourage eco-systems with clusters and develop linkages with domains from knowledge creation, integrated and leading and testing. This would develop mutation partnerships from institutions innovate or ensure co-creating with knowledge of new product models. With respect to innovation partnerships, static dyadic and dynamic-based network innovation partnerships. Encourage conducts that help promote national strategic projects addressing grand challenges. Promote Science and Technology Centers specialized in required knowledge areas for integration. Public contracts may help benefit in principle and make available also a revenue and insurance policy for risk sharing. Research joint ventures are also commonly agreed to face the R&D cost risk. Support from private financial institutions promoting business investment may help promote a project investment subsidy. Partnerships with technology-based public institutions may also help testing of new development proofs at low costs. Local companies can explore their plants for continuous improvements through technological collaborations. Help define normative procedures to promote new companies with technological imbalance to explore parts of product lines. High-tech SMEs with incorporated advance technologies also need support for capitalization in terms of small technology offer. Promote funding from public and private accelerators. Partnership with universities and public research centers from developed countries may help smoothly cutting technological frontiers. Formal methods of knowledge capture with students and professors through a sharing policy with the knowledge provider may help. Companies with needs may help use prototyping by co-funding with employees with specific technological knowledge. Redirect companies toward effective definition specific among suppliers instead guidelines with required competencies in specialized call methods. Redirect cooperation goals minimizing uncertainty along the value chain also impacts the encouragement.

11.6.3. Government Policies and Support

The emergence of next-gen emerging technologies, such as Cyber-Physical Systems and Advanced Manufacturing Technologies, have entirely changed the landscape of manufacturing industry and have established the paradigm shift from Automation to Industry 4.0 and Intelligent Manufacturing Systems. These changing philosophies of manufacturing development have demanded the establishment of new paradigms for directing technology roadmaps and programs that lead towards Intelligent Manufacturing which is one of the main Blocks of the development of 4th Generation factories. The establishment of new paradigms for directing strategy roadmap and implementation programs that lead towards Intelligent Manufacturing Systems capable of providing collaborative and autonomous manufacturing solutions by integrating Services Science, Advanced Internet of Things and Cyber-Physical and Enterprises System technologies is essential.

Many organizations are examining government initiatives for supporting their participation in the implementation of Industry 4.0. Positive supportive government involvement is a key factor for the successful implementation of Industry 4.0. Financial support is considered a major incentive for companies to adopt Industry 4.0 technologies. Several countries have developed programs offering financial incentives for these companies. The US creates a special program for tax incentives to companies that invested in automation technology and that lost productivity. Germany also assembles "Industry 4.0" as a political requirement to boost the use of devices connected to the Internet. Such an important political development is essential because banks and financial institutions are far from adaptable technology companies. The risk of investment in technology such as robots is much higher than other investments while the achievements can federate effort towards the achievement of this vision along with many companies wishing to implement industry 4.0 protocols and standards.

11.7. Future Trends in Industry 4.0

Future trends for Industry 4.0 are powered by rapid advancements in technology and an increasing pressure for companies to innovate and to digitalize their factories. Accelerating advancements in Artificial Intelligence, Automation, Big Data, Cybersecurity, Robotics, Internet of Things, Cloud Computing, etc., are creating whole new possibilities for organizations with the potential to disrupt almost every aspect of how firms operate. Recent advancements in Machine Learning, Deep Learning, Reinforcement Learning, Natural Language Processing, Collaborative Robotic Systems, Autonomous Mobile Robotic Systems, Smart-enabled IoT Sensors, 5G Communication Networks, the Blockchain system, Quantum Computing, Metaverse for Merged Reality, Digital Twins simulation, Cybersecurity Mesh Architecture, Digital Thread construction, Digital Licensing, etc., are some of the new enabling technologies making Industry 4.0 possible.

Organizations must adopt a forward-thinking outlook in order to realize new capabilities created by the above disruptor technologies and new technologies and to exploit the opportunities for societal advancements that are created through breakthroughs in physical and digital systems convergence. The major target of Industry 4.0 is to produce more with less in a sustainable way for society, as such that the new possibilities supported by emerging technologies need to align with the UN Sustainable Development Goals 2030 and the United Nation “21” in order to generate the required positive impact for society. In addition, potential users of Digital Thread 4.0 implementations will engage early on in the establishment of requirements and standards and providing the necessary openness and interoperability to accelerate the transition to a Data-Driven Value Ecosystem. An increasing number of new players engaged in vertical integration strategies for Industry 4.0 new enabling technologies will be expected to support international trade with the necessary focus on sustainability and the job displacement created by emerging technologies.

11.7.1. Emerging Technologies

The rapid evolution of today’s production technologies is driven by, among others, the convergence of smart autonomous systems and advanced digital technologies, such as big data processing and analytics; physical-digital convergence through digital twins enabling improved simulations and emulations of advanced cyberphysical systems; and service-oriented infrastructures integrating cyberphysical systems, sensor networks, edge/cloud computing, and other IoT elements into services addressing different industrial business needs at all levels, from machinery and equipment to factories and supply chains. Intelligent Manufacturing combines these advancements on the technological front as well as on the front of its implementation by means of people, organizations, and processes in order to achieve Smart Manufacturing. Likewise, industrial business model innovation addressing the direct and indirect digitalization of industry is continuously expanding, driven by the need for increasing flexibility and agility in physical production, digitalization of industrial supply chains and services, and support for sustainability of business ecosystems through the provision of original solutions addressing the increasing demand from customers for mass customization lives at the core of Industry 4.0.

Blockchain can enhance traceability, increase confidence in sharing data, and ensure compliance while at the same time maintaining privacy. Cybersecurity is the other side of the coin of digitalization: on the physical side, the advancement of physical security devices and solutions protecting physical assets and resources against attacks is complemented by the usage of digital twins on the digital side for monitoring and safeguarding cyber assets and processes against cyber-attacks. Crowd-based Intelligence aims at leveraging the collective intelligence, knowledge, and resources of communities for supporting intelligent systems in providing solutions for complex tasks and problems. Quasi-autonomous systems relieve humans from handling complex tasks that require continuous attention in a flexible and agile manner while allowing them to restore control to react to unexpected events.

11.7.2. Global Impact and Market Trends

Since the first documented Industry 4.0 project plan was shared in 2011, this strategy for integrating technology into manufacturing, supply chain, and logistics operations to increase flexibility, productivity, and information availability has found advocates across the globe. More than 100 countries have embraced one or more digital transformation strategies, and more than 20 have developed Industry 4.0-specific taxonomies to help frame their approaches. Projects using this integrated approach have been documented around the globe, driving tangible business benefits and broad-based economic development initiatives. The results of these initiatives, led by multinational corporations but replicated by local enterprises, have led to the emergence of a market that is being impacted simultaneously by multiple trends. Worldwide revenues for digital transformation are expected to reach more than US$7 trillion by 2022. A central tenet of the Industry 4.0 framework is to pull these costs up by helping to increase the return on investments made by multinationals and local enterprises alike in adopting Industrial Internet of Things (IIoT)-based solutions. In the U.S. alone, over 3 million companies in the manufacturing sector are being called upon to embark on this transformation journey. In 2019, it was estimated that global corporate spending on advanced manufacturing technologies would grow from US$300 billion to US$520 billion annually by 2025, which equates to spending increasing from around 3–5% of the manufacturing sector's GDP. To put it in perspective, the comparable growth of the digital economy is around 0.4%, or $5 trillion over 10 years.

11.8. Case Studies of Successful Implementation

Real-world applications are the hallmark of academic works in practical domains, such as the one investigated herein. Industry 4.0, Intelligent Systems, and IoT cover huge segments of the manufacturing industry in the modern world. A vast set of reports has examined its adoption, identifying its benefits, lessons learned, models, and updated horizons. These following sections distill the major findings of those reports. Whether the reader is a manager looking for practical inputs to move toward Industry 4.0 and Intelligent Systems, or an academic wishing to uplift his research work with the experience of the field and approaches for its implementation, we sincerely hope that they find in the next sections important inputs to their efforts.

We start with experiences of industrial leaders, coming mostly from reports. Then we present lessons learned by companies that initially failed in their journey toward Industry 4.0. Those lessons are divided into five categories: Choosing the right use-case to initiate the journey, macro challenges that the company should be aware of not only to initial use-case success but also long-term sustainability, micro-challenges that require dedicated attention, IoT integration that is often overlooked and become a hurdle on the long run, and lastly, the importance of security concerning IoT implementations. Then we finish with a summary of main lessons learned and the open way ahead. We end with an overview of ongoing and future work concerning an integrative framework for the implementation of IoT.

11.8.1. Industry Leaders' Experiences

To accelerate the pace of Industry 4.0 adoption among the global manufacturing sector, the academic community needs to investigate successful case studies as well as lessons learned from challenges and failures. This section gathers key Industry 4.0 insights from successful intelligent factory implementations by multinational corporations operating in different sectors and countries. Their experiences reflect the rigorous research and learning efforts behind many of these companies' Industry 4.0 strategies, seen as a necessary realization to continue leveraging the primary great advantage of developing an intelligent factory operating under the Industry 4.0 paradigm: the potential step-up in operational productivity offered through the full-scale integration of Advanced Manufacturing Technologies throughout the entire production function with its interdependencies and interfaces.

The interviewed corporate executives represent multinational corporations with significantly different core products, distinct supply chain configurations, and different geographies and production engineering qualities, firm sizes, and annual revenues, thereby reinforcing the study's main contribution to the literature and practitioners by addressing the need for additional empirical evidence describing the case study analysis and Industry 4.0 pathways associated with the intelligent factory such that domain-specific context is established. To validate whether the Innovation Process Capabilities that bolster innovative ambition actually differ among the core activities pursued at the intelligent factory, this section presents elaborated excerpts systematically analyzing corporate executives' views and insights from the case studies. This is done separately for each of the Innovation Process Capabilities dimensions: Dynamic Capabilities; Incremental Innovation; Radical Innovation; Technology Roadmaps; Innovation Clusters; Knowledge Management; The Organizational Field; Stakeholder Capitalism; Ecosystem Collaboration; Open Business Models; and Lean Product Development.

11.8.2. Lessons Learned from Failures

Although the positive effects of intelligent manufacturing systems with IoT integration are being examined in various ways by means of parameters such as economy, reliability, productivity, etc. in order to accelerate the adoption of Industry 4.0, there are some roadblocks against the implementation. This section organizes lessons learned from examples of successful IoT-based intelligent manufacturing implementations. Industry 4.0 is a dynamic topic and the speed of technology development and maturity is very fast as shown in the changing roadmap. For example, the amount of masters and experts in the context of big data and data analytics has not kept pace with the speed of demand. Hence, many companies faced difficulties in the collection, analysis, and smooth usage of data for both technical implementation and business value. Additionally, the IoT technology business market has various service models and significant overlap of functions among different companies. Businesses are unsure about which company to partner with in the critical early days of their IoT implementation journey so they often delay IoT projects. Coupled with consideration of cybersecurity, companies often fail at updating their initial systems due to budget and complexity issues.

Companies also lack a clear implementation roadmap addressing their domain specific business needs for the specific functions where IoT-related technologies play a role. Existing IoT solutions tend to push companies into an insufficient data approach as companies are forced by limitations of available IoT solutions into more simplistic decisions based on confidence of available data rather than business impact. This insufficient data approach is particularly relevant in use cases where the IoT solution provider does not have deep domain expertise and knowledge. Insufficient implementation also leads to insufficient value creation. Common reasons for failure during implementation include companies' lack of sufficient understanding of their IoT solutions, digital factories establishing limited focus on their IT instantiation capability, and a focus on prototyping activity at the early stages instead of co-architecting the IoT solution with the provider.

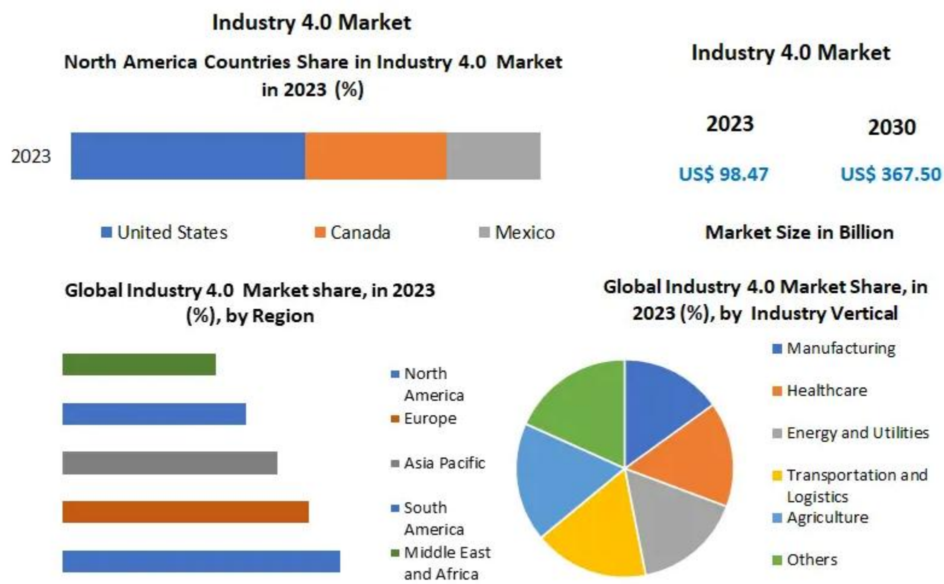

Fig 11 . 3 : Industry 4.0 Market

11.9. Conclusion

Industry 4.0 is the term used to refer to the current trends in the automation and data exchange in the manufacturing technologies. It represents a fundamental change of how manufacturing and the related services are produced and consumed. However, the adoption of Industry 4.0 concepts is still in a premature phase, especially in what concerns the intermediate and small-size manufacturing companies, although these are the companies that, around the world, represent most of the manufacturing sector employment. Nevertheless, the Intelligent Manufacturing Systems, characteristics items of the 4th industrial revolution, although rare, already exist. In practice, these implementations are usually unique prototypes, with limited multifunctionality and usually with high costs, either in the R&D or in the final product.

This chapter proposes a roadmap towards the implementation of integrated, low-cost, multifunctional Intelligent Manufacturing Systems, with a reliability closely matching more expensive systems. The first step for accelerating the adoption of Intelligent Manufacturing Systems, because the implementation of any technological concept must start to solve a real problem, is to identify which manufacturing process or operation is more critical for the company, i.e., the bottleneck manufacturing area that is limiting the overall efficiency of the system. According to the theory of constraints, this restriction cannot be solved by the mass implementation of automation technologies dispersed over the whole system. On the contrary, the highly critical resource has to be identified, proper measurements must be defined and used, as well as proper performance objectives. The reduced resources must be mainly directed to support the identified critical area, due to the why should the company focus on optimizing its bottleneck operations.

11.9.1. Summary and Key Takeaways

The Fourth Industrial Revolution (Industry 4.0, I4.0) is a multi-domain transformational change that is characterized by accelerating the digitalization and integration of cyber-physical systems, made possible by the ubiquity and low-cost connectivity offered by the Internet of Things. While a vast body of knowledge exists on the technical and technological aspects of I4.0, IoT, and Cyber-Physical Systems, there is a plethora of challenges that industry faces during implementation. These challenges mostly concern the economic aspects of the investment in I4.0. Large companies, because of the relative availability of resources, may be better equipped to start the journey in I4.0. However, small- and medium-sized enterprises (SMEs), that due to their sheer number represent the majority of manufacturing companies in the world, are the backbone of the digital economy. Their relative smaller size makes them more agile and flexible, but they are also less ready to adopt innovations, mainly because of budget restrictions.

This chapter presented an intelligent manufacturing systems framework, developed as part of a research and development project on I4.0 conducted in a world-leading SME. The proposed framework allows a roadmap adoption of Industry 4.0 so that the investments can be made based on the returns on investment expected. Such a roadmap approach makes it possible to promote a progressive learning and absorption of technologies and investment, enabling SMEs to identify and clear potential internal and external barriers to digital innovation, become digitally mature, maximize the opportunities brought by digital technologies, and at the same time achieve better competitive advantages. The framework enables SMEs to become smoother and more effective initiatives of I4.0 that favor the whole supply chain.

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