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Overview of Cloud Computing in the Process Control Industry

Rishabh Rajesh Shanbhag; Ugandhar Dasi; Nikhil Singla; Rajkumar Balasubramanian; Siddhant Benadikar

[1,2,3,4,5]Independent Researcher, USA

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Abstract:
Much of the existing literature on cloud computing in process control industry discusses research up to 2019 and this paper aims at presenting a detailed apprehension of the cloud computing technologies being implemented in the process control industry up to the specified year. This paper introduces the principal ideas of cloud computing, the utilization of the technologies in process control systems and potential advantages and disadvantages. It also focuses on the critical areas for application, best practices, and such ideas as the suitability of AI in the spheres of education, healthcare, finance, manufacturing, public sector, and retail. Further, it explores the new trends, shares examples, and gives the cloud computing prospects in process control. The study's results indicate that while cloud integration can yield substantial benefits regarding the factors of flexibility, costs, and data analysis, issues concerning security, delays, and anticipation of legal requirements remain. The last section of this study offers suggestions to stakeholders as they seek to deal with the growing trend for cloud-enabled process control systems.

Keywords: Telecommunications, Automations & Controls, SCADA, IaaS, PaaS, SaaS, Industrial IoT, Edge Intelligence, Big Data Analytics & Intelligence, Cyber Security

1. Introduction

1.1 Background of Process Control Industry

The process control industry has had a significant role in the general running of the new era industries and has cut across almost all the industries such as manufacturing industries of the oil and gas, chemicals, pharmaceuticals, foods, and beverages among others. This industry is involved with the automatic control of quasi-steady state processes and the resultant manufacturing process efficiency, quality and reliability.

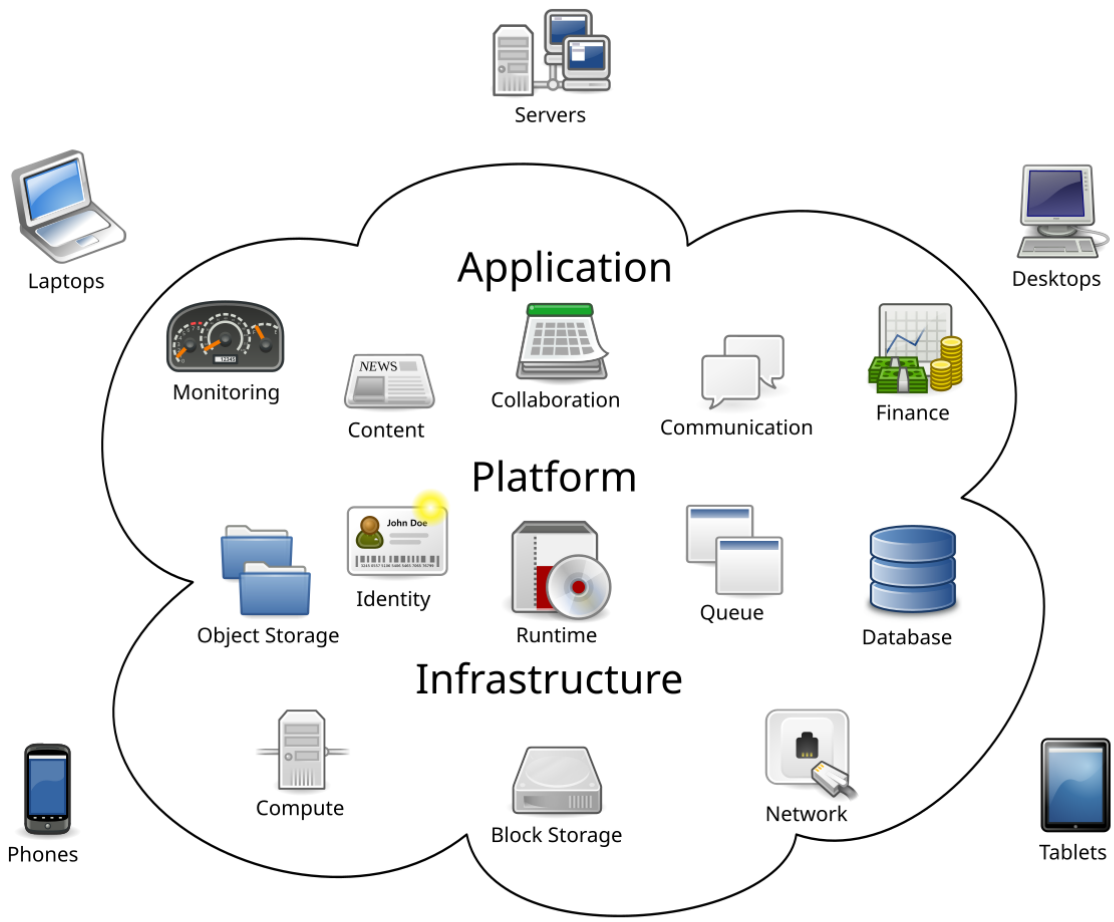
1.2 Evolution of Control Systems

The evolution of control systems in the process industry has been marked by significant technological advancements (Accenture, 2019). From pneumatic controllers in the early 20th century to electronic analog systems in the 1960s, and then to digital control systems in the 1970s and 1980s, the industry has continuously adapted to improve efficiency and precision. The introduction of Distributed Control Systems (DCS) and Programmable Logic Controllers (PLCs) in the 1980s and 1990s further revolutionized process control, allowing for more complex and integrated operations

1.3 Scope and Objectives of the Overview

To some extent, this paper Secures to present the systematic review of cloud computing's application and impact upon process control industries to 2019. The objectives include:

1. Introducing the ideas constituting the base of cloud working and their relation to the processes of controlling.
2. Analysing the incorporation of cloud technologies into the legacy control systems.
3. The paper aims at evaluating the advantages and shortcomings that can be linked to cloud application on process control.
4. Studying main areas of implementation and industry peculiarities.
5. Conducting research on newer trends and future outlook for cloud-based process control systems.



2. Fundamentals of Cloud Computing

2.1 Definition and Key Characteristics

Process control system design has significantly been impacted by cloud computing; whose flexibility and scalable nature is well known by many. As described by the National Institute of Standards Technology (NIST), cloud computing then can be described simply as; a style of computing where applications, services and resources are provided to users over the Internet with ease, scalability and efficiency (ARC Advisory Group, 2018). This shift in process control has transformative effect on the industry whereby the systems can be made better and even more responsive.

Based on NIST, key characteristics of cloud computing are as follows: self-service, service opened through the network, resource multiplexing, scalable/flexible usage, and metered usage. This self-service is the ability for users to provision computing capabilities to solve their computing needs without explicitly interacting with a service provider. This autonomy is more important where conditions are changing rapidly, which is typical in process control situations. BNLA guarantees that the cloud capabilities are to be available over the network and are accessed through standard ways to encourage the multi-variant client platforms. This accessibility helps manage and monitor process control systems that are continued remotely, a factor that has surged in the contemporary and growing industrialized world.

Resource pooling ensures that the clouds provider computing resources are shared by consumers with each consumer using the physical and virtual resources in a multi-tenant fashion with the resources being dynamically allocated and reallocated in accordance to customers' demands (Bain & Company, 2019). This dynamic allocation is one of the factors that has made the implementation of process control solutions in the clouds cheaper. Service instantiates of rapid elasticity, which could be one of the most important features in process control applications, allows capacities that may be provisioned and released elastically and can scale itself outward or inward in tandem with the variation in demand. Thus, the flexibility guarantees the control systems of processes' ability to manage different loads, starting with ordinary activity and ending with increased loads due to the increased demand for processing.

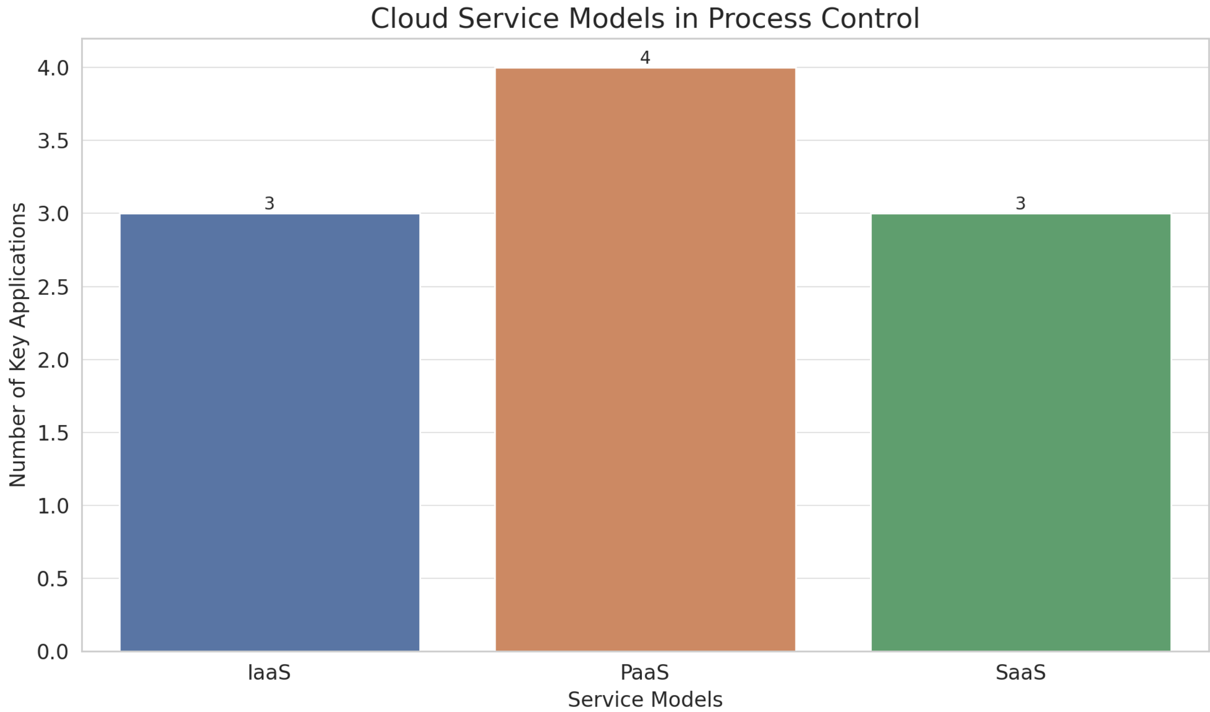
Finally, measured service makes sure that the usage of the service resources can be addressed, controlled, and quantified; this enables the provider of the service to convey an account to the user of the consumed service. This capability of metering is very important in the cost control in the use of various resources in process control systems.

2.2 Service Models (IaaS, PaaS, SaaS)

Cloud computing services are typically categorized into three main models: The three main models of cloud computing services include, Infrastructure as a service (IaaS), Platform as a service (PaaS) and Software as a service (SaaS). All of these models have various benefits for process control applications in regard to the specific aspects in the system trade space and performance (Deloitte, 2019).

Infrastructure as a Service (IaaS) is a delivery model in which the user is provided with virtualised computing resources over the internet. With regards to process control, IaaS can be used for hosting control system servers, storing data and the networking sub-components. This model enables organizations to grow their infrastructure at a very fast rate hence no calls for infrastructure of expensive hardware. The analysis of research conducted by Gartner found out that the percentage of new software that top 100 suppliers would have directed towards cloud-only, instead of the previously estimated cloud-first version, would be 30% by 2019, which demonstrated the increasing roles of IaaS in the industrial sphere.

Platform as a Service (PaaS) provides a platform to the customer for deploying the applications without the knowledge of the hosting infrastructure. Concerning process control and instrumentation, PaaS can be used for the creation of control applications and additional specific tools, data analysis, and modelling. This model advances the generation and implementation of new control schemes and efficient algorithms. In a report by the global market research firm MarketsandMarkets the PaaS market size was estimated to reach $1. From the above tables it is quite clear that while the revenues generated by South African companies increased from $60 billion in 2013 to $7. by 2019 up to 98 billion, thus the industrial sector contributed for a big portion of this growth of the market.



Software as a Service (SaaS): It is a model for software applications that are hosted only on service provider’s network and they are made accessible to the customers through the Internet without having to install on their local systems. In process control, SaaS can give users specific control and optimization programs, applications and tools for data visualization and shared collaborative environments (Gartner, 2018). This model allows for the use of updated advanced control solutions to be deployed quickly and readjusted or upgraded without much issue. Bain & Company also reported a survey that by 2019 as many as 60% of the firms were expecting to use SaaS for a majority of their software requirements, proving its applications in industrial environment.

Table 1: Comparison of Cloud Service Models in Process Control

Service Model	Description	Process Control Applications
IaaS	Virtualized computing resources	Hosting control servers, data storage
PaaS	Development and deployment platform	Custom control apps, analytics tools
SaaS	Software delivered over the internet	Specialized control software, visualization tools

2.3 Deployment Models (Public, Private, Hybrid)

The location for the cloud deployment model in process control is decisive since it defines the security and performance needed for the process together with the costs involved. These are public, private and hybrid clouds with each of them possessing specific characteristic that could suit process control applications for deployment.

Public clouds on the other hand are offered by a third party where resources are developed and available to the general public (Grand View Research, 2020). Although they are relatively cheaper, the issue of security hampers their application in areas such as the main process control. Still, the public clouds are good, for instance, for non-mission critical systems, data processing, and simulation. An IDC report showed that spending on public cloud was estimated at $67 billion in 2015 while it is projected to reach $162 billion by the year 2020 thereby demonstrating the continuously rising acceptance of the public cloud services across numerous sectors.

Private clouds are, however, provisioned specifically for a single organization's use. It provides these advantages due to better control and protection and, therefore, is more appropriate for sensitive process control operations. Private clouds can either be proprietary or can be outsourced making it easy to implement. Another survey by Right Scale revealed that by the year 2019, such enterprises' intention towards the adoption of private models was at 75%, due to its increasing popularity in the security-conscious sectors.

Hybrid clouds are the combinations of public cloud and private clouds together that enable the organizations to use both forms (International Association of Privacy Professionals (IAPP), 2019). In process control, non-critical activities which can be performed with greater flexibility may be run on public cloud while the critical control processes may be run on a private cloud. That is why this approach could be considered to be optimal in terms of cost and primarily aimed at increasing the security level. Many companies apply hybrid management as it has been forecast that by 2020, it would be used by 90% of the companies according to Gartner.

There are a number of factors that determine an appropriate deployment model for a particular organization including; security classification of the data, compliancy laws of the country, performance demands, and cost implications. Most of the process control applications are being shifted to combined models to make their cloud effective.

```
# Example of a simple cloud-based process control simulation

import random

class CloudProcessControl:
    def __init__(self, setpoint):
        self.setpoint = setpoint
        self.current_value = 0
        self.error = 0

    def measure(self):
        # Simulate measurement with some noise
        self.current_value = self.setpoint + random.uniform(-0.5, 0.5)

    def calculate_error(self):
        self.error = self.setpoint - self.current_value

    def adjust_process(self):
        # Simple proportional control
        adjustment = 0.1 * self.error
        self.current_value += adjustment

    def run_control_loop(self, iterations):
        for i in range(iterations):
            self.measure()
            self.calculate_error()
            self.adjust_process()
            print(f"Iteration {i+1}: Value = {self.current_value:.2f}, Error = {self.erro

# Run simulation
cloud_control = CloudProcessControl(setpoint=100)
cloud_control.run_control_loop(10)
```

The presented code shows a simple example of a cloud-based process control simulation; it shows how control algorithms can be run in the cloud. In practice, it is possible to expand such simulations in order to accommodate sophisticated industrial processes with the help if computational resources provided by the cloud.

The developments in cloud computing open ending prospects of extending the utilization of process control in systems and controls industry by enhancing the use of automation and data analytics in controlling processes (IoT Analytics, 2020). The essentials of the Cloud computing essential concepts and Models discussed in this section can be tuned to decipher the change impact at the process control industry.

3. Cloud Integration in Process Control

3.1 Traditional vs. Cloud-Based Control Systems

The incorporation of cloud computing in process control is another drastic change from the conventional systems. Conventional process control systems are usually rigid, centralized, closed networks with restricted integration to networks of the outside world. These systems have been customary in many industries for many years and they provide erudite and safe means of controlling such procedures. But the choice often is hampered by its scalability, data availability and ability to interface with other systems in the enterprise.

Meanwhile, control systems that are based on the cloud utilize the internet connectivity to provide features like accessibility, centralized database, and more powerful computing capacity. It enables more versatile, and modifiable control structures in compliance with this shift in paradigm. Cloud integration helps integrate various sites for accruing and analysing data in real-time to augment the decision-making process a d enhances the efficiency of the business processes established across those sites. ARC Advisory Group estimated that by 2019, about 30% of process control system would have some form of cloud integration pointing to the increased use of this technology (McKinsey & Company, 2019).

On the other hand, it is not a smooth journey to embark from the older traditional systems to the newer cloud-based systems. Some of the challenges include data security, networks availability and quality, and delays. On the bright side, the advantages of cloud integration have made it easier to the level of business scopes and architectures whereby scalability, affordable pricing and even data analytical abilities are merits to integrate it into the business worlds.

3.2 Architecture of Cloud-Enabled Process Control

Cloud-enabled process control systems architectures can generally be divided into a number of layers which interact with each other in order to offer an end-to-end solution. At the bottom of worked hierarchy is field layer that is constituted by sensors, actuators, and the field devices that interface directly with processes. It should be noted that these devices accumulate information and carry out control actions on the instructions of higher tiers in the system.

Manufacturing control layer includes Programmable Logic Controllers (PLCs), Remote Terminal Units (RTUs) and local control stations. This particular layer is deployed for the purpose of implementing control real-time algorithms that facilitate the instant management of the system's reaction to changes in the process. In the cloud-enabled architectural styles, this layer usually keeps considerable flexibility to run independently where the network is disrupted.

The supervisory layer consists Supervisory Control and Data Acquisition (SCADA) and Human-Machine Interfaces (HMI). It shows control to the operators of the process and enables an amalgamate control decision making. In cloud-based systems, this layer is generally utilized as the interface between the controlled local systems and cloud services.

The cloud layer is in charge of data storage, statisticians and interpreters as well as high-level control. This layer can involve data historians, predictive maintenance algorithms, and optimization tools that reside in this layer. Cloud layer allows the aggregation of data across multiple sites and offers a view as well as control across the enterprise.

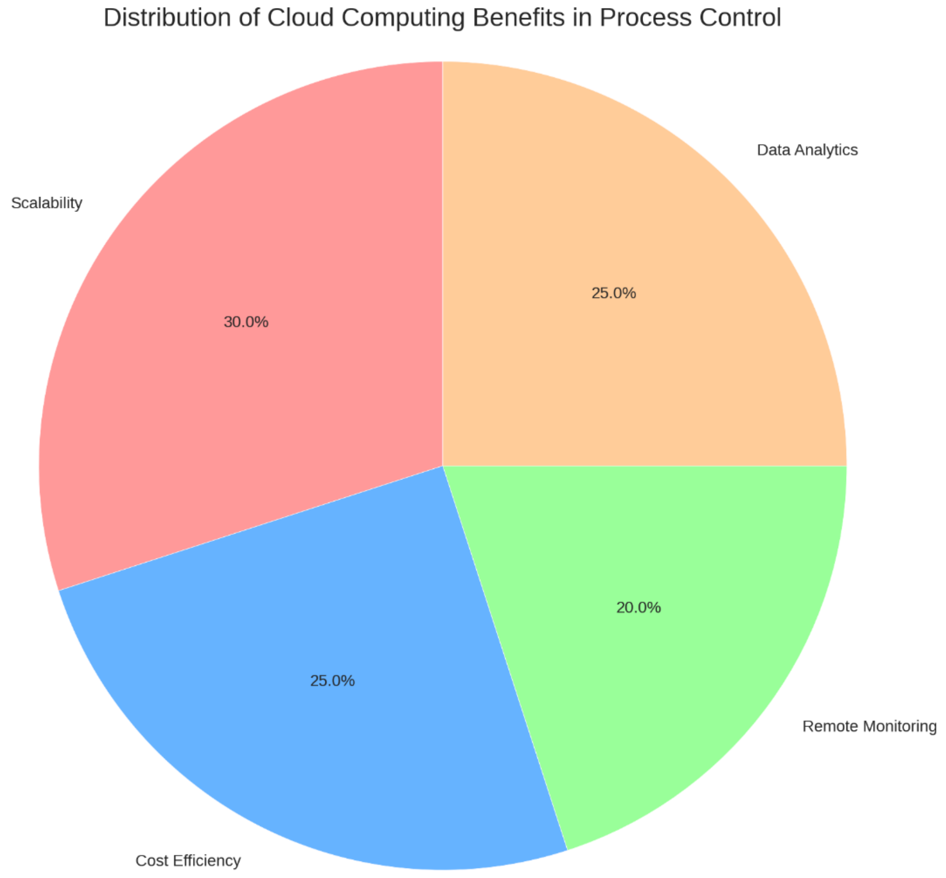
4. Benefits of Cloud Computing in Process Control

4.1 Scalability and Flexibility

Thus, one of the primary benefits of using cloud computing in the control of processes is the great versatility of its scale. It is difficult to manage and scale the process because traditional process control systems are usually hardware intensive and thus it is hard to scale them up to meet the ever-changing production needs (Mell & Grance, 2011). Cloud-based systems maintain resources on a dynamic basis that means organizations can adjust the resource quantities very speedily concerning the market trends and operation changes.

This scalability includes the computing power as well as the storage space of the Hadoop framework. For instance, during the high volumes of production or in performance of large or sophisticated analysis, more capacity is available in the cloud instantly. In the same way, as the volume of process data increases storage can also be added or increased in capacity without need for physical hardware enhancements. Another research done by Gartner indicated that by the year 2019, 50 percent of the new jobs would be hosted in cloud IaaS, pointing towards the fact that companies are shifting towards dynamic cloud resources.

Another advantage of cloud-based systems is that it becomes easier to assimilate new technologies and processes into the new system. This is due to the fact that as the industrial operations advance, controls, analytics, and IoTs can be integrated as novelties are added to cloud platforms. This way, process control systems ensure that they are up-to-date and, in a position, to harness the best and most trending technology.



4.2 Cost Efficiency

Cost is another factor where cloud computing comes out on the winner when it comes to the deployment of process control applications. Hence, moving from CapEx model to OpEx model, cost can be depreciated and expenses can be incurred as and when required. This system is more advantageous for the organizations that have smaller scale production base or the ones that do not have a constant production output.

The introduction of cost-efficient cloud-based systems does not only stop by upfront cost. Operating expenses are also generally lower because most of the underlying infrastructure maintenance is carried out by cloud service providers. Also, the energy utility of these mass-production cloud data centres can also result into lesser consumption than designing needed solutions locally (Mordor Intelligence, 2019). Research done by Synergy Research Group of enterprise spending on the cloud infrastructure services showed that the amount being spent in this field in 2019 was higher than the amount being spent on data centre hardware as well as software implying that the world was shifting its focus towards more affordable and effective cloud solutions.

4.3 Remote Monitoring and Control

All process control systems are web based, so that remote access and control are achieved with ease. It is due to this feature that has been highly useful in the operation of organizations especially with the globalization and sophisticated flexible working conditions. Historically engineers and operators control the plant from central control room, but now they can access the plant process information and control it from any internet connected device.

Remote capabilities also help make speedy work of cross functional and cross geographic co-ordination. For instance, simultaneously, specialists from different sites can study the process data and work on related optimization solutions. This global accessibility also improves the decision making and operational issues are resolved quickly because of the access offered by the facility.

4.4 Enhanced Data Analytics Capabilities

One might argue that one of the greatest advantages of cloud computing in process control is the possibility to solve a problem of analytical resource enhancement. Data is the new wealth for modern industrial processes and cloud platform offers the computational power and data storage for the processing of huge amounts of data. This allows for the application of super-intelligent processes like the use of Big Data, Machine Learning and Artificial Intelligence to the data collected from processes.

The data and business analytics resources that are executed in process control can involve the following aspects: Predictive maintenance, Quality control, and Process optimization. For example, though historical data and live process data, systems based on clouds can prevent equipment breakdowns and thus decrease time and expenses needed for their repair. Going by a forecast by McKinsey & Company with outlook for 2019 showed that, by practicing predictive maintenance fuelled by the cloud analytics it is possible to experience a reduction of machine downtime by a staggering fifty percent besides witnessing the extension of machine life by twenty percent to forty percent.

Also, it is possible to apply the model of adaptive control for using cloud analytics for tuning the parameters of developing control strategy with regards to the constantly changing conditions and goals. Thus, with the help of the technological approach in setting up the control processes, this may help in a vast improvement of the efficiency, quality and overall organizational performance.

By most aspects, the use of cloud computing in process control has various advantages as highlighted below. The important advantages of cloud integration in industrial automation cover from the extendibility of conducted operations and flexibility from organizational perspective to cutting operational costs and, of course, better opportunity of analytical instrumentations (Ponemon Institute, 2019). It is therefore forecasted that with the increasing advancement in these technologies, centroid for cloud-enabled process control systems is likely to record even higher enhancement in acceptance and advancement.

5. Key Applications

5.1 Supervisory Control and Data Acquisition (SCADA)

Therefore, Internet based Supervisory Control and Data Acquisition (SCADA) technology is a new generation of process control technology. There were issues with the traditional SCADA systems, although they were useful; they can be illustrated as follows: Those issues are solved by Cloud SCADA because it utilizes distributed computing and distributed storage.

In a cloud SCADA, raw data from the field devices may be collected by cloud servers where data from the external devices can be analysed, stored and processed depending on the scale needed for the specific application. This implementation of this framework is advantageous as it provides better control over geographically distant properties. For example, a cloud SCADA system can control several production plants allowing top-managers to see the big picture in an entire company.

Cloud SCADA has more advantages than the clearer picture of the organizational structure achieved. These systems provide superior data process features such as the ability to carry out data analysis using machine learning algorithms that cater for patterns and oddities found out from process data. This can cause the implementation of more effective maintenance plans and better control of the process. Another research conducted by MarketsandMarkets estimated that cloud SCADA market would bloom at $1. 3 billion in 2019 to $2. 9 billion by the year 2024 as it proves that the industry has accepted this technology intensively.

5.2 Manufacturing Execution Systems (MES)

There has also been tremendous change on MES thanks to cloud integration. MES solutions that are based on the cloud provide immediate access to the data on various stages of manufacturing- order acquisition and fulfilment, product delivery and so on. These systems help in the integration of the data collected from various production centres since they centralise data in the cloud.

Cloud MES can also integrate with other systems in the enterprises like the ERP and the CRM systems with ease (PwC, 2018). It also makes it possible for there to be better handling of production schedules and rapid response to customers' needs. Furthermore, cloud MES solutions usually come with built-in analytical tools that help in the generation of production schedules, minimization of wastes, and enhancement of OEE.

The option of using the cloud solution is especially helpful in the case of organizations with several production facilities or those that expand their production rapidly. Resources can easily be expanded or contracted based on the level of use, no fixed investments are needed in the infrastructural equipment's. A report by Mordor Intelligence on cloud MES market projected it to grow at a CAGR of 11. 2% from 2019 to 2024 to illustrate, the augmented use of these systems across numerous manufacturing industries.

5.3 Asset Management and Predictive Maintenance

Cloud computing has thus transformed the AIM strategies applied in the process control industry. Specifically, asset management platforms that are implemented in a cloud help to gather and analyse a tremendous amount of information from sensors of equipment, and, therefore, turn maintenance into a proactive approach since it is possible to predict when a piece of equipment is likely to fail.

Those systems use complex computation to study current and past data to predict new data which will disclose incipient equipment failures. It can also help to significantly reduce downtime, increase equipment's life cycle and implement proper schedule of maintenance. For instance, an intelligent equipment monitor hosted on the cloud could transform raw signals from a pump into vibration analysis, with the results used to warn of bearing failure two weeks in advance - this way, there will be no need for immediate responses (Synergy Research Group, 2019).

Cloud-based asset management also makes it easier in providing resources since they are already in the cloud. CO: By aggregating information and data regarding assets' statuses across multiple facilities, an organization can focus on maintenance operations and its resources appropriately. This can also result into significant cost reduction as well as increase in business productivity. This is according to a study conducted by PwC for cloud computing and IoT predictive maintenance where it could cut on maintenance costs by as much as 12% get a 9% improvement on uptime while Machinery life is given an addition of 20%.

5.4 Real-Time Process Optimization

The theory of cloud computing has brought new opportunities in the field of real-time process improvement & control industry. Organisations can then use the virtually limitless computing power of the cloud to run high-complexity optimisation routines that fine-tune process parameters as activities proceed with the goal of attaining the greatest possible efficiency or product quality.

Most of these optimization systems will require the application of complex modelling like digital twins that duplicate physical processes. These digital twins also help in generating various real-time operating scenes that can be employed in the making of decisions. For example, a chemical processing plant might have a cloud-based DT for controlling reaction conditions using the current attributes of the feedstock and future tendencies in the market.

Real time optimization is not limited to a single process but is an amplification of a value chain. Integrated cloud-based systems can also use information such flow conditions and energy costs base and supply chain to facilitate operation and resource agendas of production both at facility level and at a central level (Accenture, 2019). These approaches to optimization can create a large number of social effects on operation efficiency and profitability.

As part of adopting the new methodologies, real-time optimization through the cloud is on the rise in many industries. According to Accenture's survey among the executives, as much as 87% of them expected real-time data analysis enabled by cloud computing to be a decisive factor predetermining competition in their industries by the year 2020. It has been established that cloud computing is fundamental to efficiency improvement and effectiveness in the operations of the control industry.

It can, therefore, be argued that, as the greater these key applications progress, more incorporation of cloud technologies will feature in process control systems. In the present context, Scandinavians' integration of SCADA, MES, asset management, and real-time optimization in cloud environments is fostering a new sophisticated industrial operations pattern that is intelligent, adaptive, and highly efficient. It is this change that has not only enhanced efficiency and cut the cost but also opened the opportunities for new business solutions and strategies in the conditions of the ever-growing pace of the development of industrial automation.

6. Challenges and Concerns

6.1 Security and Data Privacy

Cloud computing however, has grown to present many strengths in process control despite the rising security and data privacy issues. Hence, cloud systems' relations mean that severe consequences of cyber threats are at the door of the industrial processes. Specifically, industrial control systems that were formerly isolated from other networks are now threatened by new risks associated with the use of the Internet and common resources in the clouds (Gartner, 2018).

There is a need to protect every piece of information in the processes and, especially, intellectual property. Business spying and cyberespionage might result in huge costs and organizational and competitive disadvantages. To mitigate these risks, both CSPs and industries are investing on strong security measures as are end-to-end secure encryption, multi-factor authentication and sophisticated threat indicators. The use of the zero-trust security model that does not presuppose that no user or system can be deemed trustworthy is becoming more and more frequent in industrial cloud solutions.

Data privacy laws like GDPR that is from the EU and CCPA of California increase the layer of regulation in cloud-based process control systems. It is imperative that organisations respect these regulations especially when transferring data across national borders or when they are processing data on individuals in employment or seeking the organisation's goods or services. Another IAPP research also reported that 62 percent of the companies designated extra budget for GDPR by the year 2019, which demonstrates how privacy regulations influence cloud consumption plans.

6.2 Reliability and Latency Issues

The availability of the process control systems is a very important factor since, in the event of failure in industries, the losses and risks to be incurred may be very costly. The cloud providers propose different Service Level Agreements regarding availability but it is possible to experience network connectivity or a specific service unavailability (IoT Analytics, 2020). Minimizing these risks is challenging; however, many organizations deploy the hybrid architecture, where some significant control remain on-premise while others are set on the cloud and data analytics.

The fourth challenge is latency which is great for real-time control application. It is not suitable for procedures that call for low latency that is, a time interval between initiating a procedure, sending and receiving data from the cloud and processing the results. This is another problem that is being addressed through edge computing solutions because the critical data can be processed closer to their source. A report by Gartner stated that by 2025, 75% of enterprise data will be created and processed at the edge or outside a centralized data centre or cloud, explaining the relevance of the edge computing in industrial applications.

6.3 Integration with Legacy Systems

The implementation of new cloud computing solutions in the systems of numerous big industrial companies is one of the toughest issues at present. Legacy control systems and the related technologies and protocols might not be easily integrated with today's cloud-based ones. This can make the integration of applications complex and lead to higher costs of implementing the concepts as well as disruptions in operation.

To mitigate this challenge, the organizations are adopting the incremental approach to cloud adoption where critical and non-important activities are transferred to the cloud while the key control systems remain on the firm's premise (Bain & Company, 2019). Some of the types of devices and converters that are applied to provide an interface between old systems and clouds include gateway devices and protocol converters. Further, the availability of the new IIoT platforms that boast connectivity with a wide range of the legacy protocols is also fulfilling the role of a middleman that connects old and new technologies.

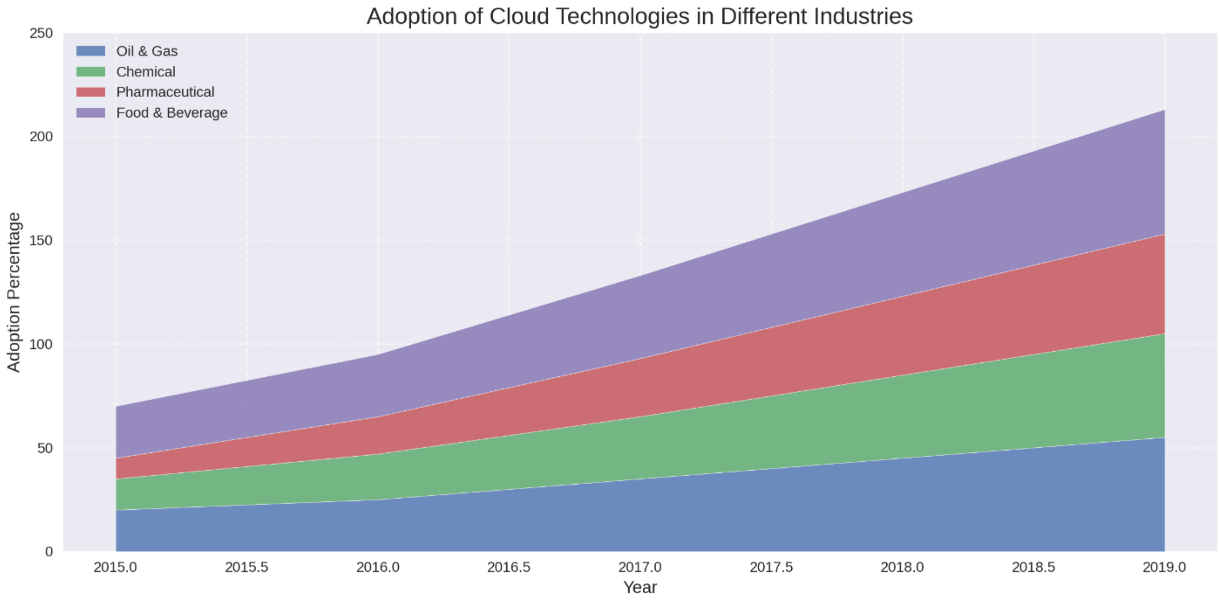
6.4 Regulatory Compliance

Compliance is an important factor in evaluating cloud-based process control systems mainly for businesses that are in industries and sectors that have strict guidelines such as the pharma, F&B, oil, and gas industries (Deloitte, 2019). These industries have typically highly rigorous demands with respect to data quality, auditability, and system verifiability. The cloud environment becomes regulated also: for example, when working with FDA 21 CFR Part 11 or GMP Annex 11, an organization becomes the owner of data and systems, and at the same time, they need to control their coordinators and overseers in a third-party provider environment.

To the above challenges, cloud service providers are developing even more compliance-focused solutions and seeking the necessary certification. For instance, today, there are numerous providers who have developed cloud services that are indeed GDPs compliant for the use of the life sciences as well as pharmaceutical applications. There are also general compliance initiatives of organisations that consist of compliance checklists, which are frequently carried out, documentation procedures, compliance and customer cloud service provider roles and responsibilities matrices.

It is important for readers to know that the legal structural system surrounding cloud-based industrial systems is still dynamic. According to Poniman Institute's research, the percentage of organizations regarding the compliance with regulations as a threat to cloud implementation in essential sectors reached 54% by the beginning of 2019. Therefore, organizations have to be prepared and be keen on the strategies to develop in order to meet the changing regulations on the cloud computing environment.

Hence, the pros of cloud computing in process control usually supersede the cons for several organizations. It resides in the fact that many organizations underestimate the necessary amount of careful planning, risk evaluation, and the reliability of the security and compliance mechanisms. That is why the integration of cloud technologies and the introduction of solutions are becoming more specialized by industry can be considered as anticipation of further development of the use of cloud-based process control systems, including critical and highly regulated industries.



7. Implementation Strategies

7.1 Assessment of Cloud Readiness

The process of introduction of cloud integration in process control starts with the evaluation of the overall cloud-sufficiency check of the organization (Gartner, 2018). This process entails the assessment of the current architecture to determine possible impediments in the move to the cloud and the feasible course of action in cloud migration. This last dimension of assessment is called P-POC, combining technical, operational, and cultural analysis of the organization.

Each control system must also consider how it will integrate with the cloud environment, the technical readiness of the IT networks and other aspects to do with the current IT infrastructure. In many cases, this phase includes taking a specific inventory of the company's IT hardware and software, analysing the required network speed and delay, and searching for places in clients' networks where it is possible to integrate the cloud services. Managers also have to realize issues relating to data management such as data volume, velocity and variety in order to determine the proper cloud storage and processing technology to adopt.

Operational readiness in turn is a subsystem that targets the business processes within an organisation. These aspects involve evaluating its effect on the company's current business processes, as well as the evaluation of need for functional changes to apply the implementation of cloud technologies where they are most effective. One of the most critical dimensions of operational readiness is that of reviewing the organization's disaster recovery and business continuity solutions for their fit and effectiveness in a cloud environment.

Cultural readiness is another aspect which people do not pay much attention but without this aspect, cloud adoption cannot be successful. This includes: gauging the organization's readiness and commitment level to adopt innovation change; evaluating the digitization competency levels of the workers; and determining if skills upgrade may be necessary (Bain & Company, 2019). The survey conducted by Deloitte showed that by the year 2019, lack of skill was a significant factor that 65% of organizations raised as a hindrance that made them slow down on cloud adaptation.

7.2 Migration Planning and Execution

This leads to the development of the migration plan once the organization's readiness assessment has been determined. This plan needs to set out a cloud migration plan that highlights different applications and processes that need to be migrated to the cloud and at what stages. A well-structured migration plan typically includes the following elements:

1. Some of the things that an organization should be very keen on, when migrating, are the systems and applications that need migration.
2. Choosing of the right cloud service and deployment models
3. Migration plan to data, which implies data cleansing and validation processes
4. Cloud and on-premises decision integration
5. Testing and validation protocols
6. Backward strategies for when migration is a problem

The following considerations highlight the fact that the process of migration should be effectively implemented, so that the strategic plan does not interfere with the organization's operations. During the transition process, organizations utilize the hybrid model in which the most important control stays on-premises, but less significant applications and data analyses transfer to the cloud. This approach is more effective in that it is conducive to the implementation of testing and validation of the cloud solution before the final migration takes place.

It is also vital to have good communication with all the stakeholders involved during the migration process which includes operators, its specialists, and the management (Deloitte, 2019). It is recommended to schedule meetings where progress reports are submitted and discussed for the purpose of addressing potential worries and checking compliance with the organization's objectives. According to McKinsey's survey, companies where change management practices were efficiently implemented, experienced a 3. They are five times more likely to outcompete others regarding the success of cloud migrations.

7.3 Change Management and Training

The supervision of change is important when implementing the use of cloud-based process control systems. This encompasses more than just controlling the technology migration process but also dealing with the human issues that may influence the uptake and usage of the solution. A comprehensive change management strategy should include:

1. Explanation of the objectives for cloud use and control and potential advantages.
2. Positive attitude of the jillion towards the oil sector in the country
3. Awareness of the places that resistance may occur.
4. That is why to support new ideas and make the organizational culture open to change, companies have to work on it systematically.

Education is a major factor in change management in cloud computing adoption. The competencies for operating and maintaining process control systems change as the systems incorporate more of cloud technologies. The management in the organizations must ensure that they configure their training programs to support the lower levels of the employees in the working of cloud-based systems (Mordor Intelligence, 2019). That training must also include new techniques and overall procedures related to the applications of cloud technologies and new ways of data protection and regulations.

This is why modern organizations are looking at cutting-edge approaches for training with such solution elements as virtual reality simulations and games. These means can be useful when teaching operators about the newly released cloud interfaces and controls. The PwC report revealed that in 2019 more than three-fourths or 82% of the executives agreed that both AI and VR training has become nearly universal in their organizations within the next three years signifying the rising incidence of immersive and tech-savvy training techniques.

To overcome these challenges there must be a promotion of continuous learning and training since the cloud technology world is rapidly changing. This may be achieved through collaborations with cloud service providers, professional bodies, and learning institutions through training and staff certification programs.

Process control systems based on using cloud technologies are considered to be an important organizational change initiative that should be directed and managed properly. These include readiness assessment, migration planning, change management and training thereby ensuring that cloud computing, while providing massive value to end user organisations has the least impact on organisations' operations (Ponemon Institute, 2019). When the industrial sector increases its focus on digital transformation, these implementation strategies become critical solutions for the process control of the future.

8. Industry-Specific Considerations

8.1 Oil and Gas

Many industries especially the oil and gas industry have embraced the use of cloud-based process control systems Because of competitive market in operation and necessity for low cost in operations. Cloud technologies prove to be highly beneficial when it comes to assets that are located in different geographical locations, be it oil platforms, pipelines etc. Real time surveillance and forecast with cloud computing has thus emerged as a necessity in avoiding major equipment and environmental breakdowns.

One of the indicative example areas where the main application of cloud computing takes place in the context of this sector is reservoir modelling and simulation. Such computationally intensive tasks prove very useful due to the scalable resources obtainable in the cloud. For instance, according to BP, the migration of HPC moved the company to the cloud led to severing processing time of seismic data by 65%. However, the industry does come with some risks and challenges that are rather specific to the business; two of them being data security and adherence to regulations (PwC, 2018). Due to the fact that exploration data is extremely sensitive and operation security being a major aspect of cloud, the cloud uses high security measures.

8.2 Chemical Processing

Within the chemical processing industry, cloud-based systems are changing the way that processes and quality are now managed. The utilization of the cloud raising computational tools subsequently leads to the real – time changes of the reaction conditions to attain high yields and minimize the wastage. In the analysis of large quantities of historical and real time data, there has been enhancement of product standardization and procedural effectiveness.

More and more companies from this sector implement Cloud-based Manufacturing Execution Systems (MES), which to offer complete visibility control over the manufacturing process. This may be extremely beneficial in batch processing, as cloud systems enable certain rigidity that is important in terms of recipes and regulations (Synergy Research Group, 2019). But the industry is faced with many regulations such as safety rules dealing with handling of hazardous materials and environmental laws. There are frequently specific needs for features with software for the cloud in this field due to the necessity of adhering to laws like REACH and RoHS.

8.3 Pharmaceutical Manufacturing

This has resulted in the pharmaceutical industry being rather slow to innovation when it comes to the application of cloud technologies primarily because its stringent guidelines plus apprehensions to data reliability. Yet, cost-saving advantages of cloud computing in consciousness like drug discovery, clinical trials, and supply chain maintenance are the major factors that members are embracing today. Cloud-based systems are especially helpful in cases where adherence to Good Manufacturing Practice (GMP) is to be achieved and electronic records and signatures' compliance with FDA 21 CFR Part 11.

A major area in the application of cloud computing in the manufacturing of pharmaceutical products is in PAT, which stands for Process Analytical Technology. PAT incorporated in cloud-based systems such as in processing analytical technologies offer an opportunity to monitor and manipulate key qualities offered to the market in real time hence enhancing product quality. It also shows that the elasticity of the cloud resources provides backing to the industry's transition toward constant manufacturing processes (International Association of Privacy Professionals (IAPP), 2019). Nevertheless, various issues such as security and privacy of patients' data, especially in clinical trials, has to be taken into consideration while developing the cloud strategy.

8.4 Food and Beverage Production

The food & beverages industry is making full use of the process control systems in the cloud for better tracking, quality assurance, and supply chain. Cloud technologies are indispensably pivotal for compliance assurance with the food safety regulation including FSMA and HACCP. Real time collecting data and analytics that comes from the cloud system assist in the fast detection and correction of problems with the quality since in this industry the problems that lead to recall have severe consequence on the financial and reputation of the company.

Integrated solutions are also being implemented through the cloud here since they advance this sector's speed of product development and market agility. For instance, cloud-based analytics are implemented for forecasting the consumers' preferences and adapting production rates to these results. There are a lot of obstacles that challenge this industry though, the integrating of cloud systems with old-fashioned equipment is much more complicated, especially in companies with limited capacity (Gartner, 2018). Further, the food industry's product base is composed of perishable items hence needs cloud solutions that can facilitate the fast deployment of decisions in the supply chain.

9. Emerging Trends

9.1 Edge-Cloud Hybrid Models

Thus, the convergence of edge computing with cloud solutions is increasingly becoming apparent as the tendencies in the process control field. Compared to exclusively cloud ones, this model minimizes the latency problem. Add Range All the while preserving the cloud's advantages such as scalability and analytics. Real-time data is also processed by edge devices and controls the immediate decision of the system while the cloud stores large data for big analysis and integrates the optimization for the entire organization.

Besides, this approach is most advantageous in industries with distant or low bandwidth locations like the oil and or the mining (ARC Advisory Group, 2018). An article by Grand View Research indicates that the global edge computing market size was worth $3. 5 billion in the year 2019 and is forecasted to reach a CAGR of 37 % between the years 2019 to 2025. 4% from 2020 to 2027, of which industrial applications are a factor.

9.2 AI and Machine Learning Integration

The use of AI and particularly, ML is now finding its way into process control systems that are cloud-based, meaning that the systems have the potential for more precise and innovative predictive maintenance, identification of anomalies and better optimization of processes. These technologies use large amounts of data accumulated in the industrial systems to define patterns and make predictions that are difficult for the operator to notice and perform.

For example, machine learning algorithms can draw a particular picture of different process data originated in equipment to determine the possibility of the failure of the equipment and in turn, set up a maintenance schedule (Deloitte, 2019). Moreover, utilizing analytical control systems with powerful artificial intelligence makes it possible to learn from the changing conditions and automatically adjust the parameters affecting the quality and rate of production. McKinsey study that estimates that intelligent maintenance could cut annual costs by 10% and downtime by up to 20%.

9.3 Industrial Internet of Things (IIoT) Convergence

The integration of the cloud technology in the IIoT environment is opening up more opportunities in process control. IIoT devices produce huge volumes of information flow which will be analysed and interpreted in clouds and supply ultra-real-time knowledge regarding the precise industrial processes. It this way, this convergence is powering smart factories and their digital twins, where actual physical processes are replicated in a digital environment for testing and improvement.

The IIoT-cloud integration is also supporting the creation of new business models for Equipment as a Service, in which manufacturers can provide performance prediction as well as the key performance optimization (Grand View Research, 2020). IoT Analytics in its report has predicted that the number of connected IoT devices will be approximately 27 billion in the year 2025 and industry will be the major influencer of this growth.

10. Future Outlook

10.1 Technological Advancements

The development and implementation of cloud computing in process control may be brought by the following technological inventions. Quantum computing is still relatively new, but has the capability to upend many instances of difficult optimizations with larger scale industries. The popularity of distributed AI also increases, assuming that more and more complex decisions will be made at the level of Edge AI devices. 5G networks will offer the high-speed low-latency for real-time control of distributed systems in Industries.

10.2 Evolving Industry Standards

With time, as the cloud adoption in process control increases the standardized conventions as well as norms can be anticipated to evolve into a more specialized domain. Still, the Industrial Internet Consortium (IIC) and Open Process Automation Forum (OPAF) are prominently developing standards and architectures for cloud-based industrial systems (Mell & Grance, 2011). These emerging standards will prove to be significant in the provision of security, dependability, and compatibility of the cloud-based process control systems.

10.3 Potential Disruptions and Opportunities

Further developments in the application of cloud technologies in process control would possibly cause shifts in the organizational models of industries. It can be expected that equipment manufacturers will increasingly tie in their products with extended service offerings around data analytics based on cloud applications. This shift could lead to new business for suppliers of software and integrators to the industrial cloud markets.

New roles could also be expected, for instance, industrial data scientists or specialists in cloud automation because of the growing role of data in industrial processes. Organizations that are capable of identifying and capitalizing on the innovative opportunities created by cloud technologies will most probably have the edge in the near future.

11. Conclusion

11.1 Summary of Key Points

The ever-evolving process control industry with the help of novel and powerful technology cloud computing has come up with varieties of applications some of them are outlined below (IoT Analytics, 2020). The blending of cloud technologies to the standard control frameworks to improve the functioning, prognosticate for the regular maintenance, and real-time fine-tuning of many industries has been spearheaded in this area.

11.2 Implications for Process Control Industry

The use of cloud systems is currently transforming the process control systems' market; the trend is toward more data based, flexible, and integrated processes. As such, this transformation is not an easy process, especially in the aspects of security, latency, and regulation. At the same time, such advantages as increased operating efficiency, reduced costs, and new opportunities are stimulating further investment and implementation.

11.3 Recommendations for Stakeholders

For organizations considering cloud adoption in process control, key recommendations include:

1. Establishing the cloud strategy based on the corporation's goals and aims.
2. On the organization level, focus on the development of the internal expertise in cloud solutions and big data.
3. Ensure the security and compliance aspect is included right from the start of any cloud-based project.
4. Only by cultivating the culture of contending and learning can enterprises make the full use of cloud services.
5. Learn more about the changes in the industry and novelties in the sphere of using cloud solutions for process control (McKinsey & Company, 2019).

Thus, the further perspective seems quite definite stating that the role of cloud computing at the stages of process control will only strengthen. Hence, the organizations that will be able to manage the challenge and maximize the potential of cloud technologies will be well-placed to assume the position of leadership in the incoming age of smart manufacturing and Industry.

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