Adoption of Industry 4.0 in Manufacturing Processes

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Highlights

- Industry 4.0
- design for six sigma
- lean six sigma

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Abstract: Industry 4.0, or digitization of manufacturing, is referred to as cyber physical systems, automation, and data exchange. It is no longer the future trend but is widely being used across the world by manufacturing organizations for acquiring benefits of improved performance, fewer inefficiencies, and less cost while enhancing flexibility. However, it is tough to implement the Industry 4.0 enabling technologies without any standardized approach and it becomes even tougher. The barriers include but are not limited to lack of knowledge, inability to realistically quantify the return on investment, and lack of skilled workforce. This study therefore brings out a summary of the enabling technologies for Industry 4.0 to show impact to the manufacturing industry as a strategic roadmap in implementing lean six sigma approaches. This paper can be used as a strategic roadmap to offer a holistic view of the phases that the manufacturers have to undertake along with the challenges they would face during their journey toward Industry 4.0 transition. The implementation of Industry 4.0 is quite likely to bring about the paperless factory. Changes to the infrastructure are a core finding. It is also shown that Industry 4.0 does not require significant alterations in traditional manufacturing processes.

Keywords: Industry 4.0; design for six sigma; lean six sigma; additive manufacturing; augmented reality; simulation; autonomous robots; internet of things; cloud computing; big data analytics; cyber security; horizontal and vertical integration

1. Introduction

Current industries require digitization and intelligentization in manufacturing processes. Production has been customized, but the industry has replaced mass production in manufacturing. Industry 4.0, by including the Internet of Things, Industrial Internet, Smart Manufacturing, and Cloud-based Manufacturing, is still a futuristic but practical notion. Industry 4.0 is the intense incorporation of humans into the manufacturing process to achieve continuous improvement, focus on value-added activities, and avoidance of waste [1].

The physical capability of the current production systems limits the physical aspect of intelligent factories. Due to the mass requirement of 4.0 industry for customization, several new non-traditional manufacturing processes are being invented or developed constantly. In regard to creating complex objects possessing advanced functionalities, AM technology has been an essential route to the production of personalized products. The world went through three industrial revolutions since 200 years back. Now we are undergoing a fourth industrial revolution [2]. This name was coined in 2011. The idea or essence of Industry 4.0 is that it makes it possible to bridge or connect the virtual/digital world with the real/physical world. That means "where intelligent objects are constantly in communication and interaction with each other. Compared with Industry 3.0 wherein integration could only be up to a certain point as that depends on the interface of which the systems were working. In Industry 4.0, machines would be in control of its process. Customer experience is improved; time to market is increased; the cost of producing these products is reduced.

There are new industries and technology on the horizon. This evolution creates new business models and value propositions as well [3]. The new concepts of Industry 4.0 are associated with Internet of Things (IoT), Cloud Computing, Big Data Analytics, Cyber Physical System, Cryptocurrency (Blockchain), Artificial Intelligence, and 3D printing. Among all the new technologies, 3D printing is considered to be one of the most promising technologies of Industry 4.0. Main drivers in industry 4.0 are IoT, which "defines a global environment where the Internet is the center of connectivity for all the intelligent devices" [4], Cyber Physical Systems (CPSs) which indicate a connection between the virtual and physical world, or "communication between humans, machines and products". The aim of the thesis is to identify the challenges of adoption of Industry 4.0 along with adjustments in traditional manufacturing processes [6]. A process for the adoption of technological innovation and a maturity model was proposed for Industry 4.0. Managerial implications are derived from the findings to enable managers to understand and address challenges in the adoption of Industry 4.0.

2. Materials and Methods

Different methods, which are normally referred to as research strategies, are applied in business research to solve a wide range of questions and objectives. Such research strategies include experiments, surveys, case studies, ethnographic research, action research, and grounded theory. The choice of method will depend on the nature of the research and the expected outcomes.

In an experiment, manipulation of the independent variable is devised to find out its impact on a dependent variable. Though experimental designs can offer strong inferences about causality, experimental designs are rarely used in business research as control over the independent variable cannot always be obtained in an organization. Surveys involve quantification by questionnaires or structured interviews or observations. Case studies are a technique for examining a phenomenon that occurs in a real context. Case studies can be singular or plural, and they can be holistic (examining the whole entity) or embedded (examining sub-units). Typically, population, target population, samples and individual cases can be differentiated as is depicted in Figure 1.

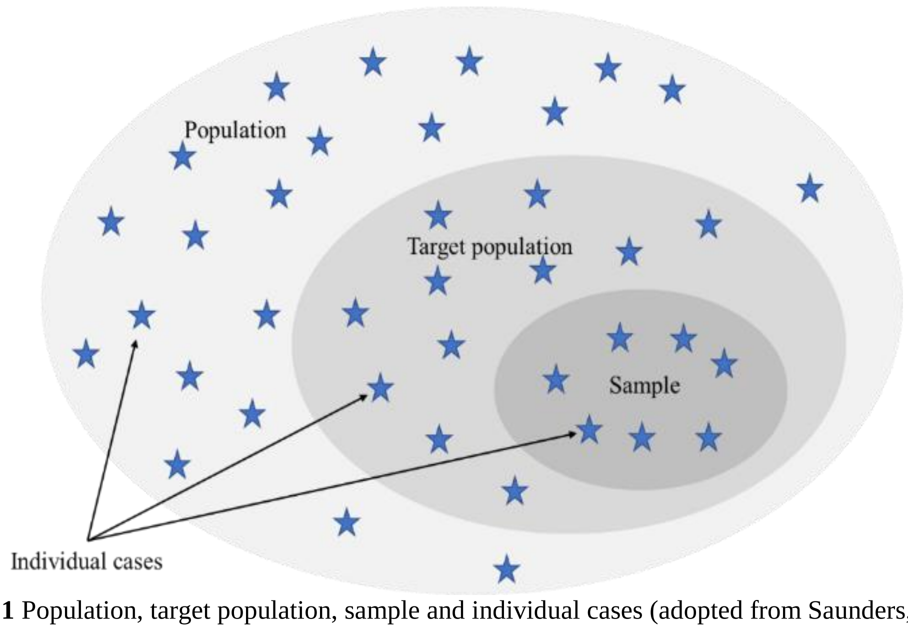

Figure 1 Population, target population, sample and individual cases (adopted from Saunders, Lewis and Thornhill, 2016, p. 275)

Sampling techniques can be categorized as probability and non-probability sampling. Four non-probability sampling types are quota, purposive, volunteer, and haphazard sampling. This study employs self-selection sampling, where potential cases are contacted, and data is collected from those who respond. Self-selection sampling requires two things:

Publish need for cases respectively contact potential cases.

Collect data from those who respond

The research philosophy adopted is pragmatism, which encompasses a comprehensive ontological view and an epistemological approach focused on the practical significance of knowledge and problem-solving. Pragmatism values the relevance of concepts and theories in supporting action rather than being purely abstract.

It emphasizes practical experiences over mere theoretical considerations. This philosophy allows for the application of a wide range of research methods, from qualitative and quantitative to mixed methods, in alignment with the specific research problem at hand. According to Bryman and Bell [7], the deductive research approach involves establishing a relationship between theory and research. It entails deducing hypotheses from existing theoretical considerations within the field and subjecting them to empirical scrutiny. The abductive research approach has gained popularity among qualitative researchers, surpassing deductive and inductive approaches in usage. Abductive research is commonly employed in the pragmatist tradition and involves a dynamic interplay between empirical data and theory. As outlined by Mantere and Ketokivi [8], organizational research encompasses three types of reasoning: theory-testing research, inductive case research, and interpretive research. For this particular study, a deductive approach has been selected as it aligns well with the research questions. Research designs can be combined or employ a single method to serve multiple purposes, resulting in combined studies. Primary data can be collected through various methods, with observations, questionnaires, and interviews being commonly utilized approaches. Observations are well-suited for analyzing human behavior through systematic viewing. Questionnaires are often used in surveys, experiments and case studies. Mail and postal questionnaires are the most prevalent forms. Interviews serve as a means to gather valid and reliable data, aiding in answering research questions and refining ideas. The methodological choices can be summarized in the “research onion” as seen in Figure 2.

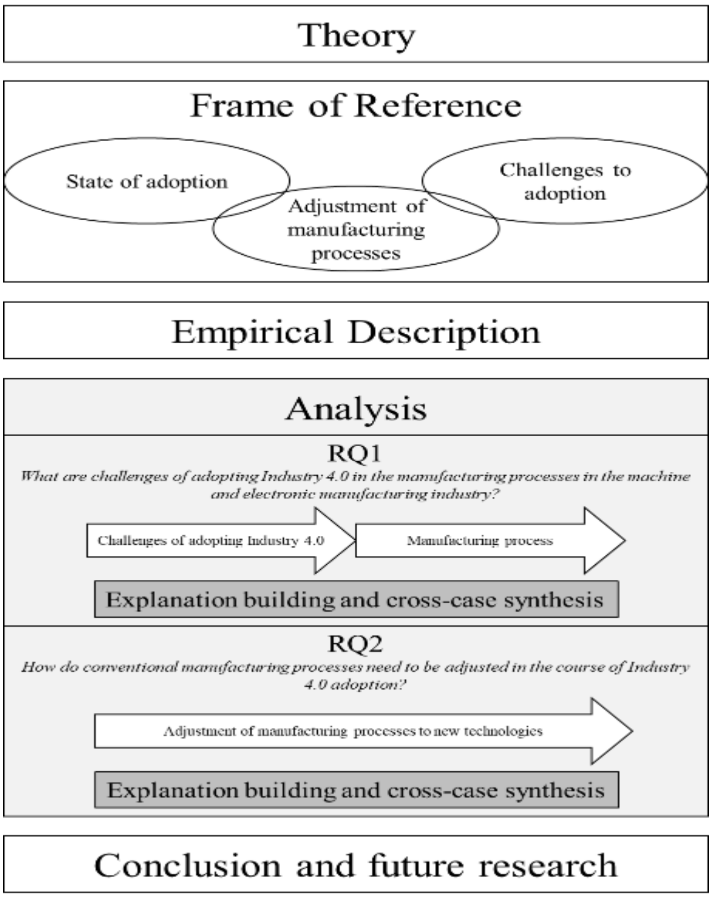

Figure 2 Research structure (own illustration)

Since it was first presented by the German government at the Hannover Fair in November 2011, the concept of Industry 4.0 has become extremely popular and important. The aim and the core of each industrial revolution is to increase productivity.

The first industrial revolution occurred because of the invention of the steam power, which created an opportunity to increase more productivity. The second occurred when electricity was used and increased productivity. The third industrial revolution took place once electronics and IT were engaged to increase productivity and have efficiency. Industry 4.0 is defined by "the manufacturing environment's increased digitization and (CPS), Internet of Things (IoT), Internet of Services (IoS), Robotics, Big Data, Cloud Manufacturing, and Augmented Reality."

2.1 Key technologies of Industry 4.0

Industry 4.0 is a change phase regarding production and supply chain processes utilizing advanced technologies. The foundation for this transformation mainly includes the concept of CPS - coupling physical processes with the virtual environment, allowing an enormous control and coordination facility concerning various sectors like health care, energy, industrial control, etc. They significantly contribute to several operations related to industrial connectivity in boosting operational efficiency.

Internet of Things has really transformed the communication in interlinked devices, and supply chain visibility, agility, and efficiency have improved significantly due to the seamless interaction. The industrial variant known as Industrial Internet of Things promises even higher degrees of automation and resource management, enabling the development of complex autonomous systems, as explained in figure 3.

Figure 3 AR glasses (Wikimedia, 2017)

Big Data is among the new foci with collection and analysis of very large information, characterized by large volume, velocity, and variety-a feature that enables businesses to drive informed decision-making, risk assessment, supplier performance measurement-thus highly influencing the effectiveness of supply chains.

There also exist Augmented Reality technologies, and through overlaying information of virtual on real life, they really enable the improvement of production procedures; thus, they actually affect problem-solving and provide experience improvement through the whole lifecycle of a process with innovative answers developed before process implementation.

Industry 4.0 encompasses various forms of integration, including the vertical integration of IT systems and processes in organizations and horizontal integration with suppliers and customers. At its core, it seeks end-to-end digital integration along the supply chain. This is possible through three key technologies: machine-to-machine communication, robotics, and Cloud Manufacturing. All these developments culminate into "Smart Factories" with Artificial Intelligence, intended to make data-driven decisions to optimize operations and add value in industries.

2.2 Challenges of adopting Industry 4.0

Implementing Industry 4.0 technologies will pose some problems to the organizations while achieving full potential from them. CPS are the largest area where serious problems occur due to the lack of a well-established theoretical framework for bringing together network and physical resources. According to Liu et al. (2017), some problems that come along with developing CPS are measurement noise, inaccuracies in data collection, and environmental interferences. Scalability, robustness, and performance have to be addressed in the design of the CPS. This includes dynamic interactions between the network and physical systems and how to manage them. Technological limitations as discussed above do not allow a full CPS utilization. It calls for further research as shown in figure 4.

For example, the Internet of Things (IoT) similarly faces its own set of limitations, mainly heterogeneity in nature. According to Hussain, the heterogeneity at devices, technologies, and application software levels makes it troublesome to follow single protocol standardization and lack of sufficient resources to overcome constraints that arise [10]. Yet, interoperability is its biggest challenge, with current limitations in devices and system capabilities that limit IoT systems from achieving their full integration. Scalability is important for the increasing number of devices and users. Resource-constrained nature of many IoT devices also raises security and privacy concerns as they may expose potential vulnerabilities. QoS needs to be ensured with solutions that enhance availability, reliability, and performance.

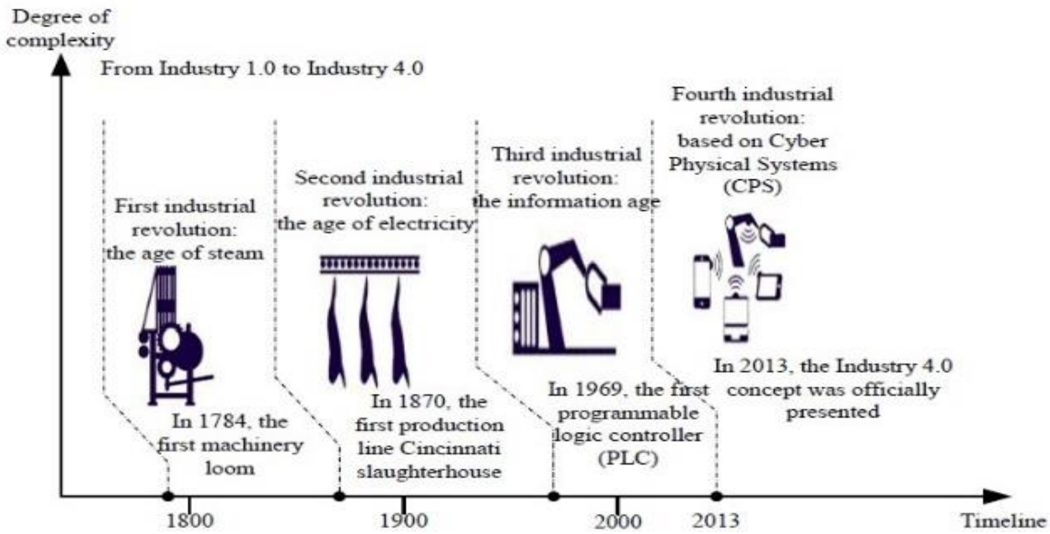

Figure 4 Concepts of Industry 4.0 (DFKI, 2011, cited in Zhou, Liu and Zhou, 2015, p. 2148)

Nowadays, Industry 4.0 is creating a new industrial field which will depend on data acquisition and sharing along the entire supply chain.

Kerkar and Zicari [11] have classified the challenges from Big Data into three groups based on the lifecycle of data, namely: data challenges, process challenges, and management challenges. Issues concerning capture, integration, transformation, analysis, and more related to privacy, security, governance, and ethical issues are indispensable to the proper exploitation of Big Data.

Augmented reality applications in manufacturing have very particular problems in terms of accuracy, registration, latency, and interfacing technology. Accuracy to a high precision in tracking and overlaying augmented information requires sophisticated techniques in tracking. Static errors result from sensor inaccuracies while dynamic errors are produced by latency and computational problems in registration. An effective AR environment will require the integration of target locations, AR content, tracking modules, and display systems to allow intuitive user interaction. This addresses some of the challenges facing AR applications in the manufacturing sector in terms of their practicality and effectiveness.

3. Results

The adoption of Industry 4.0 technologies is going to significantly affect the employees of manufacturing companies, requiring a set of precise qualifications. The employees will be required to have a spirit of learning, strong social and interpersonal skills, an action-oriented ability, and competency in network technologies and data analysis. However, challenges arise in terms of accepting new technologies among employees through concerns over data transparency, reliance on technical systems, and workplace safety. Toward successful adoption, the companies must

These could then be addressed and confidence built among the employees over the new technology and its benefits.

It will help understand the better adoption process by looking into the model of diffusion of innovation introduced by Rogers [13]. In this manner, the model lists how innovations are communicated over time among members of a social system. Four central elements influence this diffusion: innovation, communication channels, time, and the social system. Innovations are new ideas or practices that appear novel to the potential adopters, and the rate of adoption depends significantly on relative advantage, compatibility, complexity, trialability, and observability. Advantages and compatibility of an innovation increase the chances of adopting it quickly, whereas complexity acts as a barrier to adoption.

Rogerson's diffusion model has two sub-processes, which are further classified into five stages of initiation and implementation. At the initiation stage, agendas are set, a company recognizes its problems in organization, and it lines up those problems with potential innovations. Restructuring tailors the innovations to meet the organizations' needs. In this stage, clarification makes better social interactions that would slowly assimilate innovations into general understanding. Routinizing is the last stage at which an innovation gets embedded in organizational practices.

Tornatzky and Fleischer (1990) suggest a more streamlined innovation process consisting of five steps: awareness, matching, adoption, implementation, and routinization [14]. They highlight the individualistic view of Rogers' model but point out that there is no account of organizational and environmental factors. Hameed, Counsell, and Swift (2012) extend this by developing a model which incorporates initiation, adoption decision, and implementation, factoring in external characteristics and user acceptance at both the individual and organizational levels [15]. However, the two models do not incorporate the time dimension, an aspect that this thesis hopes to fill by proposing a new model for technological innovation adoption. The Technology-Organization-Environment (TOE) framework, as proposed by Tornatzky and Fleischer (1990), is a comprehensive model to understand the adoption of technological innovation. It looks at three critical elements, namely, technological context, organizational context, and environmental context, all of which influence the adoption decision. IT model is shown in figure 5.

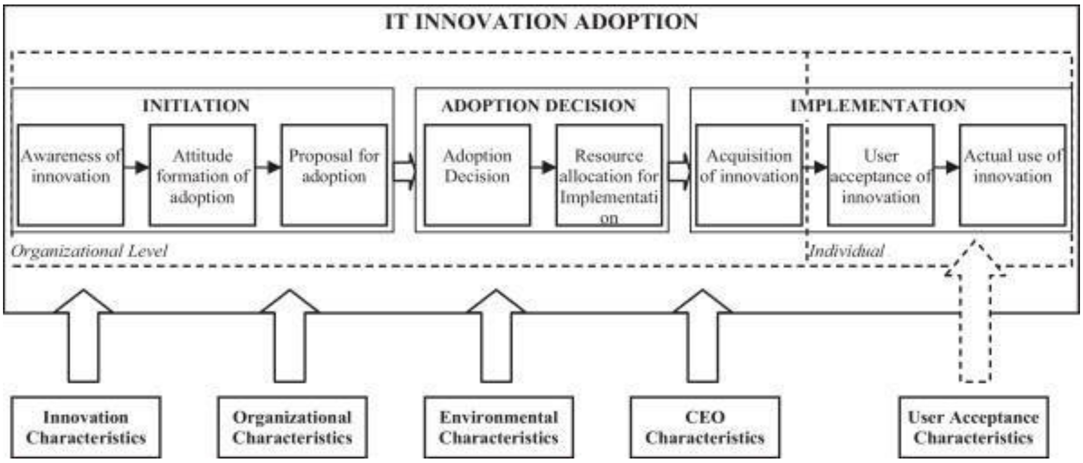

Figure 5. Conceptual model for the process of IT innovation adoption (Hameed, Counsell and Swift, 2012, p. 367)

Variables are included in the organizational context such as size, centralization, and communication process. Research has shown organic, decentralized organizations, in which teamwork and lateral communications are emphasized, to better fit the adoption phase of innovation, but mechanistic structures with formal relations, which are more effective at implementation.

Industry and business dynamics, competition, and regulatory environment are environmental factors that support or prevent innovation. High competition encourages innovation adoption due to top firms promoting partners to be innovative. Even though it has some limitations in explaining its constructs and variables, a lot of empirical evidence can be seen as supporting this model in explaining the innovation adoption process.

3.1 Suggested Procedure for Implementing the Technological Innovation:

The literature review has shown that the existing models for the adoption of technological innovations have a limitation in that they do not take into account the time dimension and the broader technological, organizational, and environmental contexts. In an attempt to fill this gap, this thesis presents a new model for the adoption of technological innovations, as shown in Figure 6.

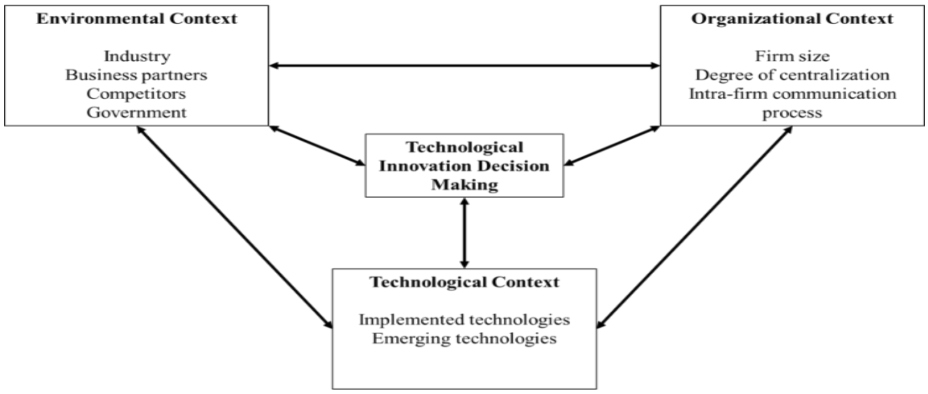

Figure 6. The technology–organization–environment framework

This five-step proposed model is categorized into three sub-processes: preparation, adoption decision, and realization. It starts with the definition of the problem and identifies an organizational problem that requires innovative solutions. The adoption decision sub-process involves decision-making, acquisition of resources, and evaluating alternatives to make a final choice. Once a decision is made, the realization sub-process involves the implementation of the innovation, which requires adjustments to match organizational characteristics, followed by implementation and evaluation for potential improvements. The final step routinizing ensures that the innovation becomes embedded in the daily operations, thus encouraging a common understanding among the employees.

Although the model linearises for simplistic purposes, it still allows for feedback loops, allowing earlier steps to be revisited based on evaluations. In addition, it emphasizes the human role in the adoption process, particularly in the routinizing stage. Furthermore, the model borrows from the TOE framework developed by Tornatzky and Fleischer (1990), hence underlining how the three contexts affect decision-making at different stages of the adoption process. Importantly, the model considers the time dimension, showing that the adoption process changes over time. The maturity model classified the different degrees of Industry 4.0 adoption for case companies.

Table 1 below introduces a maturity model. It uses the terminology beginner, intermediate, experienced, and expert to define the different levels of maturity. Maturity level: It defines how mature is the adoption level of key technologies related to Industry 4.0 discussed in this report. By linking the maturity model with empirical analysis, the thesis provides insights into the challenges faced by companies at different stages of Industry 4.0 adoption, contributing to a comprehensive understanding of technological innovation adoption in manufacturing as shown in Table 1. Moreover, very few researchers are also working on modern technology of biomedical engineering using different machine learning and artificial intelligence techniques [19-23].

Table 1. Maturity model for the adoption of Industry 4.0 in the manufacturing process (Own illustration)

	Level 1 Beginner	**Level 2 Intermediate**	**Level 3 Experienced**	**Level 4 Expert**
CPS	Few machines can be controlled through automation	Some machines and system infrastructures can be controlled through automation	Most machines and system infrastructures can be controlled through automation	Machines and systems can be controlled completely through automation
IoT	Machines (and systems) have no M2M capability	Machines (and systems) are to some extent interoperable	Machines (and systems) are partially integrated	Machines (and systems) are fully integrated
Big Data	Data is collected manually when required, e.g. sampling for quality control	Required data is collected digitally and analyze in certain areas	Comprehensive digital data collection and analyze in multiple areas	Comprehensive automated digital data collection and analyze across the entire process
CM	Cloud solution not in use	Initial solutions planned for cloud-based software, data storage and data analysis	Pilot solutions implemented in some areas of the business	Multiple solutions implemented across the business
AR	Augmented Reality Glasses or Displays not in use	Augmented Reality and Glasses or Displays used for a small areas	Augmented Reality and Glasses or Display used for some areas	Augmented Reality and Glasses or Display used for the entire process
Smart Factory	CPS, IoT, Big data, CM, AR and AI not in use	Small part of CPS, IoT, Big data, CM, AR and AI in use	Some part of CPS, IoT, Big data, CM, AR and AI in use	All of CPS, IoT, Big data, CM, AR and AI in use

4. Conclusions

The organizations that face these challenges are technological, organizational, and environmental types. A few of the notable critical issues observed are standardization, management support, skills, and costs, and these have faced data challenges coupled with many compatibility issues amongst organizations. The number of environmental challenges found correlated against maturity levels shows that issues with standardization, management support, skills, and costs represent the greatest sources of the problems.

Lean Management, therefore, is a much needed framework, and factories are coming towards paperless. The impact on the traditional process from Industry 4.0 would be not much impactful, thereby meaning the change is evolutionary rather than revolutionary. The vagueness about what exactly the change is tells us about the ambiguity

Industry 4.0 surrounding the impact on manufacturing practices.

Other limitations include diverse interpretations of challenges under Industry 4.0 and focusing more attention on production and IT departments than other business processes and cross-departmental communication. The overall quality of the data gathered supports the findings of the first research question, although the phenomena in response to the second may need further validation.

Future studies could include other SCOR model processes, such as planning and sourcing, and be expanded to interviews in other departments to further generalise into different industries and regions. A business case for sustainability with regards to Industry 4.0 would be an opportunity to establish its economic, environmental, and social value.

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