International Journal of Computer Trends and Technology
ISSN: 2231–2803 / https://doi.org/10.14445/22312803/IJCTT-V73I2P103

Volume 73 Issue 2, 18-22, February 2025

Original Article

Modernize Manufacturing: Powered by Google Cloud

Manas Srivastava

Sr. Customer Engineer at Google Cloud, Seattle, WA, USA.

Corresponding Author : manas.srivastava08@gmail.com

Received: 25 December 2024 Revised: 19 January 2025 Accepted: 12 February 2025 Published: 28 February 2025

Abstract *- This paper outlines the challenges that the manufacturing industry faces in adopting Industry 4.0 principles, and it examines how cloud platforms, particularly Google Cloud, can help manufacturers achieve their goals of becoming a factory of the future. The challenges include IT/OT misalignment, data silos, a lack of specialized talent, pilot purgatory, cybersecurity gaps, and limited flexibility. Cloud computing offers solutions by providing elasticity and scale, enhanced security, seamless integration, data centricity, and easy-to-use pre-trained models and APIs. These cloud-based solutions enable key innovations such as inventory intelligence, predictive maintenance, supply chain optimization, and agile manufacturing, which improve efficiency and decision-making. Additionally, cloud computing enhances workforce productivity by automating mundane tasks and providing access to data from anywhere. Ultimately, cloud technologies are essential for modernizing the manufacturing industry and creating smart factories that are more productive, efficient, and flexible.*

Keywords *- Cloud Technologies, Digital Manufacturing, Industry 4.0, Integration, Predictive maintenance, Real-time visibility.*

1. Introduction

The manufacturing industry has gone through several revolutions over the centuries. The mid-18th century saw the first revolution, which was powered by coal, which led to large-scale industries like iron, textiles, and coal mining, which was limited to Britain. The second industrial revolution, which happened in the mid-19th century, was powered by gas, led to mass production in industries like automobiles and took place in Britain, continental Europe, North America and Japan. Powered by electronics and nuclear, the third industrial revolution began in the 1950s and continued till the early 2000s. The Fourth Industrial Revolution, known as Industry 4.0, is focused on creating smart factories that are more on creating smart factories that are more productive, efficient and flexible. Industry 4.0 aims to improve decision-making and customization in manufacturing and supply chain operations by utilizing technology that includes Big Data, the Internet of Things (IoT), Artificial Intelligence (AI), Robotics, Automation, and Augmented reality.

The last decade has witnessed a strong shift to adopt cloud technologies to modernize and optimize business processes. Whether it is 1/ cost efficiency compared to traditional on-premises infrastructure, eliminating the need for upfront investments and ongoing maintenance cost, or 2/ Scalability and flexibility, cloud services provide businesses with the agility to scale their resources up and down on demand, enabling them to adapt quickly to changing market conditions, 3/ Increased efficiency and productivity provided by the cloud-based tools and applications that streamline workflows, fostered collaboration and enhanced productivity across teams and organizations or 4/ Innovation and growth are enabled by providing access to cutting-edge technologies, such as Artificial Intelligence (AI) and Machine Learning (ML), enabling business.

Manufacturing floors are no longer a place for isolated devices and siloed data. Manufacturers have challenges with volatile supply chains, escalating customer demands, and extensive pressure to optimize the process, reduce costs and increase efficiency. This research focuses on the challenges faced by the Manufacturing industries in adopting the principles of Industry 4.0 and how services provided by Cloud platforms, specifically Google Cloud, help the manufacturers realize their goal of becoming a factory of the future.

2. Challenges

The Manufacturing industry is facing the following challenges in adopting Industry 4.0.

2.1. IT/OT Misalignment

IT/OT misalignment is a common challenge in industrial settings, arising from differing priorities, expertise, and operational models between the two teams. The Information Technology (IT) team typically focuses on enterprise-wide systems, data management, and cybersecurity. In contrast, the Operational Technology (OT) team is responsible for managing and controlling industrial processes and equipment. This misalignment can lead to unplanned downtime, slower

production and higher anomaly rate which all impact the Overall Equipment Effectiveness (OEE).

2.2. Data Silos

Data is often scattered across numerous systems and devices in manufacturing environments. These include machine sensors, operational databases, and enterprise applications like ERP and CRM systems. Integrating this data is a significant challenge due to differences in data formats, communication protocols, and data storage locations. The data is plentiful, but it doesn't deliver any actionable insights, leading to 'Data Swamps'. According to a report from the IDC, companies are losing 20 – 30% in revenue every year due to inefficiencies caused by data silos. Proper measures like data governance, cleaning and transformation need to be implemented to turn these data swaps into actionable insights.

2.3. Lack of Specialized Talent

There is an acute shortage of skilled and specialized talent who can apply the latest technologies in the manufacturing context. Processes and technologies are seeing an unprecedented change. The workforce lacks expertise in new technologies like robotics, automation and artificial intelligence.

The aging workforce in the manufacturing industry, especially in traditional sectors, poses a significant risk. According to manufacturinginstitute.org, if workforce challenges are not addressed, more than 1.9 million of the up to 3.8 million jobs likely to be needed between this year and 2033 could go unfilled. 65% of manufacturers polled said attracting and retaining talent is their primary business challenge.

2.4. Pilot Purgatory

Usually, manufacturing companies are resistant to change, and even if they start any proof of concept or pilot project to modernize the process, these are usually vertically integrated use cases that never scale across production lines or plants. Most of the time, it is due to a lack of scalability in the technical resources on their on-premises setup or due to issues with cost.

2.5. Cybersecurity Gaps

The absence of a comprehensive cybersecurity strategy when implementing and deploying interconnected machinery and cloud connectivity significantly elevates the risk of potential cyberattacks. This lack of foresight can lead to unauthorized access, data breaches, and operational disruptions, with potentially devastating consequences for manufacturing processes and supply chains.

2.6. Limited Flexibility

Static automation systems, while efficient for large-scale, repetitive tasks, can be a significant hindrance to implementing a flexible manufacturing approach. This inflexibility arises from their inherent design, which is often tailored to specific processes and product configurations. Any deviation from these predetermined parameters necessitates substantial reconfiguration or even complete overhauls of the automation system, leading to downtime, increased costs, and disruptions to production.

3. Role of Cloud Computing in Manufacturing

3.1. Elasticity & Scale

There can be changes in the infrastructure requirement based on the requirements due to seasonality or new product launches. Cloud computing services provide the ability to scale up and down based on the requirements. Unlike traditional on-premises infrastructure, customers are not locked in and can subscribe to the required services in a pay-as-you-go model. This helps reduce the upfront cost and changes the expenditure from CapEx (capital expense) to OpEx (operational expense), which, being more predictable, allows proper budget planning.

Often, manufacturers have multiple plants and factories, and tons of telemetric data are generated, which is a prerequisite for any kind of advanced analytics that needs to be performed on that data set. To handle this amount of data and processing requires a massive scale, which the cloud services can provide, whether it is in computing (e.g., Google Cloud Compute Engine [GCE], Google Kubernetes Engine [GKE], App Engine, Cloud Functions or Cloud Run) or it in storing the data (e.g., Google Bigtable, Google BigQuery, or Google Cloud storage).

3.2. Enhanced Security

For any digital initiatives, cyber security is a concern. Manufacturers deal with a variety of sensitive intellectual property (IP) data like design, process, and blueprints. They also sometimes deal with customer and financial data. Making sure that all this data is secured, irrespective of the stage it is in, becomes extremely important.

Cloud services providers invest heavily in ensuring proper security measures are taken at each step, including encryption of data at rest and in transit, software-defined firewalls, multi-factor authentication, and DDOS protection. Google Cloud provides services like Cloud Key Management Services, Data Loss Prevention, Cloud Armor, Cloud Firewall, and Context-aware access. With its Mandiant acquisition, Google has further expanded its capabilities in threat detection and response.

Data backup is equally important as unauthorized access is. There is a broad spectrum of Cloud services that provide air-gapped and immutable backups for data protection. Managed services like Google BigQuery have 11 9's of durability. For the IaaS (infrastructure as a service) offering, Google provides native backup and DR services and multiple partner solutions.

3.3. Seamless Integration

Getting data from various sources, such as the telemetric data from PLCs, SCADA, and MES devices from the shop floor, as well as the inventory, demand, and sales data from the ERP application, is very critical. Whether the requirement is for real time or batch data, partner solutions like Litmus are very helpful. Litmus provides connectivity to 250+ devices as well as a low-code/no-code Node-Red platform for building integration flows. Google Cloud also provides Cloud Data Fusion, which has multiple plugins that connect to different source systems.

Once the data is collected, it needs to be securely ingested into the data warehouse platform so that it can be processed and actions can be taken based on the insights generated. This is where messaging services like Kafka RabbitMQ are used. Cloud providers take over the management overhead by providing fully managed services like Google Cloud Pub/Sub. This addresses the challenge of scale, and being event-based also provides near real-time data ingestion capabilities.

3.4. Data Centricity

Manufacturers are dealing with disparate data sources, and to address these data silos, they need to implement a strong data warehousing strategy while also ensuring that costs are controlled. This allows them to consolidate and analyze large volumes of data from multiple sources of operations.

Given the enormous amount of data, which can be structured, unstructured, semi-structured, from flat files, streaming data, etc., the storage requirement is usually far higher than the compute requirements for running SQL queries to process the data, whether for visualization or consumption by a downstream system. To address this, Google developed a distributed architecture that decoupled storage and compute resources, allowing them to scale independently. Google Cloud BigQuery is based on this principle. It uses Colossus for storage and Dremel for processing the queries on large datasets, and it is orchestrated via Borg.

Decisions now are augmented by more than just the data coming from the factory floor and enterprise applications. To get ahead of the competition, organizations need to tap into public data sets like weather, GDELT, Project44, and ESG books and combine them with their data to get richer insights and make informed decisions regarding their businesses.

3.5. Easy-to-use pre-trained models and APIs

Cloud providers offer pre-trained machine learning models and easy-to-use APIs, which are revolutionizing the manufacturing industry and bridging the skill gap. The employees now need not be data scientists and statisticians. The complex underlying code is abstracted and offers a user-friendly interface for access. It is also very cost-effective as these models are already trained on large datasets, and organizations don't have to spend processing hours on training and testing.

Google Cloud offers a plethora of pre-trained models and APIs. Vision AI helps with object detection, image classification and optical character recognition. Natural language processing (NLP) can be used to analyze maintenance logs and product reviews. Document AI, which can help automate the processing of documents. These open up great avenues for professionals to accelerate modernization and digital transformation.

Generative AI is another strong offering that addresses the need for transformation. Large Language Models (LLMs) are effective tools to solve a large number of use cases manufacturers have, like generating work instructions and documentation for complex assembly processes. This helps reduce the ramp-up time for new employees. It can also be used for analyzing warranty claims and maintenance logs to quickly identify recurring issues.

4. Reference Architecture

A representative reference architecture for a data warehousing solution framework for manufacturing clients is illustrated in Fig. 1. This example utilizes Google Cloud services.

The data sources, as demonstrated in the illustration, are the factory floor data that is coming from PLCs, DCS, SCADA and MES systems and the Public and private data sources coming from enterprise applications like SAP, and Salesforce. This is securely ingested to cloud services using Cloud Pub/Sub and Cloud dataflow. This is where the transformation and parsing of data also happens to normalize it.

Depending on the type and the usability of data, it is stored in Google BigQuery (analytics data), Google Bigtable (time series data), and Google Cloud Storage (for long-term retention. Complex joins, and queries can be curated here depending on the use case.

Once the data is ready for consumption, visualization tools like Google Looker Data Studio can be used. Services like Vertex AI can be used to perform advanced machine learning on the data, and the feedback can be sent back to the factory floor to close the loop.

5. Innovation driven by Cloud

5.1. Inventory Intelligence

With access to real-time data and analytics powered by cloud platforms, manufacturers can now dynamically adjust to demand fluctuations, optimize their processes, and minimize waste. The enterprise data warehouse provides a single source of truth to manage inventory. Potential disruptions can be identified proactively by AI-driven forecasting and demand-sensing models. These models utilize historical data and are enhanced by relevant public data that could potentially impact inventories.

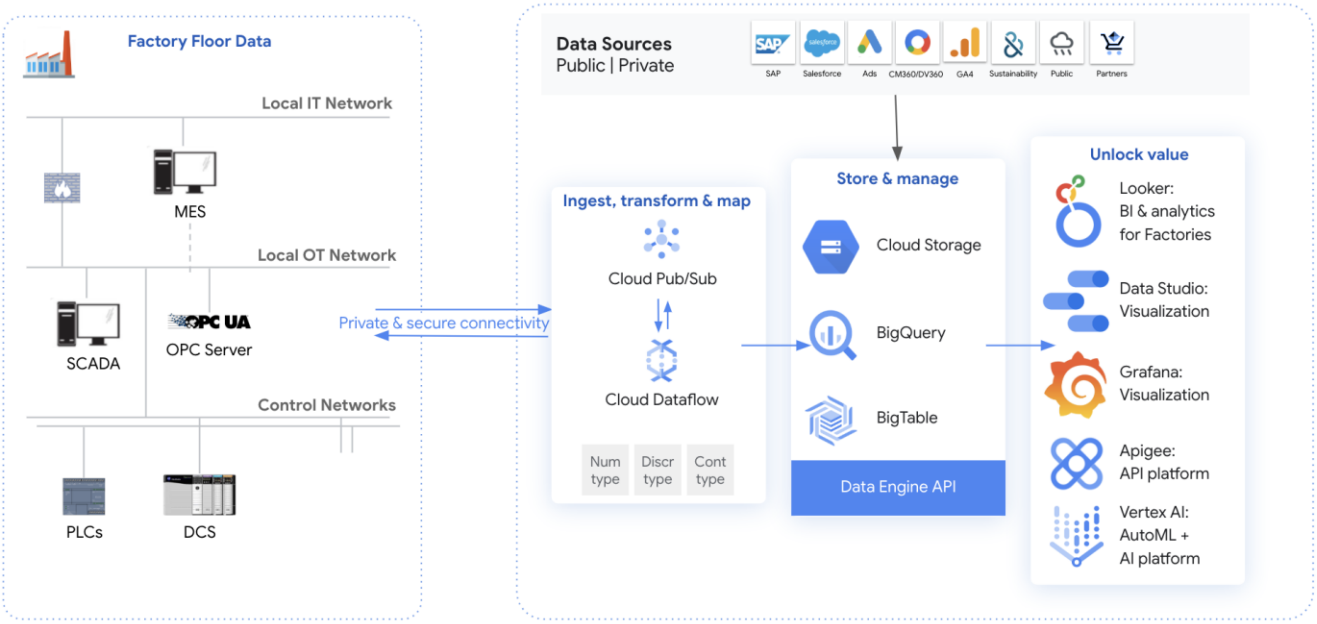

Fig. 1 Reference architecture

Manufacturers get real-time visibility into what inventory they have, where, and in what quantities and conditions it is at any given moment. Organizations with comprehensive data insights can accurately predict future demand using historical data, market trends, and other variables.

5.2. Predictive Maintenance

Unplanned downtime in manufacturing can lead to significant revenue loss along with lost productivity and unhappy customers. With access to all the telemetric and key performance indices (KPIs), technicians can now proactively identify challenges and issues with the machines on the factory floor.

KPIs like Overall Equipment Effectiveness (OEE) give a holistic view of the device's health. Technicians and factory floor supervisors can combine this with real-time telemetry data and quickly pinpoint the root cause of the problem and take corrective action.

In addition to this, analyzing historical data and trends also allows technicians to predict when a machine might malfunction. This enables proactive maintenance scheduling, preventing breakdowns before they occur. Organizations can also build integrations between the data from the factory floor managed by the supervisor and backend Enterprise Resource Planning (ERP) systems, such as SAP.

Utilizing tools like ABAP Software Development Kit (SDK), organizations can now automate workflow for issue identification and remediation. This includes maintenance procedures or the procurement of replacement components, streamlining operations and enhancing efficiency.

5.3. Supply Chain First Approach

By providing real-time visibility into every stage of the supply chain, from raw material sourcing through finished goods delivery, manufacturers are enabled to track inventory, monitor shipments, and identify potential bottlenecks. The approach now is shifting from supply chain built for manufacturing to manufacturing built for the supply chain. The collaboration tools offered by cloud platforms enable seamless communication between manufacturers, suppliers, distributors, and customers. This helps in building strong relationships and enables faster decision-making.

Manufacturers can now build Digital Twins to optimize and manage complex supply chains. They can model the entire supply chain, from sourcing raw materials to delivering finished products, and get end-to-end visibility along with interdependencies. Since it is connected to real-time data, the digital twin can provide up-to-date information and help in detecting disruptions. Digital twins help create a more resilient and responsive supply chain to handle uncertainties presented by today's global market.

5.4. More Sustainable

Sustainability is extremely important for manufacturing organizations. It can significantly impact their long-term viability by reducing environmental impact, enhancing brand reputation and focusing on eco-friendly approaches and products. Cloud-based analytics can help organizations identify areas where energy and resources are being wasted. This allows companies to optimize their process, reduce carbon footprint and minimize environmental impact. They can not only track but also report their sustainability

performance, enabling them to meet regulatory requirements and their commitments to environmental responsibilities.

5.5. Agile Manufacturing

Cloud computing enabled manufacturers to quickly adapt to changing market demands and customer needs and make the process agile. Cloud-based solutions can be deployed quickly, helping manufacturers implement new technologies and processes faster. Whether it is implementing IoT sensors on the factory floor or leveraging ML and AI for predictive maintenance, the cloud accelerated the adoption of innovations that drive agility.

5.6. Workforce Productivity

Automation plays a crucial role in improving the productivity of the workforce. Mundane tasks like monitoring data entry can be automated, freeing up employees to focus on higher-value tasks that require creative thinking. This not only increases productivity but also provides job satisfaction to the employees. Cloud solutions also allow employees to access data and applications from anywhere, anytime, using any device securely. This enabled production managers to monitor real-time factory floor data on their hand-held devices while they were traveling, allowing them to address issues promptly and make informed decisions on the go.

Generative AI empowers organizations to develop user-friendly chatbots. By inputting a single prompt, such as an error code for a specific device within the production plant, the chatbot can direct users to the precise location within the relevant manual detailing the solution. This functionality streamlines the troubleshooting process, eliminating the need to navigate extensive manuals, thereby accelerating the onboarding of new personnel and enhancing overall productivity.

6. Conclusion

In conclusion, cloud technologies, such as Google Cloud, are playing a pivotal role in modernizing the manufacturing industry. As we find ourselves amidst the Fourth Industrial Revolution, also known as Industry 4.0, the focus is on creating smart factories that are not only more productive and efficient but also adaptable and responsive to change. Cloud technologies are instrumental in achieving these goals. Cloud is not merely a tool for modernization; it is a catalyst for transformation. By embracing cloud technologies, manufacturers can unlock new levels of efficiency, agility, and innovation, paving the way for a more competitive and sustainable future. The cloud is not just the future of manufacturing; it is the present and those who fail to adapt risk being left behind.

References

[1] Philip Ross, and Kasia Maynard, "Towards a 4th Industrial Revolution," *Intelligent Buildings International*, vol. 13, no. 3, pp. 159-161, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[2] V. Ramana Reddy, and E. Sakshal Sreeman, "Sustainable Aspects of Green Supply Chain Management in Manufacturing Environment," *SSRG International Journal of Industrial Engineering*, vol. 3, no. 3, pp. 17-22, 2016. [CrossRef] [Google Scholar] [Publisher Link]

[3] Usama Awan et al., *Artificial Intelligence for Supply Chain Success in the Era of Data Analytics*, The Fourth Industrial Revolution: Implementation of Artificial Intelligence for Growing Business Success, Springer, Cham, pp. 3-21, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[4] Erik Hofmann et al., "Supply Chain Management and Industry 4.0: Conducting Research in the Digital Age," *International Journal of Physical Distribution & Logistics Management*, vol. 49, no. 10, pp. 945-955, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[5] Mohsen Attaran, Sharmin Attaran, and Diane Kirkland, "The Need for Digital Workplace: Increasing Workforce Productivity in the Information Age," *International Journal of Enterprise Information Systems*, vol. 15, no. 1, pp. 1-23, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[6] Google Cloud Helps Manufacturers Bridge IT and OT Data with Manufacturing Data Engine and Cortex Framework, 2024. [Online]. Available:https://cloud.google.com/blog/topics/manufacturing/manufacturing-bridging-it-ot-data-engine-cortex-framework?e=48754805

[7] Rajesh Thallam, BigQuery Explained: An Overview of Big Query's Architecture, 2020. [Online]. Available: https://cloud.google.com/blog/products/data-analytics/new-blog-series-bigquery-explained-overview?e=48754805

[8] Helping Businesses with Generative AI, 2023. [Online]. Available: https://cloud.google.com/blog/products/ai-machine-learning/generative-ai-for-industries?e=48754805

[9] Chan Jian Jern et al., "Cloud Security: Counteracting Evolving Threats in a Digital Age," *Preprints*, pp. 1-19, 2025. [CrossRef] [Google Scholar] [Publisher Link]

[10] Alain Aoun et al., "A Review of Industry 4.0 Characteristics and Challenges, with Potential Improvements Using Blockchain Technology," *Computers & Industrial Engineering*, vol. 162, 2021. [CrossRef] [Google Scholar] [Publisher Link]