Big Data Analytics by Cloud Computing in Industry 4.0, A Review

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Abstract: In the context of Industry 4.0, cloud computing offers the scalability, flexibility, and wide range of services required to facilitate big data analytics. This enables enterprises to extract meaningful insights from the vast amounts of data produced by intelligent and networked production processes. Industry 4.0 demands real-time decision-making as cloud-based analytics enable quick processing of streaming data for immediate insights. Big data analytics and cloud computing together have become the cornerstones of the digital revolution, transforming how companies operate, grow, and get value from their massive data warehouses. Organizations may expand their computer capabilities according to the amount of data and processing demands thanks to cloud platforms. By evaluating equipment data in real-time and cutting down on downtime, cloud computing makes predictive maintenance possible while also increasing efficiency. By evaluating data from several sources, cloud-based analytics enhance supply chain operations and facilitate better inventory control and logistics. Furthermore, real-time processing at the point of data production is made possible by the developing combination of edge computing and cloud analytics, which lowers latency. The present assessment underscores the revolutionary effect of merging Big Data Analytics and Cloud Computing within the framework of Industry 4.0, stressing the benefits, obstacles, applications, and forthcoming patterns in this ever-evolving domain. The goal of this in-depth analysis is to further our knowledge of how important it will be for Industry 4.0 to integrate Big Data analytics with cloud computing.

Keywords: Big Data Analytics, Cloud Computing, Industry 4.0

1. Introduction

Big data analytics is the process of analyzing and processing vast volumes of data to generate meaningful conclusions. Cloud computing is essential for teaching big data analytics skills in the context of Industry 4.0, the fourth industrial revolution characterized by the integration of digital technology, automation, and data exchange in production [1, 2]. Industry 4.0 is the term used to describe the integration of digital technology, data exchange, and robotics in industrial operations, especially manufacturing [3]. Scalable and flexible cloud computing resources can help process, store, and analyze the vast amounts of data generated by Industry 4.0 [4]. A scalable and adaptable foundation for data management and storage is offered by cloud computing. Business can manage and store enormous volumes of data whenever you need them by using cloud computing services like AWS, Azure, and Google Cloud [5]. Large upfront hardware costs are no longer necessary as a result. Cloud-based storage options and distributed computing frameworks like Spark and Hadoop may be used to effectively handle large datasets [6].

Big Data analytics, the process of drawing conclusions that can be put into practice from enormous and varied datasets, is now essential to making well-informed decisions [7, 8]. Meanwhile, Cloud Computing has emerged as the bedrock of scalable and flexible computing resources, enabling organizations to process, store, and analyze massive datasets without the constraints of on-premise infrastructure [9]. Combining Big Data Analytics with Cloud Computing within Industry 4.0 provides new possibilities for innovation, operational efficiency, and strategic growth in addition to solving the problems caused by the sheer volume of data [10, 11]. Ensuring robust security measures are implemented throughout the cloud migration of sensitive industrial data is crucial to prevent data breaches and unauthorized access. Respecting data privacy regulations and data protection laws is another issue that has to be tackled [12, 13]. Figure 1 illustrates how big data analytics applications using cloud computing are used in industry 4.0.

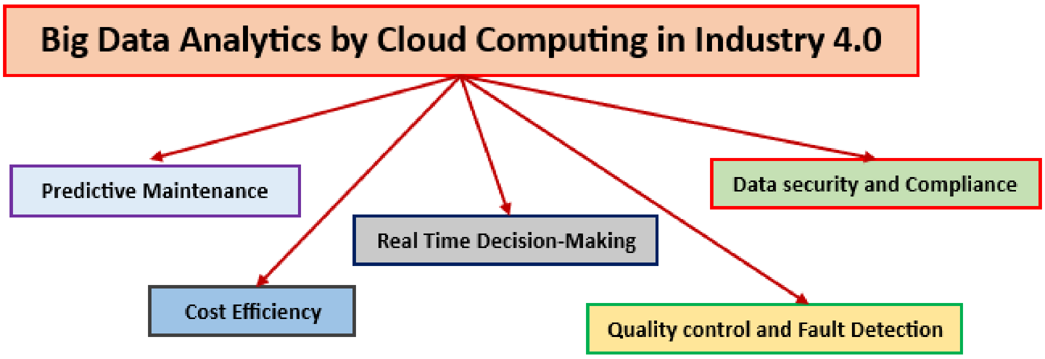

Fig. 1. Cloud computing applications for big data analytics in industry 4.0.

Manufacturers can employ cloud-based systems to use advanced analytics methods like artificial intelligence (AI), machine learning, and deep learning to glean valuable patterns and trends from industrial data [14]. Real-time data processing and predictive analytics are made possible by cloud computing, which helps businesses foresee problems, cut down on downtime, and make better decisions [15]. Furthermore, cloud-based solutions make it easier to integrate digital twins, enabling continuous monitoring and enhancement of industrial processes. This enhances quality control, production efficiency, and supply chain management, all of which lead to a more adaptable and intelligent manufacturing procedures [16].

Soori et al. [17-21] recommended methods for virtual machining to assess and improve CNC production in virtual settings. Soori et al. [22] discussed the most recent advancements in friction stir welding techniques in an attempt to evaluate and improve the process' effectiveness during component manufacturing.

Soori and Asamel [23] examined ways to minimize residual stress and movement inaccuracy during turbine blade five-axis milling operations by utilizing virtual machining machinery. Soori and Asmael [24] considered the prospect of employing virtualized machining techniques to mill materials that are challenging to cut while keeping an eye on and lowering the cutting temperature. Soori et al. [25] suggested that when milling turbine blades in five axis milling operations, surface characteristics be improved by using a sophisticated virtual machining technique.

Soori and Asmael [26] developed virtual milling methods for five-dimensional impeller blade milling to minimize deformation error. Soori [27] offered virtual innovation as a means of investigating and learning more about the process of making parts in virtual worlds.

Soori and Asmael [28] gathered the findings of current research from the literature in order to assess and enhance the parameter strategy for simulating machining processes. To increase the accuracy and reliability of component manufacture, the supply chain's data availability and quality, and the efficiency of energy use, Dastres et al. [29] suggested examining current developments in wireless manufacturing systems based on RFID. Soori et al. [30] looked at how artificial intelligence and machine learning could assist CNC machine tools become more profitable and efficient in the element production industry. To improve the functionality of machined parts, Soori and Arezoo [31] explored the issue of calculating and reducing residual stress during the milling process. To improve surface integrity and lessen residual stress during the Inconel 718 grinding process, Soori and Arezoo [32] recommended obtaining the optimal machining settings by applying the Taguchi optimization approach. To increase the lifespan of the cutters used in machining operations, Soori and Arezoo [33] examined a variety of techniques for forecasting tool wear. Soori and Asmael [34] investigated the application of computer-assisted process scheduling to boost component manufacturing methods' productivity. Dastres and Soori [35] examined approaches to improve decision-making by offering choices for data storage and administration using web-based developments in decision-support systems. Dastres and Soori [36] explored the potential applications of artificial neural network technology to boost product efficacy. Dastres and Soori [37] recommended using channels of communication for environmental issues in an effort to decrease the detrimental impact of technology development on disasters. In order to enhance online privacy and security, Dastres and Soori [38] presented the secure socket layer. Dastres and Soori [39] developed a decision support system strategy by talking about the advancements in web-based decision support systems. The latest advancements in data network security were investigated by Dastres and Soori [40] to improve techniques for security of networks. Dastres and Soori [41] investigated picture processing and assessment systems to increase the range of potential uses. Soori and Arezoo [42] have enhanced the accuracy of 5-axis CNC milling processes by correcting errors in tool motion, temperature, geometry, and measurements. Soori et al. [43] studied recent advances in the literature to analyze and modify the effects of neural networks, deep learning, and machine learning on advanced robotics.

To determine whether the milling process's cutting specifications have an impact on the tool's life and the temperature at which the cutting occurs, Soori and Arezoo [44] created an application for a virtual machining technique. Soori and Arezoo [45] investigated how coolant changed throughout the turning of Ti6Al4V material in terms of cutting temperature, tool choice, and roughness on the surface. Soori [46] examines and modifies composite materials and structures by doing a review of current developments from published research. Soori et al. [47] investigated strategies to improve industrial quality control and streamline the manufacturing of parts. 4.0 smart factories that use IoT applications. To reduce the amount of harm that is done to drilling tools, Soori and Arezoo [48] stuided a virtual machining. To enhance the overall quality of the product produced by water jet cutting using an abrasive, Soori and Arezoo [49] reduced roughness of surface and residual stress in machining operations. To improve the precision of turbine blade five-axis machining operations, Soori [50] detects and corrects any possible errors in the deformation. To assess and improve the precision of CNC machining procedures and parts, Soori and Arezoo [51] examined the application of finite element analysis to CNC machine tool customization. To assess and maximize the energy utilization of industrial robots. Soori et al. [52] examined several methods for optimizing energy consumption. Applications of blockchains for the industrial internet of things are studied by Soori et al. [53] in order to improve the performance of industry 4.0's sustainable supply chain management.

Soori et al. [54] conducted a study to evaluate and enhance the production process for Industry 4.0 components by balancing the advantages and disadvantages of virtual manufacturing methods. Soori et al. [55] are investigating how AI may be used to integrate supply chain management in high-tech manufacturing. In order to improve the way that the next electric airplanes are managed by their batteries, Raoofi and Yildiz [56] studied machine learning strategies for estimating battery states in aviation propulsion battery management platforms. Raoofi and Yasar [57] examine how cutting-edge digital technology is being incorporated into frameworks and applications for airworthiness management to get insight into the state of the link between the digital world and maintenance practices. Raoofi and Ölçen [58] emphasize the legal stances taken by continental airlines on eco-friendly aircraft and airport facilities in order to ensure the long-term viability of aviation.

The authors' earlier works offer a thorough framework for examining how AI and virtual simulation affect sophisticated manufacturing processes [59-61]. The authors have used artificial intelligence (AI) to improve manufacturing processes, including machining accuracy, residual stress reduction, tool life optimization, and surface features [62-64]. Several research on AI-driven manufacturing systems, such as supply chain management blockchain applications, digital twins, and IoT-enabled smart factories, provide pertinent background for examining AI's potential in smart manufacturing processes [54, 65, 66]. By employing AI to improve process performance, increase productivity, and ease decision-making, the authors hope to adapt these developments to additive manufacturing. This will enhance AM technologies' scalability, precision, and production quality inside Industry 4.0 frameworks [53, 67]. In order to increase mechanical properties of metals during cutting process, mechanical properties are studied [68].

In the framework of the industry 4.0 paradigm, this study contributes to the expanding discourse discusses how the IoT and blockchain technologies will change sustainability management of supply chains. It looks at how better accountability and transparency could reduce carbon footprints, make the most accessible resources that are, and promote moral conduct [69]. First, an overview of Industry 4.0 is provided, along with an emphasis on its pivotal role in shaping the trajectory of industrial processes. The integration of IIoT technology into supply chain processes is covered in the article along with how it may increase visibility, efficiency, and traceability.

This review article provides an in-depth examination of the ways in which cloud computing and big data analytics interact within the framework of Industry 4.0, emphasizing the ways in which these advancements can encourage productivity, innovation, and a competitive edge. In the framework of Industry 4.0, this paper explores the fundamental ideas, uses, and advantages that result from the combination of cloud computing with big data analytics. The report critically evaluates the effects of this integration on a wide range of industrial domains, illuminating real-world uses, case studies, and obstacles that businesses must overcome to leverage cloud computing for big data analytics. By understanding and leveraging this powerful alliance, industries can embark on a journey towards data-driven excellence, positioning themselves at the forefront of innovation and resilience in an era defined by digital transformation [70]. The analysis's conclusion outlines potential directions for further study and development, emphasizing the value of enhanced security protocols, interoperability standards, and ethical concerns when using cloud computing and big data analytics in Industry 4.0. Therefore, this analysis adds to the comprehensive knowledge of the revolutionary influence of Big Data Analytics by Cloud Computing in defining the Industry 4.0 environment by combining insights from academic research, industry practices, and technology breakthroughs. [71].

2. Scalability in big data analytics

In the context of Industry 4.0, flexibility in big data analytics using cloud computing is essential. Because cloud computing offers scalable resources, businesses may easily scale up or down in response to changes in data volume and processing requirements [72]. This is necessary to manage the enormous volumes of data produced in Industry 4.0 settings. Here's an overview of how scalability is important in this context:

1. Handling Massive Data Volumes: Industry 4.0 produces enormous amounts of data from a number of sources, including as sensors, IoT devices, and industrial processes. Cloud computing offers the scalability required to effectively manage these enormous amounts of data. Cloud solutions may dynamically assign resources as data volume grows, guaranteeing that the infrastructure can accommodate the increasing demand without sacrificing performance [73].

2. Resource Provisioning and Elasticity: As cloud computing enables on-demand resource provisioning, businesses may scale up or down in response to workload fluctuations. This flexibility is necessary to manage different degrees of real-time data processing requirements [74]. For example, during peak production periods, more computing resources can be allocated to process and analyze data, while during idle times, resources can be scaled down to save costs [75].

3. Parallel Processing and Distributed Computing: Complex calculations that can be aided by distributed computing and parallel processing are frequently a part of big data analytics. Cloud systems offer the infrastructure needed to divide work across several nodes, increasing data processing speed and effectiveness [76]. Cloud computing scalability makes it simple to integrate parallel processing frameworks, such Apache Spark and Hadoop, to divide workloads among a group of virtual machines [77].

4. Cost Efficiency: Scalability in cloud computing aligns with a pay-as-you-go model. Organizations can scale their infrastructure based on the actual demand, avoiding over-provisioning and minimizing unnecessary costs during periods of low activity. This cost-efficiency is particularly important in Industry 4.0, where operational expenses need to be optimized while still meeting the demands of a highly dynamic and data-intensive environment [78].

5. Real-time Analytics: Real-time analytics are made possible by scalable cloud solutions, which enable businesses to get insights from data as it is being created. This is crucial in Industry 4.0 scenarios where real-time decision-making can impact operational efficiency and responsiveness. Cloud-based analytics platforms can dynamically scale to accommodate the rapid processing requirements of real-time data streams [79].

6. Data Storage and Retrieval: Scalable options for storing enormous volumes of data are provided by cloud storage services. This includes options for both structured and unstructured data, providing flexibility in managing diverse data types generated in Industry 4.0 environments. Scalable storage solutions ensure that organizations can efficiently store and retrieve data as their requirements evolve.

In conclusion, Industry 4.0's scalability in big data analytics through cloud computing offers the agility and effectiveness required to manage the enormous amounts of data, enable real-time analytics, minimize expenses, and adjust to shifting workloads in a dynamic industrial environment. Scalability is a critical component that allows enterprises to fully utilize Industry 4.0 technology.

3. Cloud data storage and management

Big data analytics is especially relevant to the context of Industry 4.0 when paired with cloud computing, storage, and data management. Intelligent factories need reliable and affordable cloud systems to store the massive volumes of data produced by sensors, equipment, and other Internet of Things devices [4, 80]. Different formats, including structured and unstructured data, can be used to store data [81]. The following are essential components of cloud computing-based big data analytics storage and data administration in the context of Industry 4.0. as,

1. Scalable Storage Solutions: Processing and analyzing huge datasets is a part of big data analytics. Platforms for cloud computing provide scalable storage options that could satisfy the different storage requirements of Industry 4.0 applications. This scalability ensures that organizations can adapt to changing data volumes without the need for significant infrastructure investments [82].

2. Data Warehousing: A consolidated location for both structured and unstructured data is offered by cloud-based data warehouses. Large-scale analytics workloads can be effectively managed by these warehouses thanks to their design [83]. Cloud data warehouses also support the integration of data from various sources, enabling comprehensive analytics across the entire value chain in Industry 4.0 [84].

3. Data Security and Compliance: Industry 4.0 utilizes important and sensitive data. To guarantee the integrity and confidentiality of data, cloud providers use strong security features including encryption, access limits, and compliance certifications [85]. Compliance with industry regulations is critical, and cloud services often provide tools and features to assist organizations in meeting these requirements [86, 87].

4. Data Lifecycle Management: Effective data management in the cloud involves considering the entire data lifecycle, from creation and ingestion to storage, processing, and archiving. Cloud platforms enable enterprises to cut storage costs and guarantee data availability when required for analytics by providing services and tools for automated information lifecycle management [88].

5. Data Integration and ETL (Extract, Transform, Load): In Industry 4.0, cloud-based services make it easier to integrate data from many sources. Cloud-based ETL procedures may be used to convert and get data ready for analytics. Organizations can guarantee that data is in the proper format for analysis and expedite data integration processes with cloud-based ETL technologies [89, 90].

6. Serverless Computing for Analytics: Serverless computing models, such as Function as a Service (FaaS), allow organizations to run analytics functions without managing the underlying infrastructure. This approach can lead to cost savings and increased agility in deploying analytics solutions for Industry 4.0 applications [3, 91].

7. Distributed Computing and Parallel Processing: The distributed computing and parallel processing capabilities of cloud platforms enable efficient analysis of massive datasets. With cloud-based technologies like Hadoop and Apache Spark, big data analysis may benefit from distributed processing power [92].

8. Real-time Analytics: Industry 4.0 scenarios often require real-time analytics to support decision-making processes. Cloud-based solutions offer the necessary infrastructure and tools to implement real-time analytics, allowing organizations to gain insights and respond quickly to changing conditions [93].

Cloud data storage and management process in industry 4.0 is shown in the figure 2.

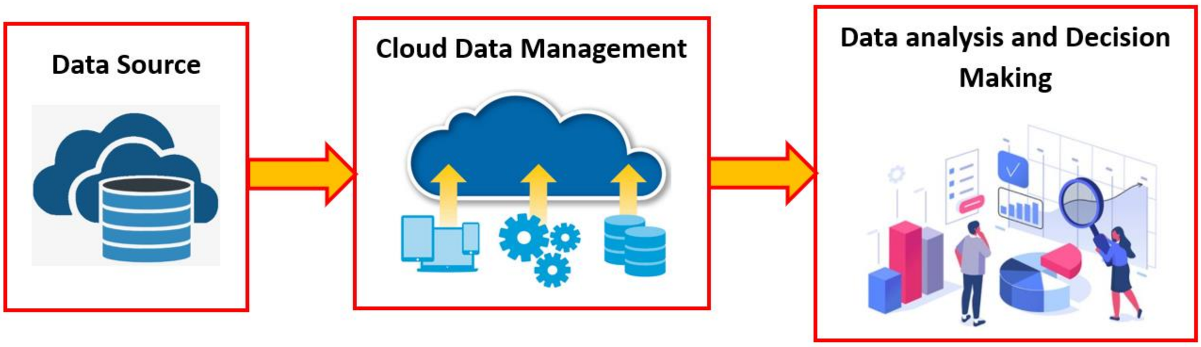

Fig. 2. Cloud data storage and management process in industry 4.0.

In summary, big data analytics, cloud computing, and Industry 4.0 together offer enterprises revolutionary opportunities. In the dynamic world of Industry 4.0, organizations may get important insights from massive datasets, improve their operations, and make data-driven choices by utilizing scalable storage systems, sophisticated data management techniques, and cloud-based analytics tools.

4. Advanced computational power

Within the context of Industry 4.0, the utilization of cloud computing's increased processing capacity has revolutionized big data analytics. It is usually ask for a lot of processing power. Cloud computing enables enterprises to handle and analyze large information efficiently by providing customers with access to advanced computer capabilities [94]. This is particularly important for running complex algorithms and machine learning models [95]. Here's how advanced computational power in Big Data Analytics, facilitated by cloud computing, contributes to Industry 4.0:

1. Scalability and Flexibility: Businesses can quickly scale their processing capability in response to the volume of data they need to manage since cloud computing provides on-demand scalability. This adaptability is crucial for managing the enormous volumes of data produced in Industry 4.0 settings, adjusting to changing workloads, and guaranteeing peak performance.

2. Storage Capabilities: Large and affordable storage solutions are provided by cloud platforms, enabling businesses to effectively store and handle massive information. In Industry 4.0, big data analytics frequently entails processing and evaluating enormous datasets from several sources, and cloud-based storage makes sure the data is easily accessible for study [96].

3. Distributed Computing and Parallel Processing: Cloud computing environments enable parallel processing and distributed computing, allowing organizations to distribute complex analytics tasks across multiple servers or nodes. This parallelization accelerates data processing, reducing the time required for analytics tasks and supporting real-time decision-making in Industry 4.0 scenarios [97].

4. Machine Learning and Artificial Intelligence (AI): Predictive analytics and anomaly detection are two examples of complex data processing jobs that might benefit from the strong machine learning and artificial intelligence capabilities offered by cloud platforms. These abilities are essential in Industry 4.0 because they enable the derivation of useful insights from Big Data, which in turn supports industrial system optimization, quality assurance, and predictive maintenance [98, 99].

5. Cost Efficiency: Pay-as-you-go cloud computing enables businesses to only pay for the services they really utilize. This cost-efficient approach is particularly advantageous for companies in Industry 4.0, as

they can avoid upfront infrastructure investments and adapt their computational resources based on evolving data processing requirements [98].

6. Real-time Analytics: Real-time stream processing and analysis are made possible by cloud-based big data analytics. Applications like supply chain optimization, real-time monitoring and management of intelligent manufacturing processes, and quick response to changing circumstances all depend on this capacity.

7. Collaboration and Accessibility: By offering a centralized platform where engineers, data analysts, and decision-makers may access and share analytics tools and findings, cloud computing promotes teamwork. In Industry 4.0 ecosystems, this accessibility encourages cooperation amongst many stakeholders, resulting in better decision-making and increased overall efficiency [100].

In summary, the integration of advanced computational power through cloud computing in Big Data Analytics significantly enhances the capabilities of Industry 4.0. It makes it possible to create scalable, adaptable, and affordable solutions that enable businesses to glean insightful information from massive volumes of data, eventually spurring innovation and competitiveness in today's industrial world.

5. Flexibility and agility in choosing the right analytics tools

In the context of Industry 4.0, big data analytics should be flexible and quick to adjust, especially when cloud computing is involved. You are free to choose the right frameworks and analysis instruments while using cloud systems. Big data analytics and cloud computing combine to provide the flexibility and agility needed to effectively collect and derive insights from enormous and diverse amounts of data in the context of industry 4.0. Because of this synergy, firms can swiftly make well-informed decisions, maximize resource utilization, and adjust to changing requirements. Without needing to make large upfront expenditures in hardware and software, organizations may swiftly embrace new tools and technologies [101]. The flexibility allows organizations to adapt quickly to changing data volumes in Big Data Analytics [102]. Cloud platforms enable automatic scaling to accommodate increased data processing requirements, ensuring agility in handling varying workloads. Cost efficiency contributes to agility as organizations can allocate resources efficiently, avoiding unnecessary expenses while responding promptly to changing analytical needs. Quick and reliable access to data is essential for timely decision-making in Industry 4.0 [103]. Cloud-based storage technologies provide the flexibility needed for efficient data analysis and retrieval. Industry 4.0 incorporates state-of-the-art technology such as artificial intelligence and machine learning to assist businesses in reliably and quickly extracting crucial insights from data, enabling prompt and flexible decision-making [92, 104]. The impacts of cloud computing technology in in choosing the right analytics tools is shown in the figure 3.

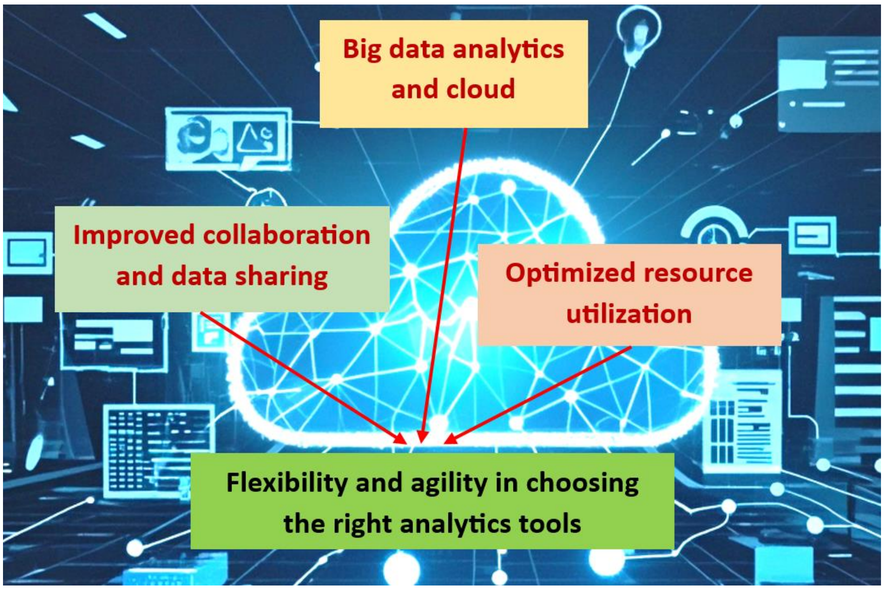

Fig. 3. The impacts of cloud computing technology in in choosing the right analytics tools.

6. **Cost efficiency**

Cloud computing is one of the primary drivers of Industry 4.0's reduced big data analytics costs. The scalable and adaptable resources offered by cloud computing may be tailored to satisfy the constantly evolving needs of big data processing. Pay as you go Businesses may only pay for the resources they really utilize thanks to cloud computing [4, 95]. Businesses trying to manage their budgets, particularly while handling several big data analytics workloads, would benefit from this cost-effective strategy [105]. Here are several ways in which Cloud Computing contributes to cost efficiency in Big Data Analytics within the context of Industry 4.0:

1. Scalability and Resource Flexibility: Depending on the amount of data that has to be processed, cloud platforms provide resources that may be scaled up or down. Because of its flexibility, companies may only pay for the resources they really utilize, maximizing their costs during peak and off-peak periods.

2. Pay-as-You-Go Model: The majority of cloud providers use a pay-as-you-go pricing structure. Due to the fact that enterprises are now charged according to how resources are really used, significant upfront expenditures in hardware and infrastructure are avoided. Pay-as-you-go models are a good fit for Big Data workloads because of their changeable and unexpected nature [106].

3. Reduced Capital Expenditure: The use of cloud computing removes the requirement for large capital investments in physical infrastructure. By using the infrastructure that cloud service providers offer, businesses may avoid having to handle hardware replacement, updates, and maintenance [107].

4. Resource Consolidation: Through virtualization and resource pooling, cloud platforms enable multiple users to share the same physical infrastructure. This resource consolidation improves overall efficiency and reduces costs by maximizing resource utilization [108].

5. Automated Resource Management: Cloud platforms offer automation tools that dynamically allocate and deallocate resources based on workload requirements. This automation minimizes human intervention, reduces operational costs, and ensures optimal resource utilization [109].

6. Global Distribution of Data Centers: Cloud providers have data centers distributed globally. This allows organizations to deploy Big Data Analytics workloads closer to their target audience, reducing latency and improving performance. Additionally, it helps in complying with data sovereignty regulations [110].

7. Managed Services for Big Data: A range of managed services, including fully managed data warehouses, analytics platforms, and machine learning services, are available from cloud providers for Big Data processing. These services save businesses money by removing the need to develop and manage intricate big data infrastructure. [6].

8. Improved Collaboration and Data Sharing: Cloud platforms make it easier for teams and departments inside a business to collaborate and share data. This improved cooperation can prevent duplication in data processing attempts and result in a more effective use of resources.

9. Security and Compliance: Cloud providers make large expenditures in security measures to guarantee data protection and compliance with industry standards [111]. As a result, companies may have less work to do in independently implementing and maintaining strong security measures [112].

10. Continuous Innovation: Cloud providers regularly introduce new features and services. By leveraging these innovations, organizations can stay ahead of the curve without incurring additional costs for upgrading or maintaining legacy systems [12].

The cloud computing contributes to cost efficiency in Big Data Analytics of industry 4.0 is shown in the figure 4.

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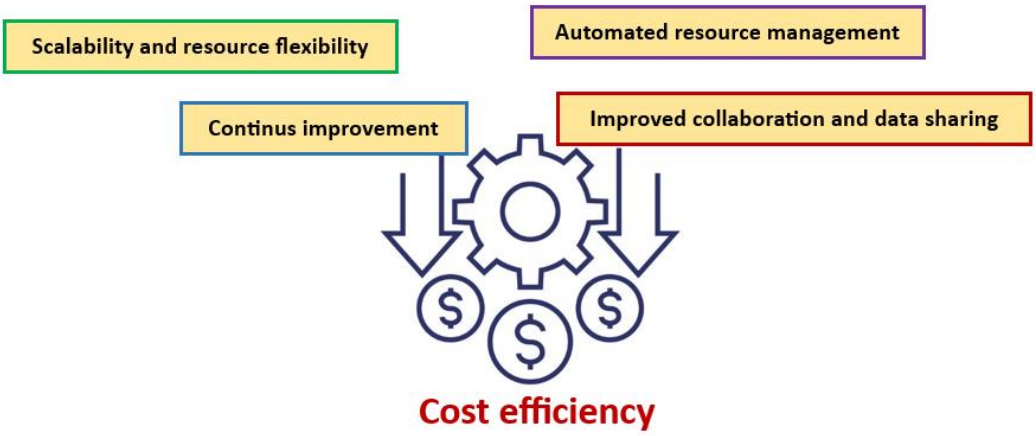

Fig. 4. The cloud computing contributes to cost efficiency in Big Data Analytics of industry 4.0.

In summary, although cloud computing offers a scalable, adaptable, and reasonably priced infrastructure that is well-suited to the dynamic nature of contemporary data processing requirements, it significantly improves the cost-effectiveness of Big Data Analytics in Industry 4.0.

7. Collaboration and accessibility

Cloud-based analytics solutions facilitate collaboration among teams located in different geographical locations. Data scientists, engineers, and analysts can access the same data and analytics tools from anywhere, fostering collaboration and improving decision-making processes [83]. Here's an overview of how these elements intersect and contribute to the effectiveness of data analytics in the cloud within the Industry 4.0 framework:

1. Data collaboration:

    - Cross-functional Teams: Collaboration in Industry 4.0 entails bringing together individuals from a variety of disciplines, including data science, domain expertise, and information technology. By giving these teams a single platform to work on and facilitating the easy exchange of tools, data, and insights, cloud computing promotes cooperation [113].
    - Real-time Collaboration: Cloud-based Big Data Analytics allows for real-time collaboration, as team members can access and work on the same datasets simultaneously. This real-time collaboration is essential in addressing complex industrial challenges that require quick decision-making [114, 115].
    - Scalability and Flexibility: Teams can adjust to different workloads thanks to the scalable infrastructure provided by cloud platforms. This is particularly beneficial in data analytics where the amount of data to be processed may vary significantly over time.

2. Data accessibility:

    - Anytime, Anywhere Access: Cloud computing provides the advantage of accessing data analytics resources from anywhere with an internet connection. This is especially important in Industry 4.0 scenarios where data might be generated across different locations or by devices in the field [116].
    - Resource Sharing: Computational resources are used as efficiently as possible thanks to cloud systems, which provide effective resource sharing. In addition to being cost-effective, this enables firms to assign resources according to the particular requirements of analytics jobs [117].
    - Integration with Edge Computing: Industry 4.0 often involves the use of edge devices for data collection and processing at the source. Cloud computing facilitates the integration of edge

computing with centralized analytics, ensuring that insights generated at the edge can be seamlessly incorporated into the broader analytics framework [90].

3. Security and compliance:

    - Secure Data Sharing: Collaboration in BDA requires secure sharing of sensitive data. Strong security measures like encryption and access restrictions are frequently included in cloud systems, guaranteeing that data is exchanged safely between authorized users.

    - Compliance Management: In industries with strict regulatory requirements, cloud platforms offer tools and services to assist in compliance management. This is crucial for ensuring that data analytics processes adhere to industry-specific regulations [118].

4. Cost efficiency and resource optimization:

    - Pay-as-You-Go Models: Cloud computing typically follows a pay-as-you-go model, allowing organizations to optimize costs based on actual resource usage. This is advantageous in BDA scenarios where resource requirements may fluctuate [119].

    - Elasticity: As cloud platforms are elastic, businesses may adjust their resource levels to meet demand. The dynamic nature of data analytics workloads in Industry 4.0 necessitates this adaptability [120].

In summary, establishing a smooth and effective working environment for teams, guaranteeing safe and legal data sharing, and optimizing resources for economy and scalability are the main components of Big Data Analytics through Cloud Computing in Industry 4.0's accessibility and collaboration aspects [121]. These aspects collectively contribute to the agility and effectiveness of data analytics processes in the context of Industry 4.0.

8. IoT Integration of big data analytics

IoT devices, which generate massive amounts of data, are heavily utilized in Industry 4.0. Businesses may make data-driven choices and streamline processes by using cloud computing to quickly integrate, process, and analyze data from many devices in real time [80]. Here's a breakdown of how these components work together:

1. IoT in Industry 4.0:

    - Sensor Networks: Sensors on Internet of Things devices gather data in real time from the outside environment. These sensors may be integrated with other assets, machinery, and equipment [122, 123].

    - Connectivity: Since IoT devices are online, they may exchange data and interact with one another. Regarding monitoring and control during advanced manufacturing process, this link is essential [124].

2. Big Data Analytics:

    - Data Collection: Data generated by IoT devices is enormous. To extract useful insights, big data analytics processes and analyzes this data [125].

    - Data Processing: Techniques such as data filtering, aggregation, and transformation are applied to make sense of the raw data.

    - Machine Learning: Advanced analytics, including algorithms of machine learning, can identify patterns, anomalies, and predictions based on historical and real-time data [126].

3. Cloud Computing:

    - Scalability: Cloud platforms provide the necessary infrastructure to scale resources according to the data volume and processing requirements [86, 127].

- Storage: Cloud storage solutions allow for the efficient storage of large datasets generated by IoT devices [128].
- Computational Power: Cloud computing platforms offer powerful computational resources needed for processing and analyzing big data [129].

4. Integration Points:
   - Data Ingestion: IoT-generated data is ingested into cloud-based storage systems. This could involve data lakes or other storage solutions.
   - Real-time Processing: Cloud platforms facilitate real-time data processing, allowing organizations to make instant decisions based on the incoming data [130].
   - Analytics Services: Cloud services often provide analytics tools and services that can be integrated with IoT data to gain insights [108].
   - Machine Learning Models: It is possible to create and use models for quality assurance, predictive maintenance, and optimization using cloud-based machine learning services [131].
5. Benefits:
   - Real-time Decision-Making: Businesses can utilize the integration to evaluate IoT data and instantly make decisions based on facts.
   - Cost-Efficiency: Cloud computing enables a pay-as-you-go model, reducing the need for upfront infrastructure investments [132].
   - Scalability: Organizations can manage increasing volumes of data without worrying about infrastructure constraints because to the scalability of cloud resources.
   - Predictive Maintenance: Companies can organize maintenance proactively by predicting when equipment is likely to break by studying IoT data [133].
6. Challenges:
   - Security Concerns: Protecting sensitive IoT data and analytics results is crucial to prevent unauthorized access [134, 135].
   - Data Integration: Ensuring seamless integration of data from diverse IoT devices and sources can be challenging.
   - Interoperability: Standardization and compatibility between different IoT devices and cloud platforms need attention for smooth integration [136].

In conclusion, using cloud computing to integrate big data analytics and IoT, Industry 4.0 offers a solid framework for creating intelligent, data-driven industrial ecosystems. It assists companies in making better decisions, more efficient operations, and increased competitiveness by utilizing real-time data [137].

9. Security and compliance

Big Data analytics solutions that are scalable and effective are made possible in large part by cloud computing, but there are unique security and compliance issues that must be carefully considered. Cloud service companies make significant investments in compliance requirements and security safeguards [138]. This is critical for industries dealing with sensitive data, ensuring that the data analytics processes adhere to regulatory requirements. This is crucial for Industry 4.0, where sensitive data from manufacturing processes and IoT devices must be handled securely and in compliance with industry regulations [139]. For the Security in Big Data Analytics by Cloud Computing, the considerations can be,

1. Data Encryption: Implement robust encryption protocols for data that is in motion or at rest. Use secure protocols (such as TLS/SSL) for transferring data between cloud and on-premises systems.
2. Access Controls: To restrict access to data based on roles and responsibilities, use strong access controls. Manage and audit user rights by implementing identity and access management systems.
3. Authentication and Authorization: Use multi-factor authentication to enhance user authentication security. Implement fine-grained authorization to control access to specific data and analytics resources [87].
4. Network Security: Employ Virtual Private Clouds (VPCs) and network security groups to isolate and secure cloud resources. Implement intrusion detection/prevention systems and firewalls to keep an eye on and safeguard network traffic.
5. Data Residency and Sovereignty: Be aware of data residency regulations and ensure compliance by choosing appropriate cloud regions. Implement mechanisms to control where data is stored and processed to meet regulatory requirements [140].
6. Incident Response and Monitoring: Establishing a solid incident response plan can help you respond to security situations more swiftly. Using logging and continuous monitoring can help you locate and address security problems [110].

For the compliance in big data analytics by cloud computing, the considerations can be,

1. Regulatory Compliance: Understand and adhere to industry-specific regulations (e.g., GDPR, HIPAA, etc.) relevant to the data being processed. Regularly audit and update processes to ensure ongoing compliance [141].
2. Data Governance: Data governance procedures and guidelines can be followed to ensure data compliance, quality, and integrity. Create and execute data lifecycle management protocols.
3. Audit Trails: To monitor data access, alterations, and processing operations, keep thorough audit trails. Make that audit logs are easily auditable and meet all regulatory standards [142].
4. Certifications and Standards: Choose cloud providers that adhere to relevant certifications and standards (e.g., ISO 27001, SOC 2, etc.). Regularly review and update security and compliance practices based on evolving standards [143].
5. Privacy Considerations: Prioritize privacy in data handling, especially when dealing with personally identifiable information (PII). Implement data anonymization and pseudonymization techniques to protect privacy.
6. Vendor Management: Ensure that cloud service providers have robust security and compliance measures in place. Regularly review and update contracts to reflect the latest security and compliance requirements [144].

Businesses can use cloud computing to leverage the benefits of Big Data Analytics in the context of Industry 4.0 while lowering risks and ensuring the confidentiality and integrity of their data by taking these security and compliance considerations into account. Security measures must be examined and modified on a frequent basis due to the rapid evolution of rules and technology.

10. Real-time analytics

Analytics on streaming data can be done in real time with cloud systems. For Industry 4.0 applications in particular, this is crucial since prompt insights may lead to predictive maintenance and improved operational effectiveness [125, 145]. Here's how real-time analytics in Big Data, powered by cloud computing, contributes to Industry 4.0:

1. Data Processing Speed: In Industry 4.0, the volume, velocity, and variety of data generated by machines, sensors, and devices are immense. Real-time analytics, enabled by cloud computing, ensures that this data is processed and analyzed at high speeds. Cloud platforms provide scalable and distributed computing resources, allowing organizations to handle the increased processing demands of real-time analytics [146].

2. Predictive Maintenance: Real-time analytics helps in predictive maintenance, where machines and equipment conditions are continuously monitored. Proactive maintenance has been made possible by this, which minimizes downtime and maximizes operational effectiveness [147, 148]. Large volumes of sensor data can be processed and analyzed in real time by cloud-based analytics tools, which can then be used to forecast future failures and send out maintenance notifications [149].

3. Optimization of Supply Chain: Real-time supply chain monitoring has been provided by cloud-based big data analytics. [121]. This includes monitoring logistics data, demand variations, and inventory levels. Real-time analytics enable firms to optimize their supply chains, save lead times, and improve overall efficiency through well-informed decision-making [150, 151].

4. Quality Control and Fault Detection: Real-time analytics helps in monitoring the quality of products during the manufacturing process. Any deviations or faults can be detected immediately. Cloud computing provides the necessary resources to process and analyze data from various sensors and devices, ensuring that quality control measures are implemented in real time [96, 152].

5. Improved Decision-Making: Industry 4.0 requires quick and informed decision-making. Real-time analytics, supported by cloud computing, provides decision-makers with up-to-date information [153]. Cloud platforms offer the flexibility to scale resources based on the analytical workload, ensuring that decision-makers have access to timely insights regardless of the data volume [79].

6. Enhanced Data Security: Cloud computing services often include robust security measures. In the context of real-time analytics in Industry 4.0, ensuring the security and integrity of the data is paramount. To safeguard sensitive industrial data, cloud providers make significant investments in security infrastructure, such as encryption, access restrictions, and monitoring.

7. Cost Efficiency: Cloud computing offers a cost-effective solution for deploying and managing real-time analytics infrastructure. Pay-as-you-go methods enable organizations to scale resources as needed. Because of its adaptability, firms may adjust to their evolving analytics needs without having to make large upfront expenditures in infrastructure and hardware [114, 154].

In summary, real-time analytics in Big Data, powered by cloud computing, is instrumental in enabling Industry 4.0 by providing the speed, scalability, and insights necessary for smart and efficient industrial processes. It enhances decision-making, optimizes operations, and contributes to the overall competitiveness of organizations in the rapidly evolving industrial landscape.

11. Machine learning and AI integration

Cloud-based AI and ML, together with big data analytics, are key components of Industry 4.0. The infrastructure needed to develop and implement machine learning models is provided by cloud computing [155]. Organizations can leverage cloud-based AI services and frameworks to enhance their big data analytics capabilities [141]. Incorporating machine learning algorithms in cloud-based analytics enhances the ability to derive actionable insights and predictions from data.

Here's how machine learning, artificial intelligence, cloud computing and big data analytics, intersect in the context of Industry 4.0:

1. Data Collection and Storage:

- Big Data Analytics: Large volumes of data are produced by Industry 4.0 via sensors, gadgets, and other sources. This data is processed using big data analytics to find trends, get insightful knowledge, and make wise choices [156].
- Cloud Computing: Cloud systems offer scalable and cost-effective solutions for managing and storing enormous volumes of data. They provide storage options like Amazon S3 and Azure Blob Storage in addition to scalable computing resources.

2. Data Processing and Analysis:

- Big Data Analytics: Big data sets are subjected to sophisticated analytics tools and algorithms in order to reveal latent patterns and trends. In order to extract useful information, data that is structured as well as unstructured must be processed.
- Machine Learning and AI: Complex activities like anomaly detection, pattern recognition, and predictive analytics are carried out by ML and AI systems. Over time, these algorithms' performance may be constantly enhanced via learning [157].

3. Real-time Insights:

- Cloud Computing: Cloud platforms enable real-time processing and analysis of data. Services like AWS Kinesis or Azure Stream Analytics allow businesses to analyze streaming data for immediate insights [158].
- Machine Learning: Real-time machine learning models can be deployed on cloud infrastructure to provide instant predictions and decision support based on incoming data [159].

4. Predictive Maintenance:

- Machine Learning: Predictive maintenance models use historical data and machine learning algorithms to predict when equipment is likely to break. By scheduling maintenance activities before an issue arises, this reduces costs and downtime [95].
- Cloud Computing: Cloud platforms provide the necessary resources to run and scale predictive maintenance algorithms, ensuring timely and efficient analysis of large datasets [160].

5. Supply Chain Optimization:

- Big Data Analytics: Analyzing data from the supply chain helps in optimizing inventory, improving logistics, and enhancing overall efficiency.
- AI and Machine Learning: Artificial intelligence (AI) algorithms are able to forecast demand trends, optimize routes, and pinpoint supply chain cost-saving opportunities [161].

6. Cost Efficiency and Scalability:

- Cloud Computing: Cloud services provide cost-effective and scalable solutions, allowing businesses to pay for the resources they use and scale up or down based on demand.
- Big Data Analytics and AI: Cloud systems provide effective processing of massive datasets and sophisticated algorithms by supporting the scalability needs of machine learning and big data analytics [132].

7. Security and Compliance:

- Cloud Computing: Cloud providers offer robust security measures and compliance features. This is crucial for handling sensitive data in accordance with industry regulations.
- AI and Machine Learning: Advanced security measures, including anomaly detection and threat intelligence powered by AI, enhance the overall security posture of cloud-based systems [162].

8. Human-Machine Collaboration:

    - AI and Machine Learning: Collaborative robots (cobots) and intelligent systems enhance human-machine collaboration on the factory floor, leading to increased productivity and efficiency [163].
    - Cloud Computing: Cloud platforms facilitate the integration of AI and machine learning models with various devices, enabling seamless communication and coordination in Industry 4.0 environments [152, 156].

In summary, the integration of machine learning and artificial intelligence with big data analytics on cloud computing platforms is a powerful combination for driving innovation and efficiency in Industry 4.0. It helps companies to take advantage of data, make wise decisions, streamline operations, and maintain their competitiveness in the quickly changing modern business environment. [164].

12. Conclusion

Big data analytics and cloud computing together offer a breakthrough synergy within the context of Industry 4.0 that has huge promise for businesses across a range of sectors. In addition to enabling the efficient processing and analysis of massive information, the combination of these cutting-edge technologies offers scalability, flexibility, and cost-effectiveness that have never been seen before. The combination of big data analytics and cloud computing appears to be a catalyst for innovation as we traverse the intricacies of the contemporary business environment. Businesses may improve operations, make data-driven choices, and obtain a competitive edge thanks to this relationship. The ability to assess and extract relevant insights from massive datasets may help businesses improve operations, gain a competitive edge, and make informed decisions. Furthermore, the flexibility and scalability of cloud-based solutions enhance an organization's ability to adapt to the evolving demands of Industry 4.0. Real-time processing capability from cloud-based big data analytics boosts overall operational effectiveness and enables predictive maintenance and faster reaction times. Businesses may more easily explore new income streams and business models thanks to the opportunity for innovation created by this technological convergence. Additionally, it facilitates data-driven decision-making.

Essentially, the study emphasizes how merging Cloud Computing with Big Data Analytics within the context of Industry 4.0 might have a revolutionary effect. This mutually beneficial partnership has the potential to completely transform how companies use data, ushering in a new age of productivity, efficiency, and competitiveness in the quickly evolving field of modern business. Big Data analytics and cloud computing working together is predicted to influence Industry 4.0's future by creating previously unimaginable opportunities and setting a new benchmark for operational excellence and data-driven decision-making. The review has delved into the key facets of this convergence, exploring the enhanced data processing capabilities, real-time analytics, and the seamless scalability that Cloud Computing provides. Moreover, the discussion has highlighted the role of Big Data Analytics in uncovering actionable insights from these extensive datasets, empowering businesses to extract meaningful value. These technologies have a collaborative potential that is demonstrated by their capacity to propel predictive modeling, optimize decision-making procedures, and eventually support Industry 4.0's main objectives. But it's important to comprehend the difficulties and factors involved in putting big data analytics into practice on the cloud. Concerns about data governance, security, and privacy remain significant and need for ongoing consideration and innovative solutions. In order to protect sensitive data, stakeholders must give top priority to robust cybersecurity and compliance frameworks as Cloud Computing in Industry 4.0 continues to embrace Big Data Analytics. As the industry develops, these issues need to be resolved to guarantee the proper and moral use of data in the context of Industry 4.0.

Thus, the combination of cloud computing and big data analytics within Industry 4.0 ushers in a new age of data-centric, intelligent, and networked industries. Advancements in productivity, enhanced judgment, and the opening up of fresh opportunities characterize the path towards digital transformation. As organizations navigate this landscape, a strategic and well-executed approach to harnessing the power of these technologies will undoubtedly define their success in the evolving industrial landscape.

13. Future research works directions

As Industry 4.0 continues to transform traditional industrial processes, cloud computing and big data analytics have emerged as a powerful means of handling the enormous amounts of data generated by networked devices and systems. This report identifies significant research directions to enhance the cooperation between cloud computing and big data analytics within the context of Industry 4.0. The recommended initiatives attempt to solve present issues and explore new potential for enhancing data-driven decision-making processes, assuring scalability, security, and efficiency.

1. Scalable and Elastic Cloud Architectures: Examine cutting-edge cloud architectures that can adapt to the changing needs of Industry 4.0 applications by dynamically scaling resources. Examine how serverless computing paradigms might be integrated to improve resource usage and save operating expenses.

2. Edge and Fog Computing Integration: Examine how combining edge and fog computing with cloud-based analytics enables real-time data processing and network edge decision-making. Establish frameworks for the efficient transfer of data processing and offloading between cloud infrastructure and edge devices.

3. Enhanced Data Security and Privacy: Analyze safe multiparty computation, homomorphic encryption, and advanced encryption techniques to address privacy and data security concerns associated with processing and storing private industrial data on the cloud. Establish robust access control and authentication protocols that are appropriate for Industry 4.0 environments.

4. Real-Time Analytics and Predictive Maintenance: Explore machine learning algorithms for real-time analytics to enable quick decision-making in dynamic manufacturing environments. Investigate predictive maintenance models that leverage cloud-based analytics to minimize downtime and optimize equipment performance.

5. Interoperability and Standardization: Research on standardized data formats and communication protocols to facilitate seamless interoperability between heterogeneous devices and platforms in Industry 4.0. Develop frameworks for data integration and exchange across different cloud service providers to avoid vendor lock-in.

6. Energy-Efficient Cloud Computing: Investigate energy-efficient algorithms and resource management strategies for cloud-based BDA systems to minimize environmental impact. Explore the use of renewable energy sources in cloud data centers to align with sustainability goals [108].

7. Human-Machine Collaboration and Explainability: Explore methods for improving human-machine collaboration through interpretable and explainable AI models in the context of Industry 4.0. Develop frameworks that allow domain experts to understand, trust, and interact with analytics models for better decision support.

8. Ethical Considerations and Governance: Consider prejudice, equality, and transparency while examining the ethical implications of Industry 4.0 big data analytics. Establish governance frameworks that balance the demands of data-driven innovation, legal compliance, and ethical considerations.

To sum up, these new lines of inquiry will push Industry 4.0's integration of Cloud Computing and Big Data Analytics forward, tackling obstacles and opening up fresh possibilities for intelligent and productive manufacturing processes. To support Industry 4.0's ongoing development, researchers, business professionals, and legislators are urged to work together to advance these fields.

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