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Exploring Cloud Adoption Possibilities for the Manufacturing Sector: A Role of Third-Party Service Providers

By

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Abstract

As the manufacturing sector strides towards digitalization under the influence of Industry 4.0, cloud services have emerged as the new norm, driving change and innovation in this rapidly transforming landscape. This study investigates the possibilities of cloud adoption in the manufacturing sector by developing a conceptual model to identify suitable cloud-based solutions and explores the role of third-party service providers in aiding manufacturers throughout their cloud adoption journey. The research methods consist of a comprehensive literature review of the manufacturing industry, digital transformation, cloud computing, etc., followed by qualitative analyses of industrial benchmarks case studies and an investigation into an application of the developed model to a hypothetical food manufacturing company as an example. This study indicates that cloud adoption can yield substantial benefits in the manufacturing sector, including operational efficiency, cost reduction, and innovation, etc. The study concludes that the developed conceptual model provides a practical framework to identify the most suitable cloud-based solutions during the cloud adoption process in the manufacturing context. In addition, third-party service providers like Capgemini are capable of not only filling the technical gaps but also consulting strategic directions and innovations for their client organizations, hence playing a vital role in driving the industrial digital transformation process. With an extensive mapping of their capabilities, a set of recommendations intended to assist Capgemini in enhancing capabilities and improving competitive performance in the market has been offered.

Keywords: *Cloud computing; Cloud adoption; Digitalization; Manufacturing; Food manufacturing; Third-party service providers.*

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Acronyms

AI Artificial Intelligence. 19–21, 24, 29, 34, 40, 46, 61, 76–79, 81, 84, 90, 91
Amazon EC2 Amazon Elastic Compute Cloud. 27
Amazon S3 Amazon Simple Storage Service. 27, 28, 41
Amazon VPC Amazon Virtual Private Cloud. 27
AWS Amazon Web Services. 24, 41, 42, 49, 85

BI Business Intelligence. 50, 60, 72

C&CA Cloud & Custom Application. 82–85
CAGR Compound Annual Growth Rate. 7
CNC Computerized Numerical Control. 12
CSC Cloud Service Customer. 23–26, 31, 32
CSP Cloud Service Provider. 23–26, 31, 32, 83–85
CV Computer Vision. 20, 21, 27, 28, 39–42, 47–49, 54, 68, 69, 76, 77, 83

EAS Enterprise Application Software. 11
ENG Engineering. 82–84
ERP Enterprise Resource Planning. 11, 50, 65, 67
ESG Environmental, Social, and Governance. 33
EU European Union. 57

GDP Gross Domestic Product. 7
GPS Global Positioning System. 64

HCL Tech HCL Technologies. 73, 78, 80–82
HTTPS Hypertext Transfer Protocol Secure. 23

I&D Insights & Data. 82–85
IaaS Infrastructure as a Service. 24–26
IDC International Data Corporation. 7

IIoT Industrial Internet of things. 22
IoT Internet of Things. 8, 21, 22, 27, 29, 34, 40, 44–47, 50–55, 61, 64, 65, 67, 68, 70–72, 75, 84, 85, 90, 91
IT Information Technology. 11, 17, 21, 24, 26, 30–32, 48, 50, 54, 67, 72, 80, 81, 87

MES Manufacturing Execution System. 11
ML Machine Learning. 19–21, 24, 27, 28, 30, 34, 39, 40, 44–49, 52, 54, 55, 61, 68–70, 72, 75, 83–85, 90, 91
MTBF Mean Time Between Failures. 28
MVA Manufacturing Value Added. 7

NIST National Institute of Standards and Technology. 22

OEE Overall Equipment Effectiveness. 28, 78
OPC Open Platform Communications. 46
OPC UA OPC Unified Architecture. 53
OT Operational Technology. 11, 12, 17, 50, 54, 67

PaaS Platform as a Service. 24–26
PCB Printed Circuit Board. 21
PLC Programmable Logic Controller. 12
PoC Proof-of-Concept. 84

RFID Radio Frequency Identification. 43, 62–65, 67, 72

SaaS Software as a Service. 24–26
SCADA Supervisory Control and Data Acquisition. 12
SCM Supply Chain Management. 11
SDG Sustainable Development Goal. 57
SDK Software Development Kit. 28

TCP/IP Transmission Control Protocol/Internet Protocol. 23
TCS Tata Consultancy Services. 73, 79–81

UDP User Datagram Protocol. 23

Chapter 1

Introduction

1.1 Background

The manufacturing industry appears as an essential component in modern economies, significantly contributing to employment and economic output [1][2]. The industry is incrementally turning to adopt digital technologies, especially cloud-based services, in order to address the diverse challenges of the contemporary industrial environment [3]. Cloud computing has emerged as a pivotal enabler of the digital transformation of manufacturing enterprises. Kässer [4] reported that two-thirds of surveyed manufacturing companies are embracing cloud technology and customizing it to suit their specific requirements. Furthermore, these organizations are continuously seeking to implement cloud solutions on a broader scale, encompassing entire operational areas. The inherent characteristics of cloud services, such as their flexibility, scalability, agility, and cost-effectiveness, offer an appealing option that can significantly enhance operational efficiency and foster innovation for today's manufacturers. This innovative solution possesses the capability to transform the context of supply chain management, promote data accessibility, and streamline the process of making informed decisions in real time. In general, the transition towards the cloud has the potential to revolutionize manufacturing enterprises into agile, versatile, and data-driven organizations, thereby granting them a unique advantage in a rapidly evolving marketplace [5][6][7].

Despite its potential, the shift towards cloud-based solutions is a complex process that includes various phases and may present significant obstacles for manufacturing enterprises. The challenges include understanding and adopting novel technology, aligning cloud strategies with business goals, guaranteeing data security and privacy, and managing organizational changes. The successful adoption of cloud solutions necessitates a comprehensive strategy, an effective framework, and the right expertise to lead the organization through this transition and guarantee the recognition of the cloud technology's potential benefits.

As the demand for cloud adoption grows, consulting firms are becoming increasingly important. With their specialized knowledge and skills, those professionals can help ensure that cloud technology is utilized to its fullest potential while minimizing potential risks. By partnering with these consultants, companies can achieve greater efficiency, productivity, and success in cloud adoptions and operations.

Given the increasing significance of digital transformation within the manufacturing sector and the crucial role of cloud computing in this process, this study attempts to provide a structured approach to enhance a consulting firm's capabilities of guiding their clients through the journey to the cloud. This effort will strengthen and highlight the supportive role of IT consulting firms in this process, thereby making an important contribution towards the development of this field.

1.2 Thesis objective and scope

The overall aim of this study is to explore the possibilities of cloud adoption in manufacturing by developing a framework and emphasizing the critical role of third-party service providers in assisting manufacturers throughout their cloud adoption journey.

More specifically, the following sub-objectives need to be delivered:

- Develop a conceptual model for cloud adoption in the manufacturing sector. This model helps identify the most suitable cloud-based solutions by connecting and taking manufacturing assets, business needs, and application areas into account.

- Analyze benchmark case studies to extract key features and components essential for the successful implementation of cloud-based solutions in specific application areas.
- Apply the proposed conceptual model that I have built to a hypothetical case of a food manufacturing company. Identifying the best-fitted cloud solutions, along with essential features and components needed to be in place, demonstrates the model's practical relevance and effectiveness.
- Map capabilities and roles of third-party consulting companies, especially Capgemini, in fulfilling the previously identified features and components and facilitating cloud adoption in the manufacturing sector.
- Give recommendations for broadening capabilities and improving the competitiveness of Capgemini.

1.3 Methodology

In order to accomplish the main aim and the corresponding sub-objectives, I have adopted a research approach involving a combination of qualitative analysis, case analysis and applied research.

I first search and review relevant literature, including peer-reviewed journal articles, conference papers, books, technical reports, cooperate reports, etc., about the manufacturing industry and digital technologies, especially cloud computing. It allows us to have a foundational understanding of such concepts, as well as identify current trends and potential within these fields. Understanding such concepts and the potential of cloud computing, I develop a conceptual model for cloud adoption in manufacturing companies.

I then examine real-world case studies from industry benchmarks in cloud computing and services to extract essential practical elements for successful cloud adoption corresponding to the developed conceptual model.

I introduce a hypothetical scenario featuring a food manufacturing company as a practical example for the application of the developed conceptual model and extract the most critical elements needed for successful implementation.

I map the capabilities of some leading consulting companies via their published contents in relation to how they fulfill the identified essential elements of cloud solutions. Meanwhile, through various discussions with different teams at Capgemini, I also map their capabilities in terms of fulfilling the key features and components of cloud solutions identified previously. This highlights how a consulting company can effectively contribute to successfully implementing cloud solutions in a manufacturing context.

Finally, I come up with some recommendations for enhancing the competitive performance of Capgemini for cloud adoption based on insights from literature reviews and capabilities mapping.

Through this combination of analyses, conceptual modeling and practical application, I can ensure a holistic approach to fulfill the main aim and sub-objectives of this study.

1.4 Delimitation

One limitation of this study is that the availability of comprehensive and updated case studies on cloud adoption in a manufacturing context is quite limited. Data confidentiality may be a reason for this limited access to the most relevant and recent data and case studies. Given that, the study focuses on three selected application areas, which might not cover the full range of possible applications in the manufacturing sector.

Applying the conceptual model to a hypothetical scenario could provide a simple and illustrative example. However, the case may not fully capture every aspect of a real-world situation, despite the attempt to make it as realistic as possible.

In the field of technology, including cloud computing, things are continuously evolving at a quick pace. As a result, while the knowledge contained in this study is accurate at the time of writing, the high pace of change in this field could make some findings less relevant over time.

1.5 Thesis outline

This thesis is divided into eight chapters and is structured as follows:

Chapter 1: Introduction

This chapter introduces the research background, study aim and sub-objectives, methodology, limitations and structure of this thesis.

Chapter 2: Literature review

The chapter aims to establish a theoretical foundation for the main topics of this thesis, including the manufacturing sector, digitalization, digital technologies, the cloud computing concept and the trend toward sustainability.

Chapter 3: Developing a conceptual model for cloud adaption in manufacturing and selecting industry benchmarks

This chapter includes the development of the conceptual model for cloud adoption in manufacturing, along with the description and in-depth analyses of the selected industry benchmarks.

Chapter 4: Developing a hypothetical cloud-based manufacturing concept for the food manufacturing industry

This chapter explores the food manufacturing industry and its challenges and demonstrates the application of the conceptual model within a hypothetical scenario to extract key features and components for specific cloud solutions, providing an example of practical implementation.

Chapter 5: Capability mapping of third-party service providers for cloud adoption

This chapter investigates the capabilities of third-party service companies in satisfying technical features which are identified in Chapter 4 and non-technical attributes necessary for the successful implementation of cloud solutions for the hypothetical case. Notably, Capgemini is chosen as a representative for consulting firms and is given the main focus.

Chapter 6: Recommendations for competitive performance of Capgemini for cloud adoption

Based on findings from previous chapters, this section presents recommendations to enhance the competitive performance of third-party service providers, focusing primarily on Capgemini.

Chapter 7: Discussion

This chapter consists of an overview of the whole project, the main takeaways from my perspective, the practical challenges I've encountered throughout the process, and the prospective outlook for future research in the area.

Chapter 8: Conclusion

This final chapter revisits the project's aim and reflects on the research processes, challenges and the main takeaways. It also reaffirms the benefits of cloud adoption and the need for continued research.

Chapter 2

Literature review

2.1 Manufacturing industry

Manufacturing is the process of transforming raw materials or parts into finished goods by utilization of human labor, tools, machinery, equipment, chemical processing, etc. [8]. The manufacturing sector can be classified by sub-sector based on its products. Some of the most common ones are automotive, chemicals, maritime, food and beverage, pharmaceutical, textiles and apparel, computer and electronics, etc. [9].

Manufacturing plays a significant role in the global economy, contributing to employment, innovation, and economic growth. Manufacturing Value Added (MVA) is one of the most commonly used indicators by economists and statisticians to compare the manufacturing output to the total size of a country's economy, which is presented as the Gross Domestic Product (GDP). The World Bank reported that 16.6% of the world GDP in 2021 was contributed to manufacturing. That was approximately $16.0 trillion [2].

The advances in technology and the increasing demand for automation and efficiency have been driving the manufacturing industry to dramatically accelerate its digital transformation process. According to the International Data Corporation (IDC), worldwide spending on the digital transformation is expected to increase by 17.6% compared to 2021, reaching $1.8 trillion. This growth is forecasted to continue at a Compound Annual Growth Rate (CAGR) of 16.6% from 2021 to 2025. Geographical-wise, The United States is anticipated to account for 35% of the 2020 global digital transformation spending, followed by Western Europe and China, the fasted growing region with a five-year CAGR of 18.5% [10]. From an industry point of view, the manufacturing industry has the most

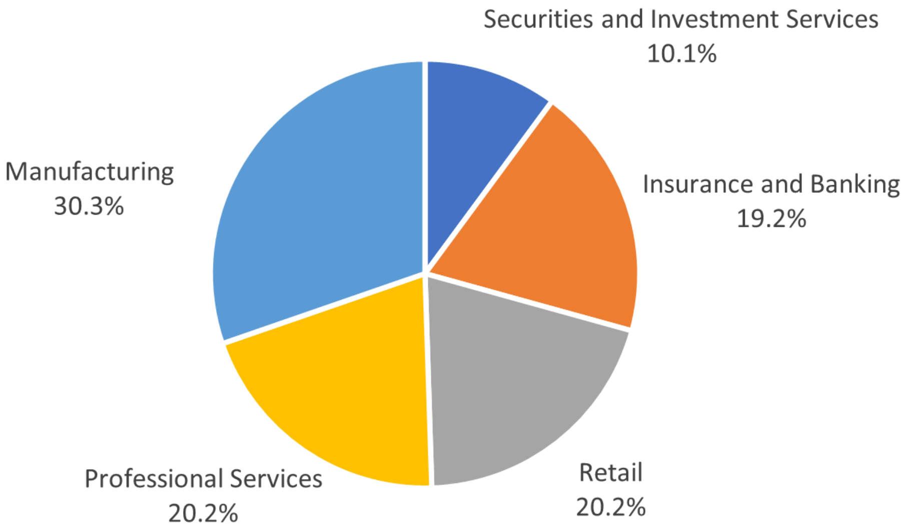


Figure. 2.1 Global spending on the digital transformation by industry (2022). Based on [10]

considerable expenditure in digital transformation and is expected to account for above 30% of worldwide digital transformation spending in 2022 (Figure 2.1). A recent survey by Deloitte has revealed that more than 60% of the surveyed manufacturers plan to employ robotics, automation, and data analytics in their facilities to enhance operational efficiency in the next 12 months. While over one-third of the manufacturers are interested in implementing Internet of Things (IoT), additive manufacturing and cloud computing technologies [3].

The reason why so much time and money have been invested in the digital transformation process is that once implemented successfully, these new technologies yield enormous returns. According to their study on the true value of Industry 4.0, [11] suggested that it is frequently observed across sectors of manufacturing to see an overall reduction in machine downtime of 30 to 50%, a boost in output of 10 to 30%, an improvement in accuracy forecasting of 85% and an increase in labor productivity of 15 to 30%. Digital technology is revolutionizing every facet of manufacturing, including not only efficiency and processes but also the workforce. Appropriate technology utilization may lead to better decision-making, more opportunities for employee professional growth, cross-functional collaboration, and increased workplace safety and satisfaction among staff.

Both manufacturers and consumers have acknowledged that traditional production processes have resulted in many adverse environmental effects, including the depletion of natural resources, pollution, and climate change. These could eventually significantly harm nature, ecosystems, and human health. Furthermore, there is a growing trend among consumers to be more mindful of the environmental impact of their purchases, leading to an increased demand for environmentally sustainable products. In addition, governmental bodies are taking action to foster sustainable manufacturing by implementing novel regulations and policies and incentivizing the adoption of more eco-friendly practices. The current manufacturing environment has witnessed a discernible shift towards sustainable practices, characterized by a heightened emphasis on renewable energy utilization, resource optimization, enhanced reuse and recycling, and the minimization of hazardous substances and chemicals, among other measures.

2.2 Manufacturing assets and value chain

The International Standard of asset management generally defines an asset as:

> *"An asset is an item, thing or entity that has potential or actual value to an organization. The value will vary between different organizations and their stakeholders, and can be tangible or intangible, financial or non-financial [12, p. 2]."*

Amadi-Echendu et al. [13] specify that an engineering asset is a physical object, such as equipment, facilities, buildings, inventories, etc., related to a legal entity, such as a person or company or a collection of legal entities that have legal rights on that object. Each engineering asset possesses a typical capability value and financial value. The capacity value is the ability to perform specific tasks, for example, the output that a machine/equipment produces within a given timeframe. The financial value is determined in different forms with various monetary scales depending on the intended use of the assets.

We could broadly say that an engineering asset is a physical asset with a legal entity and has certain values to someone.

Engineering assets of an organization are usually recorded in an accounting system, e.g., a balance sheet [13]. From an accountant's perspective, engineering assets could be viewed as physical assets or "real assets" including non-current and current assets. Non-current or fixed assets are physical objects like land, buildings, equipment, machinery, hardware, etc. While faster-moving assets, such as raw materials, cash, finished goods, spare parts, consumables, etc., are referred to as current assets. Intangible assets consist of, but not limited to, patents, licenses, software, intellectual property, etc., [14]. In accordance with the asset structure proposed by Amadi-Echendu [15], which mirrors the assets defined in accounting and financial language, adjustments have been made to align more closely with assets in the manufacturing sector. The resulting tailored manufacturing asset structure is illustrated in Figure 2.2.

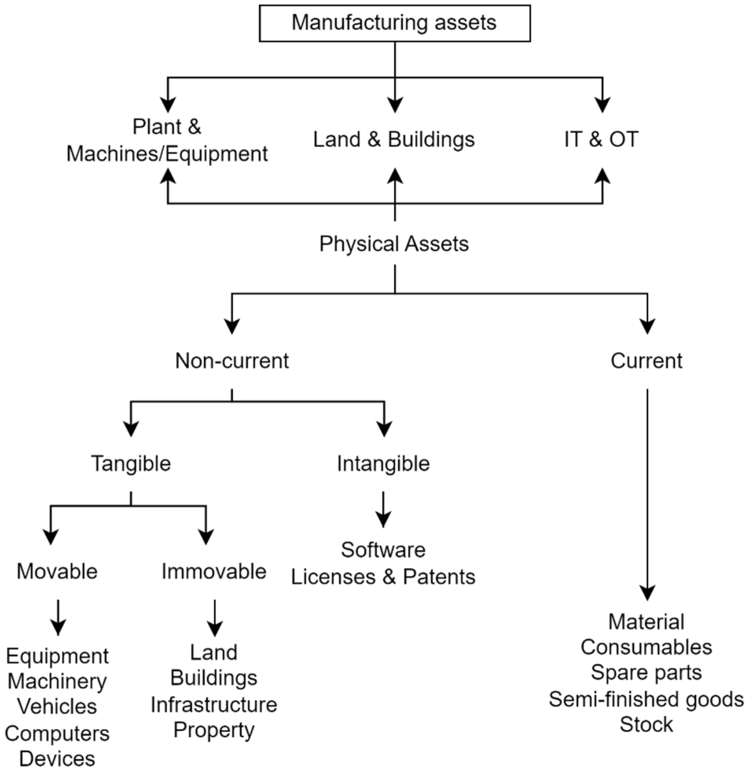


Figure. 2.2 Manufacturing asset structures. Based on [15]

Manufacturing is a complex process involving numerous factors and challenges that businesses must consider to achieve their key objectives. Engineering assets play a critical role in manufacturing, enabling companies to fabricate products, maintain quality, achieve production goals, etc. The process typically involves moving the materials or products along a conveyor belt or other automated system, with each station or work area along the line performing a specific task or operation. Those materials, semi-finished goods and finished goods, along with spare parts and other consumables typically classified as current assets, are diverse and can vary in distinct types of manufacturing. Engineering assets used in manufacturing systems, which may be referred to as manufacturing assets, are diverse and can vary based on factors such as the complexity of the production process, the type of products being manufactured, and the raw materials required.

It is not uncommon for a manufacturing system to have a wide variety of equipment and machinery. For example, an automotive assembly factory may include robots for welding and painting, assembly machines for assembling parts, conveyor belts for transporting materials, and testing equipment for checking product quality [16]. A dairy product manufacturer may have pasteurizers, homogenizers, cheese-making equipment (including vats, curd cutters, presses, molds, etc.), packaging and labeling equipment [17]. A steelmaking facility may be equipped with blast furnaces, basic oxygen furnaces, electric arc furnaces, continuous casting machines, rolling mills, surface-treating equipment, and other material handling equipment [18].

Apart from those diverse equipment and machinery, manufacturing systems may also share some elements in common, like conveyor belts, utility systems, waste management systems, transportation equipment, etc. Software, Information Technology (IT) and Operational Technology (OT), licenses, patents, etc., are often tightly connected or integrated with above-mentioned assets. For example, a chemical manufacturing company may need to purchase production technology licenses for certain products from a licensor. Enterprise software or Enterprise Application Software (EAS) are widely used by organizations to manage and automate their business processes across departments. Some common types of such software are Enterprise Resource Planning (ERP), Manufacturing Execution System (MES), Supply Chain Management (SCM), etc. Along with IT, OT is a vital part of manufacturing system. OT has historically been associated with industrial settings and encompasses the hardware and software systems in charge of controlling and executing activities on the shop floor. Supervisory Control and Data Acquisition (SCADA), Programmable Logic Controller (PLC), and Computerized Numerical Control (CNC) machining systems are examples of such technologies.

The manufacturing industry has been increasingly competitive to achieve lower prices, higher product quality, and stronger customer loyalty, especially with the rise of technological advancement in recent years. Regarding the circumstances, understanding the value chain framework can provide businesses with a systematic way of assessing their manufacturing assets and their contributions to the overall value-generating process. As a result, they can improve their overall efficiency, streamline processes, as well as increase customer values, drive innovations, and manage risks.

With a similar emphasis on the sequence of activities related to the production and delivery of products to customers, the manufacturing value chain can be effectively depicted by the generic value chain model proposed by Michael E. Porter [19]. This model provides deeper insights into the value creation process and offers strategies to differentiate enterprises from their competitors.

The generic model of a value chain within an organization comprises primary activities and support activities (Figure 2.3). The primary activities include five main stages of value creation as follows:

- ***Inbound logistics*** refers to obtaining and handling the required input for the production or manufacturing process throughout various functions such as material handling, warehousing, and inventory management.
- ***Operations*** comprises activities involving actual production to convert raw materials into the final product form, namely processing, assembly, packaging, testing, maintenance, and quality control of the product.
- ***Outbound logistics*** involves storing, handling, and distributing completed products to customers and vendors.

- ***Marketing and sales*** encompass strategies that aim to capture customers' attention and promote the sale of goods through various means such as advertising, sales promotions, and public relations.
- ***Service*** provides customer support and resolves any issues or concerns that consumers may have with the products to maintain their products' values, consisting of various sorts of activities like installation, maintenance, training, (spare) parts supply, and product adjustment/calibration.

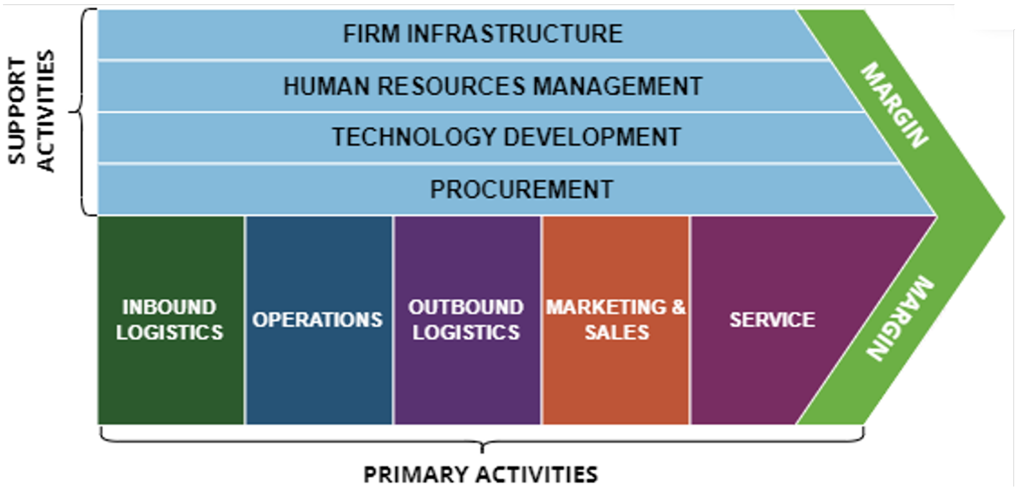


Figure. 2.3 The generic value chain proposed by [19]

Another critical part of the value chain is the support activities. These activities help optimize the primary activities and ensure that the overall value chain operates smoothly and efficiently. There are four main support activities:

- ***Procurement*** is the process of obtaining raw materials, commodities, and services required for a company's operations.
- ***Technological development*** includes activities such as research and development, improvement of existing products, and creation of new ones needed for a company's growth.
- ***Human resources management*** is the process of recruiting, training, developing, and retaining employees. These activities are pivotal to a company's business since they ensure that competent personnel with essential skills and expertise to carry out their work are always available.

- ***Infrastructure*** refers to the physical and organizational structures that are necessary to support a company's operations. This includes not only buildings, equipment, transportation systems, and communication systems but also other activities like general management, planning, finance, accounting, quality management, etc.

The value chain model developed by Michael Porter provides a framework for conceptualizing how businesses create value through a series of interconnected activities. Traditionally, the model adopts a firm-centric viewpoint, observing value creation as an internal process occurring within an isolated organization.

A conventional firm-centric perspective of the value chain is evolving due to, but not limited to, the following trends:

- ***Globalization***: Businesses today frequently operate on a global scale where materials are procured from all over the globe, production occurs in multiple locations, and products are distributed to international markets. This has resulted in an increasingly complex global value chain [20][21].
- ***Digitalization***: The introduction of digital technologies has drastically altered how value is created. A variety of products and services now incorporate data, software, and digital platforms as integral elements [22][20][21].
- ***Interconnected ecosystems***: Businesses tend to co-create value with a network of partners, suppliers, and clients. The boundaries between companies are becoming less rigid, and multiple parties are frequently involved in the creation of value [22][21].
- ***Sustainability***: Increasing attention is being placed on the social and ecological impacts of industrial operations. Circular or sustainable value chains seek to minimize waste generation, reduce carbon footprint, and improve equality in society [21].

Due to the dynamic nature of value chains, there has been a paradigm shift towards a network-centric perspective, commonly referred to as a value network. A value network is an ecosystem where organizations and/or individuals cooperate to benefit the whole group. The connections between them might be physical or intangible, reflecting a change from the traditional linear value chain model [23][24].

Consider the example illustrating the global smartphone industry by [25], leading firms such as Apple, Huawei, and Samsung operate under strong brands and are responsible for significant research and development, product design, and specifications. However, these companies rely on sourcing components and technologies from third-party suppliers. All of these specialized components, such as chipsets, have their own global supply chains, for example, they are designed by a specialized American company, fabricated in China, and packaged in Malaysia before reaching the end-user. Furthermore, smartphone manufacturers must have access to interoperability and connectivity standards technology, which is provided by firms such as Nokia, Ericsson, Qualcomm, and others. These technologies are typically licensed independently, which necessitates the payment of licensing fees. Smartphones require software to function, including a mobile operating system and many other mobile apps, which third parties frequently provide. The final product is often assembled by large contract manufacturers such as Flextronics, Foxconn, and Wistron, whereas Samsung has in-house factories for assembly. Finally, distribution and retail vary among companies. Apple operates their own online and physical stores, whereas Android phone producers rely on regular distributors and retail outlets. The smartphone industry's worldwide value chain is dynamic and subject to changes driven by evolving technology and consumer preferences. Lead firms may shift away from established suppliers, develop high-value components and intellectual property internally, and experiment with new manufacturers or assembly locations to meet high demand.

It is evident that a finished smartphone is the result of a complex value network. Value is not simply added in a linear, step-by-step process. Instead, it's created through a complex network of interactions between various players. Understanding this network helps the smartphone company enhance their offering, whether by sourcing better components, partnering with preferred third-party suppliers, or encouraging them to create better applications and improve the operating systems.

Having similar observations, [26] pointed out that evaluating a company's performance or value creation alone is neither meaningful nor relevant. This is due to the fact that a variety of internal and external factors contribute to the rapid growth of network activities across industries. For example, changes in the business environment, product complexities, international customer's diverse needs, and preferences, which go beyond the basic requirements, possibilities for location-based cost advantages, requirements for certain skill sets and supply that cannot be met in-house, associated risks, adoption of previously unconventional technologies, cooperation in procurement and logistics activities. Given these dynamics, it is crucial to include the associated network and the corresponding value creation points in assessments of a business's value chain. Without doing so, evaluations may lack accuracy and fail to provide meaningful insights into the overall business value chain. Therefore, it is essential to take a holistic view that encompasses network dynamics and its impact on value creation.

2.3 Challenges of the manufacturing industry

One of the biggest concerns in the manufacturing industry is "quality". To maintain quality standards, defect and anomaly detection is absolutely critical since defective products have reportedly caused recalls costing over $2 billion between 2012 and 2017 [27].

The supply chain is an essential aspect of the manufacturing industry, involving a variety of activities and entities, from the procurement of raw materials to the delivery of finished products to consumers. However, many factors ranging from global distress and extreme weather to supplier incapacity or product recalls, may considerably influence the effectiveness and efficiency of the supply chain. According to Deloitte's latest supply chain investigation in 2022, 80% of surveyed industry leaders witnessed "heavy" to "very heavy" disruption in their supply chains over the last 18 months [3]. Because of this vulnerability, it is critical for organizations to gain more visibility into their supply chains in order to build resilience while maintaining a competitive advantage. In response to this issue, many manufacturers are adopting various digital technologies due to their growing immediate accessibility to enhance monitoring and management of their supply chain and generally improve visibility [3][28].

However, despite the benefits of such digital platforms, the manufacturing sector still confronts difficulties because of a lack of interoperability across different platforms spanning IT and OT. Most businesses run many IT systems in parallel and with conventional OT, which are either only partially integrated or completely incompatible [28]. In addition, although data may be invaluable, the associated expense of gathering data from multiple sources may be prohibitively costly.

Another major concern of the manufacturing sector is unplanned downtime caused by machine failure due to the inability to predict machine and equipment failure in advance. That failed equipment primarily causes production disruptions and may cause a ripple effect throughout the whole operation. Such interruptions may pose a negative impact on an organization's entire supply chain, causing delays, unnecessary costs, and possibly damaging consumer relationships. Moreover, due to inflations, higher production capacity, and overall higher cost of resources and workforce, downtime is getting much more costly yearly. For example, according to a new report from Siemens, the world's 500 biggest manufacturers are expected to lose over \$1.5 trillion in 2023, approximately 11% of their annual revenue, almost double that of 2019 [29].

In modern manufacturing, product design and development must deal with the rising difficulties of complexity and customization. The growing consumer demand for multifunctional and technologically advanced products calls for highly complex designs, demanding validation procedures, and meticulous interdisciplinary coordination. Poor management of this complexity can result in design flaws, production issues, waste of resources, and potential damage to the company's competitive position. Concurrently, increasing consumer demand for customized products requires a change from conventional mass production towards more flexible manufacturing methods. Deloitte [30] reported that over 50% of customers showed interest in buying personalized or custom-made products. Maintaining an appropriate balance between customization and operational efficiency becomes crucially significant in order to prevent a surge of production expenses, extended lead times, and potential flaws in the product. Furthermore, it also adds a layer of complexity to supply chain management and inventory control due to the requirement for a wider variety of components or raw materials.

These challenges lay the foundation for developing the conceptual model for cloud adoption presented in Section 3.1. They also serve as important points of reference for identifying principal challenges for analyzing industrial benchmarks discussed in Section 3.2.

2.4 Digitalization and digital technologies

Despite being a common “buzzword”, digitalization does not have a universal definition, and different authors have their own idea based on various contexts. According to Oxford English Dictionary [31], digitalization refers to *“the adoption or increase in the use of digital or computer technology by an organization, industry, country, etc.”* Meanwhile, digitalization or digital transformation can be defined as *“the changes that digital technology causes or influences in all aspects of human life”* [32, p. 689]. Shukla [33] stated that a company’s adoption of digital technology to streamline existing processes across all divisions is known as digital transformation; it’s a campaign to strengthen their existing systems regarding value creation, innovation and overall experience. Parviainen et al. [34] generally concluded the term as shifts in working practices, roles and responsibilities, and business offerings brought about by adopting digital tools within an organization or in the organization’s setting. An establishment of the Norwegian Ministry of Trade, Industry and Fisheries, Digital21, outlined that digitalization is about using the opportunities offered by digital enabling technologies to improve, innovate and create new things. Therefore, digitalization is not only about technology but also about the willingness and ability to change [35].

Throughout this thesis, the terms “digitalization” and “digital transformation” are interchangeable, and both refer to the use of digital technology by organizations to optimize current procedures and workflows across all departments and enhance the general experience for internal and external stakeholders. This is an essential strategy to upgrade and innovate their existing infrastructure, demonstrating the desire and capability to transform it into the best shape.

Digitalization of information-rich processes can reduce costs by up to 90% and improve turnaround times significantly. Additionally, replacing paper-based methods with automatic data collection software enables businesses to gain better insights into their process performance, cost drivers, and risk sources [36]. The opportunities offered by digital technologies will naturally be perceived and exploited differently in different industries and different companies, from those that use disruptive technologies to deliver products, goods, or services in entirely new ways or with a different benefit to those that are content to streamline operational processes [35]. Thus, the impact of digitalization and the goals of digitalization for an organization may vary from improving ways of working via digital means and re-planning internal processes to capturing external opportunities (new services, new customers, etc.) or to shifting organizational roles and responsibilities in a disruptive manner [34].

The digital transformation process across various industries is only made possible by the emergence and rapid developments of some disruptive technologies, which will be discussed in detail in the following sections, with Section 2.5 dedicated to cloud computing.

2.4.1 Artificial intelligence

Artificial Intelligence (AI) is an area of computer science that specializes in creating intelligent computers capable of doing tasks that would ordinarily need human intelligence, such as visual and speech recognition, learning, reasoning, decision-making, and even adapting to new situations. The primary goal of AI is to develop computer systems that can reproduce human cognitive processes, capable of detecting patterns and making predictions or evaluations based on the analysis results of massive volumes of data [37][38].

2.4.1.1 Machine learning

Machine Learning (ML) is a component of AI that enables computer systems to learn and improve their performance without having to be explicitly programmed [37] because certain tasks are too difficult or impossible to program, especially tasks accomplished subconsciously. For example, recognizing handwriting is a skill that comes effortlessly to humans, but programming a computer to do that effectively is quite challenging. Without the help of ML techniques, computers, unlike humans, cannot easily discern patterns in handwriting. A computer with ML algorithms has the ability to analyze and learn from the data that is fed into it, allowing it to execute specific tasks and constantly improve its performance [38]. Therefore, López-Gómez et al. [39] suggested that ML is an essential building block of AI for numerous applications as it provides a foundation for systems that can make independent decisions merely based on data analysis.

There are three main types of learning algorithms employed in ML: supervised, unsupervised and reinforcement learning. Supervised learning algorithms are trained using labeled data (“correct answer given”), for instance, when given product images with labels “normal” or “anomaly” as the inputs, a trained model can predict the correct label of a new image. Whereas, in unsupervised learning, the ML algorithm is fed with unlabeled data (“no answer given”) and learns the patterns and structures in them. In reinforcement learning, learning is strengthened by a reward and punishment system, this allows the ML algorithms to continuously aim for maximum rewards, in other words, the best possible output [37][38].

2.4.1.2 Computer Vision

Computer Vision (CV) is a field of AI that extracts semantic information from digital photos, videos, and other visual media. This technology allows computers to “see” and “understand” the content of images and utilize that intelligence for various useful applications such as identification, navigation, and augmented reality [40][41], especially in this era when cameras and visual media are present everywhere.

It is scientifically proven that human vision is considered among the best in the animal kingdom [42]. In addition, humans have years of experience in perceiving and differentiating objects. That briefly explains how effortlessly we perform such functions; meanwhile, CV algorithms, which often have limited exposure to digital images taken by cameras, struggle to mimic these intellectual abilities accurately [40][41].

Despite the numerous challenges, CV has successfully established its position in various industries and applications [40][43]. The CV market will continue expanding, with an estimated value of $11.22 billion in 2021 [44]. For example, smartphone producers use CV for quality inspection, allowing them to simultaneously inspect and detect defective Printed Circuit Boards (PCBs) [45]. An automated industrial arm is empowered by CV to pick items from storage containers and place them into smaller boxes for shipping [46]. Testing self-driving cars are now able to drive as well as humans do in the tested environment, suggesting massive potential for the next citywide autonomous transportation project [47].

2.4.2 Internet of Things

The Internet of Things (IoT) was coined by Kevin Ashton in 1999, referring to the wireless networks of sensors, equipment, machines, computers, hardware, software, etc., and the Internet. This interconnectivity enables them to collect and exchange data over the Internet without the help of humans [48].

IEEE has defined it as follows:

> *"IoT refers to any systems of interconnected people, physical objects, and IT platforms, as well as any technology to better build, operate, and manage the physical world via pervasive data collection, smart networking, predictive analytics, and deep optimization [49, p. 3]."*

The combined power of numerous digital technologies, such as wireless networks, cloud computing, big data, AI, ML, etc., enables and promotes the implication of IoT [39]. At the same time, it has a wide range of applications in different fields, such as the manufacturing industry, energy, transportation, healthcare, entertainment, public services, etc.[49][50][51]. The implementation of IoT in manufacturing contexts is commonly known as the Industrial Internet of things (IIoT). Apart from the above mentioned technologies, IIoT also integrates communication and automation technologies that are already in place on the industrial shop floors [39].

2.4.3 Big data analytics

The widespread adoption of IoT will lead to a huge rise in the amount of data created, which is often known as big data. Although there is no globally recognized definition of big data, it is commonly defined by five fundamental characteristics [52]: 1. A large volume of data; 2. The variety of data types; 3. Data creation at a high velocity; 4. Data produced has high business value; 5. Data's correctness and accurate can be verified. Alternatively, the National Institute of Standards and Technology (NIST) has defined big data as follows:

> *"Big Data consists of extensive data sets — primarily in the characteristics of volume, variety, velocity, and/or variability — that require a scalable architecture for efficient storage, manipulation, and analysis [53, p. 5]."*

Despite the numerous advantages and opportunities offered by big data, its development creates significant technological challenges. Traditional information technology infrastructure, data management, and analysis methodologies are particularly unprepared to handle the rapidly growing and increasing complexity of big data. Therefore, big data analysis demands new software, database systems, and analytical tools to fully exploit its value to give semantic insights about processes in real-time [39][54].

2.5 Cloud computing

According to Mell & Grance, cloud computing refers to:

> *"Cloud computing is a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction [55, p. 2]."*

Meanwhile, cloud computing also implies the provision of various on-demand services, including servers, databases, storage, analytics, networking, etc., via the Internet, enabling customers to pay for only what they use when needed [5][56].

Mell & Grance [55] have also presented five characteristics of cloud computing services as follows:

- ***On-demand self-service*** refers to a Cloud Service Customer (CSC)'s ability to automatically and independently provision as-needed computing resources, such as network storage and server time, without interacting directly with individual service providers.
- ***Broad network access*** indicates the ability of CSCs to access resources and services provided by a Cloud Service Provider (CSP) over a network from anywhere, at any time, through a variety of client devices such as mobile phones, tablets, laptops, workstations, etc. This access is enabled by standard protocols, such as Hypertext Transfer Protocol Secure (HTTPS), Transmission Control Protocol/Internet Protocol (TCP/IP), User Datagram Protocol (UDP), etc., used to establish connections between the client devices and the CSPs [57].
- ***Resource pooling*** refers to CSPs offering their computing resources as a pool that is logically divided and allocated among CSCs based on their demands using a multi-tenant model. It allows two or more CSCs to share various virtual resources, such as storage, computing capacity, and bandwidth, with their own virtual environment [57].

- ***Rapid elasticity*** indicates the ability of cloud computing services to rapidly scale (grow or shrink its capacity) based on CSC needs. It relates to horizontal scaling, even though it is not always automated, it is considered unlimited, and any amount may be allotted.
- ***Measured service*** refers to a CSP's capability to automatically monitor, control and notify CSCs of the consumption of their resources. It offers transparency as well as the optimization of resource utilization.

CSPs are businesses that offer a variety of computing services through the internet, commonly referred to as the "cloud". These services are often divided into three groups, i.e., SaaS, PaaS, and IaaS, and range from basic storage and processing services to more advanced analytics, AI, ML, etc., capabilities. These will be discussed further in the upcoming sections.

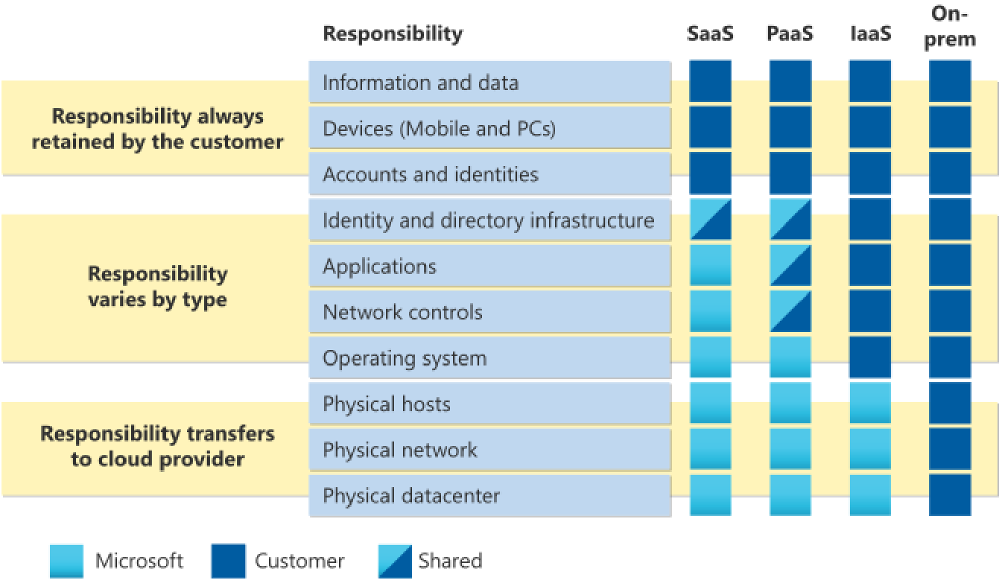
CSPs have played a vital role in the digital transformation of businesses across sectors, allowing them to utilize cloud services and take advantage of those in their systems for improvement, innovation, and evolution. Organizations are enabled to scale their IT structures, build and manage customized applications, collect and analyze data efficiently, and capitalize on emerging technologies in a flexible and cost-effective manner.

Amazon Web Services (AWS), Microsoft, and Google are among the most dominant cloud-based solution providers, known for their technical capacity, innovative services, and broad industrial understanding. Gartner, a leading research and consulting firm, has verified their position in the field, classifying them as the leader in the Magic Quadrant for Cloud Infrastructure and Platform Services in 2022 (Figure 2.4). This award recognizes their proven track record and ability to influence industries with revolutionary technologies.

Figure. 2.4 Magic Quadrant for Cloud Infrastructure and Platform Services [58]

2.5.1 Cloud service models

Cloud services are categorized into three types of service models, such as Infrastructure as a Service (IaaS), Platform as a Service (PaaS), and Software as a Service (SaaS). The primary difference between these three models is the level of control and responsibilities shared by CSC and CSP, shown in Figure 2.5.



	Responsibility	SaaS	PaaS	IaaS	On-prem
Responsibility always retained by the customer	Information and data	■	■	■	■
	Devices (Mobile and PCs)	■	■	■	■
	Accounts and identities	■	■	■	■
Responsibility varies by type	Identity and directory infrastructure	◩	◩	■	■
	Applications	□	◩	■	■
	Network controls	□	◩	■	■
	Operating system	□	□	■	■
Responsibility transfers to cloud provider	Physical hosts	□	□	□	■
	Physical network	□	□	□	■
	Physical datacenter	□	□	□	■

□ Microsoft ■ Customer ◩ Shared

Figure. 2.5 Share responsibilities between CSP and CSC [59]

Infrastructure as a Service (IaaS) typically provides CSCs access to computers (virtual or physical servers), storage spaces, network features, and other fundamental computing resources. CSCs have the maximum flexibility and administrative control of their IT resources. While they manage and control their own software, including operating systems and applications, CSPs take care of expenses and difficulties in purchasing and managing the physical infrastructures [5][56][55].

Platform as a Service (PaaS) provides CSCs with an application-hosting environment with supported tools, services, libraries, and programming languages. It allows CSCs to bypass managing underlying infrastructure, including operating systems which are entirely in charge by CSPs. Thus, they can focus only on developing their software applications and have control over deploying and managing them [5][56][55].

Software as a Service (SaaS) provides CSCs with a complete product they can connect to and use over the internet through a web browser or program interface. CSCs do not have to worry about how to maintain and update applications or manage the underlying infrastructure, which CSPs are responsible for, they just need to think about how they will use that service [5][56][55].

2.5.1.1 Cloud service categories

Cloud computing services are classified into the following categories: compute, storage, database, analytics, networking, ML, IoT, etc.

- ***Compute services*** provide virtual servers, containers, and serverless computing for running applications and services, e.g., Amazon Elastic Compute Cloud (Amazon EC2), AWS Lambda, Azure Functions, etc.
- ***Storage services*** provide several data storage types, including object storage, block storage, and file storage, e.g., Amazon Simple Storage Service (Amazon S3), Azure Blob Storage, Azure Data Lake Storage, etc.
- ***Database services*** offer managed relational and NoSQL databases, as well as data warehousing and data lake services, e.g., Amazon Aurora, Amazon DynamoDB, Azure SQL Database, etc.
- ***Analytics services*** enable businesses to analyze large volumes of data to gain insights and make informed decisions, e.g., Amazon EMR, Amazon Kinesis, Azure Synapse Analytics, Azure Databricks, etc.
- ***Networking services*** provide tools for managing and connecting networks and resources securely, e.g., Amazon Virtual Private Cloud (Amazon VPC), Azure Virtual Network, Azure ExpressRoute, etc.
- ***ML services*** enable businesses to build, train, and deploy ML models and integrate them into their applications, e.g., Amazon Lookout for Vision, Amazon SageMaker, Azure Machine Learning, etc.
- ***IoT services*** offer the capability to connect, manage, and analyze data from connected devices, e.g., Amazon IoT SiteWise, Amazon IoT Greengrass, Azure IoT Hub, Azure IoT Edge, etc.

Below are some examples of the categories indicated above, which will be addressed more in the sections 3.2 and 3.3 of this thesis.

- ***Amazon Lookout for Vision*** is a fully managed ML service that utilizes CV to detect anomalies in manufacturing products/processes at scale. This service allows manufacturers to automate their visual inspection process with an easy-to-use interface and no ML/CV expertise [60][61]. Amazon Lookout for Vision enables manufacturers to quickly train and deploy an ML model into their operation with a small training data set. The service is also easily integrated into the existing infrastructure. By providing a feedback mechanism, the service allows users to review the model predictions, verify their accuracy, and re-train the model if needed to ensure it meets their performance targets [61].

- ***AWS Panorama*** is a set of ML devices and a Software Development Kit (SDK) that enable users to add CV to their already installed cameras to analyze video streams in real time and automatically make accurate predictions at the edge with low latency [62]. AWS Panorama simplifies the CV process by making it easier to use live video streams to enhance operations that conventionally need visual inspection and monitoring, like quality evaluation, defects detection, safety inspection, etc. [63].
- ***Amazon S3*** is an object storage service that provides best-in-class scalability, data availability, security, and performance. Using cost-effective storage classes and user-friendly administration tools, Amazon S3 helps minimize expenses, organize data, and establish tailored access control to meet organizational and compliance requirements [64].
- ***AWS IoT SiteWise*** is a fully managed service that facilitates the efficient collection, storage, organization, and monitoring of industrial equipment data on a large scale. This service makes valuable insights into industrial operations accessible to businesses by configuring and monitoring metrics like Mean Time Between Failures (MTBF) and Overall Equipment Effectiveness (OEE). Furthermore, AWS IoT SiteWise Edge allows for data processing and viewing directly on on-premises devices [65].
- ***Azure Data Factory*** is a cloud-based data integration service enabling organizations to create, schedule, and manage data pipelines that can move and transform data from various sources and destinations [66].
- ***Azure Data Lake Storage (Gen 1)*** is a cloud-based storage solution intended for scalable and secure storage of massive volumes of structured, semi-structured, and unstructured data in its original format. The service provides unlimited storage

capacity, high performance, and compatibility with essential analytics platforms for ingestion, processing, and visualization [67].

- ***Azure Blob Storage*** is a cloud-based storage service intended to store vast volumes of unstructured data, such as text, photos, audio, video files, etc., as "blobs" (Binary Large Objects). It offers an intuitive method for storing and accessing data, with the option to scale up or down as needed [68].
- ***Azure Data Lake Store Gen2*** combines every key feature of Azure Data Lake Storage Gen1 and Azure Blob Storage into a single service [69].
- ***Azure SQL Database*** is a cloud-based relational database that arranges data into the form of tables. It automatically allocates necessary resources, handles updates and backups, and provides serverless computing and hyperscale storage that quickly responds to changing needs. This service also contains tools for monitoring database usage and protecting data from unauthorized access [70].
- ***Azure HDInsight*** is a fully managed cloud-based service that delivers a scalable and secure environment for executing big data workloads of commonly used frameworks like Hadoop, Spark, or Kafka. It effectively simplifies the deployment and management of big data processing without the need for hardware installation [71].
- ***Azure Databricks*** is an analytics service that offers streamlined workflows and a collaborative workspace that enables data scientists, data engineers, and business analysts to develop and run large-scale data processing and analytics workloads [72].
- ***Azure IoT Hub*** is a managed service featuring a secured and reliable communication channel for sending and receiving data from billions of IoT devices. This service allows for understanding the conditions of IoT devices and establishing message routes to other Azure services without writing any code. In addition, it can provide necessary tools for secure, efficient, and scalable device management and communication to extend solutions from the cloud to the edge [73].
- ***Azure IoT Edge*** is a service that deploys and manages cloud-native workloads such as AI, Azure services and third-party services, or custom business solutions to run directly on IoT devices. With this service, IoT devices can continue operating

and performing necessary computations locally, even when they are offline or have intermittent connectivity to the cloud [74].

- ***Azure Stream Analytics*** is a cloud-based real-time data streaming and analytics solution that allows enterprises to process and analyze streaming data from a variety of sources in real-time using a SQL-based query language [75].
- ***Azure Synapse Analytics*** is a cloud-based analytics service that includes data integration, enterprise data warehousing, and big data analytics, along with a flexible querying system [76].
- ***Azure Machine Learning*** is a cloud-based service that allows users to quickly build, train, and deploy ML models in a collaborative environment with a drag-and-drop interface. In addition, the platform offers scalable computing power, model management, deployment, and monitoring features, while aligning with security and compliance regulations [77].
- ***Power BI*** is a business analytics tool that allows users to easily visualize and analyze data in real time, facilitating data-driven decision-making. It provides an easy-to-use interface to generate interactive dashboards and charts and offers tools for integrating numerous data sources. This service also features secure and scalable data-sharing tools, allowing teams to cooperate and share insights in a safe environment [78].

2.5.2 Cloud deployment models

The term “cloud deployment model” describes the process used to deploy and make a cloud computing environment accessible to users. Three main cloud deployment types are private cloud, public cloud, and hybrid cloud.

A ***private cloud*** is a cloud computing resource solely utilized by an organization or a group of businesses [79]. It can be in the company’s own data center or hosted by a third-party provider. The company’s IT department is responsible for managing the private cloud, similar to conventional data center ownership since the services and infrastructure of a private cloud are maintained within a private network [80]. However, it still offers some of the advantages of a public cloud, like elasticity, scalability, service-based computing as compared to on-premises infrastructure [81], and also more control and flexibility [7].

In a ***public cloud***, the CSP owns and manages all hardware, software, and other supporting infrastructure and delivers cloud resources publicly via the Internet for open use. Thus, customers can take most of the advantages of the cloud, such as no maintenance, scalability, reliability, etc. It offers lower costs to deploy IT solutions, especially for small or medium-sized businesses [81][82].

A ***hybrid cloud*** is a composition of public and private clouds through a technology that enables data and applications to be transferred between them [55]. With data and application portability, a hybrid cloud offers the company better flexibility, additional deployment options, and optimization options for existing infrastructure, security, and compliance [80].

2.5.3 Advantages of cloud computing

Adopting cloud computing has several benefits for enterprises, the most notable of which is its cost-effectiveness. It shifts from capital to operational expense while eliminating the upfront expenditures associated with purchasing hardware and software as well as establishing and administrating on-site data centers. Thus, companies only pay for the resources they actually use at significantly reduced prices due to the CSPs' massive economies of scale. In the context of cloud computing, a CSP spreads all the costs associated with its infrastructure, development, maintenance, and administration over its large number of CSCs; as a result, the cost per user dramatically reduces [5][6][80].

With cloud computing, many demanding tasks associated with infrastructure management, such as racking, stacking, and powering servers, etc., are offloaded to CSPs. This can dramatically reduce the workload for in-house IT personnel, as a result increasing overall productivity by allowing them to concentrate on other high-value tasks that are useful for the business [5][6][80].

Another significant benefit is the scalability of cloud services which allows companies to scale up or down their infrastructure swiftly as required within a few minutes notice. IT departments have long faced a considerable challenge in infrastructure capacity planning. Due to the uncertain and changing nature of business environments, these estimations usually end in a surplus of idle resources or an insufficient capacity, resulting in poor system performance and the potential loss of business opportunities. By leveraging the scalability offered by cloud computing, organizations can easily overcome these challenges. This revolutionary change not only ensures optimal resource utilization but also frees up valuable time and resources within the organization, enabling more focus on added-value operations rather than the complex yet ineffective capacity planning [5][6][80].

In the cloud environment, access to new IT resources is virtually immediate, significantly enhancing speed and agility compared to conventional IT settings, which are constrained by hardware limitations and slow procurement processes. Businesses can take this advantage to better respond to fluctuations in the market and seize available opportunities while addressing critical issues. In addition, cloud computing encourages innovation by making it easier for developers to test new ideas and design new applications. They can rapidly spin up or retire instances, accelerating the development and deployment processes. As a result, companies can uphold a competitive advantage by constantly refining their goods and services [5][6][80].

In the traditional IT model, launching an application in a newly-targeted location includes establishing servers, network connections, ensuring compliance with local legislation, and so on. Since most CSPs have data centers worldwide, the process is considerably simplified. CSCs can quickly deploy their apps in any of those locations with just a few clicks. This brings the software closer to the end users, leading to lower latency and a better user experience [5][6][80].

Cloud computing also enhances reliability by simplifying and reducing the expenses of data backup, disaster recovery, and business resilience. Data is mirrored and stored at numerous redundant locations within the CSP's network. Additionally, CSPs, especially reputable ones, continuously invest in state-of-the-art security technologies, and employ top-tier security experts, to offer comprehensive security solutions, including a wide variety of policies, technologies, and controls that strengthen overall security posture, helping to protect data, applications, and infrastructure from possible attacks [6][80].

2.6 Sustainability

With its extensive use of natural resources, energy usage, and carbon emissions, the manufacturing industry has long been recognized as a significant contributor to the ongoing climate crisis [83]. Governmental organizations around the globe have been introducing more stringent sets of standards or requirements to address these environmental issues. The regulatory forces, together with the growing public awareness, have now made manufacturers obliged to take the environmental impacts of their operations more seriously. Recognizing the need for change, manufacturing companies are increasingly incorporating environmental concerns into their development strategies by promoting manufacturing processes that minimize environmental impact [84], such as applying various approaches to reduce waste, optimize resource utilization, reduce their carbon emissions, redesign products with better circularity, etc.

With the incorporation of these environmental considerations, manufacturers have been able to not only mitigate their negative environmental effects but also realize numerous benefits. One of the most immediate effects is cost savings, which come from less waste generation and enhanced resource utilization efficiency. However, the benefits of these more sustainable practices go beyond monetary [85][86][87]. It has been reported that firms that implement sustainability initiatives can also recognize these intangible benefits, such as improved brand reputation and its Environmental, Social, and Governance (ESG) rating [88][89], easier talent recruitment and retention [85][87], increased innovation via novel materials and processes [85].

Given these tangible and intangible advantages, it is clear that an innovative type of manufacturing must include not only economic viability but also environmental and social responsibility. Therefore, the U.S. Environmental Protection Agency defined:

> *"Sustainable manufacturing is the creation of manufactured products through economically-sound processes that minimize negative environmental impacts while conserving energy and natural resources. Sustainable manufacturing also enhances employee, community, and product safety [87]."*

However, the journey toward sustainable manufacturing is complex, requiring significant changes and investments [86]. Despite setting an ambitious sustainability target, many industrial players are failing to keep track of meeting their targets [85][90]. For example, 87% of surveyed organizations aim to be carbon neutral by 2040, but only 51% align targets with the Paris Agreement's goals, and over 90% struggle to scale up their sustainability measures [85].

Manufacturing companies may boost their sustainability and ensure profitable development with the support of innovation that is powered by data and technological advances. Many businesses are beginning to use cloud computing as the first essential brick in building the technological foundation for their smart and sustainable manufacturing [86]. With the cloud as an enabler in place, utilizing emerging digital technologies like IoT, AI, ML, digital twins, etc., becomes more accessible and may significantly improve operational productivity and efficiency. According to the Association of German Engineers, applying digital technologies in industrial settings has the potential to reduce carbon emissions by 20% and boost resource efficiency by 25% [91]. By enabling monitoring production conditions in real-time and identifying any necessary repairs or replacements for industrial assets in advance of incidents, IoT devices combined with AI and big data analytics may increase manufacturing transparency, extend their useful time and avoid breaks down.

In summary, this Section 2.6 has covered a broad overview of the sustainability trends in manufacturing, setting the context and emphasizing the importance of sustainable practices. The significance of sustainability in the manufacturing sector will be underscored through a progressive and layered approach throughout the following sections. Section 3.3.4 will expand the foundation understanding obtained here and shed light on how each cloud-based solution can contribute towards sustainability while solving distinct challenges in different areas through analysis of several industrial benchmarks case studies. The connection between sustainability and manufacturing challenges, specifically within the food manufacturing industry context, will be further explored in Section 4.2. The section will emphasize the inherent intertwining of manufacturing challenges and sustainability objectives. Consequently, in Chapter 6, the study also offers actionable recommendations for enhancing sustainability ratings within a representative third-party service provider's operations. By doing these, the research underscores the importance of aligning digital transformation goals with sustainability objectives, ultimately paving a path towards a more sustainable and digitalized future in manufacturing.

Chapter 3

Developing a conceptual model for cloud adaption in manufacturing and selecting industry benchmarks

The manufacturing sector's inherent diversity with distinct application areas, each having unique requirements and assets, introduces considerable complexity in adopting cloud technologies. It is especially challenging for manufacturers unfamiliar with the excess of cloud services. This complexity extends to the decision-making process due to the distinct features and potential benefits each cloud service offers. The dynamic nature of the manufacturing business adds new layers of complexity as evolving needs and challenges arise. Collectively, these intricacies highlight the necessity for a conceptual model for cloud adoption within the manufacturing sector. Such a model would address these challenges through a structured approach considering the specific requirements and assets of different manufacturing application areas. It ensures that the selected cloud solutions are tailored and optimally utilized to meet each scenario's unique needs in the ever-evolving industry landscape.

This chapter starts with the developed conceptual model in Section 3.1 and then investigates its relevance and applicability to finding cloud solutions for addressing manufacturing challenges through the lens of industrial benchmarks in Section 3.2. These benchmarks serve as valuable references and sources of inspiration, displaying successful examples of how cloud computing, coupled with other novel technologies, has been applied to address manufacturing challenges in the real world. I further explore and analyze the solutions offered by cloud computing in various application areas, paying specific attention to how they address different needs and challenges within the manufacturing industry and their key features and components in Section 3.3. This understanding, in turn, facilitates acceptance of cloud adoption, enabling manufacturers to drive positive transformations in their operational practices.

3.1 The conceptual model for cloud adoption in manufacturing

The manufacturing sector is constantly evolving, especially with the emergence of digital technologies and the increasing focus on sustainability. Manufacturers are facing several obstacles in this setting outlined in Section 2.3, including complex product design, constant adaptation to evolving and more stringent quality standards, the need for more effective supply chain management, and the obligation to fulfill sustainability requirements, etc. Such challenges pose the need for effective, scalable, and innovative solutions that take full advantage of the potential of digital technologies. At the same time, cloud-based services have emerged as a disruptive solution with the ability to tackle these industrial difficulties thanks to their inherent flexibility, scalability, agility, and cost-effectiveness.

However, cloud technology can be complex and unfamiliar to many individuals within the manufacturing industry, leading to a lack of understanding of how cloud services work, their potential applications, and their specific advantages to different manufacturing areas.

Adopting cloud technology in the manufacturing industry indicates a paradigm shift in operations that goes beyond the mere installation of new software or hardware. Determining the best fit of cloud services for the unique demands and requirements of various application areas within the manufacturing landscape is a complex process.

Given the wide variety of cloud services available in the market, it is critical to note that not all solutions are equally beneficial for every application area within manufacturing.

This difference comes from the unique nature of each application area, each presenting its own unique set of requirements and constraints, as well as the assets that must be leveraged effectively. While some areas might derive significant value from adopting certain cloud applications, others might require distinct solutions tailored to fulfill their unique requirements and effectively leverage the available manufacturing assets.

These considerations underline the need for a structured approach by connecting the specifications of existing manufacturing assets or processes with equivalent cloud solutions to identify the most appropriate options that fully unlock the potential of the cloud in addressing the specific needs of each manufacturing application area effectively. Moreover, as the manufacturing industry, along with its needs and challenges, continue to evolve, the conceptual model can provide a flexible framework that can be adapted to future changes, ensuring the relevance and effectiveness of cloud solutions.

To achieve this, I have developed a conceptual model for cloud adoption. This model, illustrated in Figure 3.1 and elaborated below, connects manufacturing assets, needs, and application areas to corresponding cloud-based solutions:

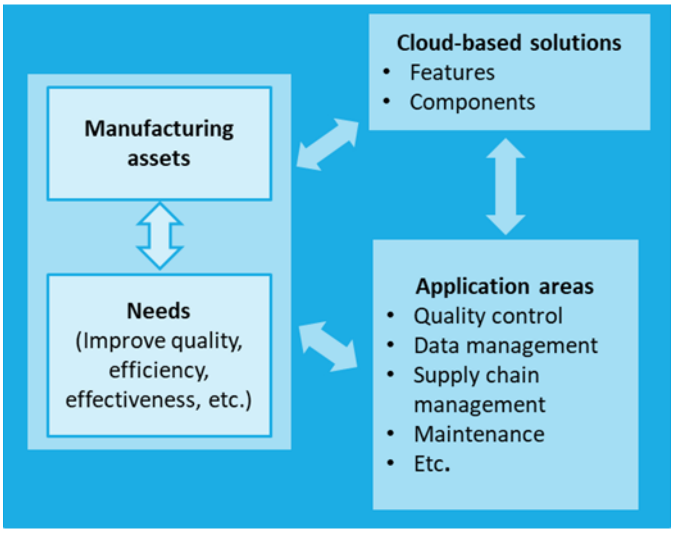


Figure. 3.1 The Conceptual model for cloud adoption in manufacturing

- Challenges/needs are what kinds of problems the company faces right now or what requirements and objectives they aim to fulfill/achieve.

- Application areas are the specific domains in which the firm intends to apply cloud-based solutions to address their challenges/needs.
- Manufacturing assets include a manufacturer's physical and digital resources, such as machinery, equipment, instruments, technologies, software, data, etc.
- Cloud-based solutions refer to the most suitable cloud services or combinations of services determined in relation to the manufacturing assets, needs, and application areas.

3.2 Selecting industry benchmarks

The range and complexity of cloud solutions in the manufacturing sector are tremendous. Various application areas can benefit from adopting cloud-based solutions, each with its unique context, needs, and challenges. An investigation of all potential application areas and corresponding case studies would be a significant task beyond the scope of a single study. The selection of three application areas is a practical and reasonable approach for this study. Therefore, I decided to focus on quality control, supply chain management, and maintenance, presented in Section 2.3, and have them analyzed in more depth, understand each specific context, and extract meaningful insights. The following describes various novel technologies that potentially solve the challenges mentioned above.

Defective products pose a significant challenge in terms of quality control. To address this issue, visual inspection has emerged as one of the most common and effective methods for detecting defects or anomalies. Throughout the digital transformation, conventional visual inspection with human naked eyes has evolved into automated visual inspection utilizing emerging technologies. Many manufacturers are turning to ML and CV for defect detection to reduce costs and increase product quality, productivity, and safety. Compared to manual inspection, the smart solution can raise anomaly detection rate by up to 90% and productivity by 50% potentially becoming a $130 billion market by 2025 [37].

In supply chain management, due to the diverse data sources, interoperability issues and the associated costs, it is crucial to carefully select and align data with the desired outcomes of each organization to guarantee profitable utilization. In response, manufacturers are developing a unified platform that is capable of integrating diverse data from production through logistics to consumption across the supply chain, allowing improved cooperation and efficiency across businesses.

The application of predictive maintenance plays a pivotal role in mitigating unexpected downtime due to machine breakdown. This approach plays a crucial role in reducing costs and boosting productivity by utilizing advanced technologies to predict and prevent equipment failure. IoT sensors can be used to monitor machinery and equipment in real time, accumulating vast information about their performance and condition. In addition, AI, ML, and advanced data analytics can process these data to identify breakdown patterns and symptoms. With this approach, any potential failure can be addressed and prevented prior to causing damage.

The following industrial benchmarks with similar problems outlined above demonstrate how cloud computing empowers other digital technologies to tackle and transform operations within the manufacturing setting.

3.2.1 Cloud-based ML and CV for quality control

A large-scale food manufacturing firm has implemented CV to assist workers with time-consuming tasks. But they wanted to further improve productivity, efficiency, and safety at their plants by incorporating it with ML. For example, operators used to painstakingly inspect thousands of product carriers in every shift to identify faulty pins to prevent damage to humans, operations, and products. Therefore, ***Amazon Lookout for Vision*** is employed to automate the quality inspection process in production lines using CV, without the need of prior ML expertise. In addition, now that the camera system is already in place, ***AWS Panorama***, a system of edge devices typically performing data processing close to the data source, and only transmitting necessary data to the cloud for further analysis. Since streaming and processing video feeds in the cloud necessitates significant network bandwidth, the system is a perfect choice to integrate seamlessly and bring CV to those existing on-premises cameras, which can lower latency to/from the cloud and save bandwidth costs.

Figure. 3.2 Video processing and model training process [92]

The general approach for this solution could be broken down into five stages as demonstrated in Figure 3.2. The process starts with a simple object detection model on the ***AWS Panorama*** device where interested objects are detected and cropped from video streams as images. This object detection model could be any CV model of desire, either in-house models, or pre-built models from AWS or from third-party providers [63]. Then those images are imported into ***Amazon Lookout for Vision*** for labeling as normal or faulty. Once images are labeled, they are stored on ***Amazon S3*** as a data set that is later used by ***Amazon Lookout for Vision*** to train its anomaly detection model. After these steps, the model can process data in image format.

Continue onto the video processing phase, as objects constantly move across the video frame, the same object could be detected more than once resulting in wasting processing resources. An inference code is therefore developed to avoid duplicated images from being sent to ***Amazon Lookout for Vision*** for anomaly classification and also track those objects' locations. Finally, the trained model together with inference scripts and other configurations, are packaged into a single cloud-based container which is ready to be deployed to ***AWS Panorama***. Once deployed, the model is copied from AWS Cloud to on-premises ***AWS Panorama***-enabled devices and constantly performs object inspection for anomalies in every video frame. When an anomaly is detected, images of the defect are sent to and stored in ***Amazon S3***, while the associated metadata is collected, structured and visualized by ***AWS IoT SiteWise***. These data are compiled into an automatic alert email, triggered by a Lambda function, to plant employees at the end of each shift, so that immediate corrective actions can be taken during the next shift change. The ***Amazon Lookout for Vision*** model performs its task brilliantly at over 99% accuracy rate [92].

The designed and integrated infrastructure, applications and services utilized at the plant above could be easily replicated for different projects involving visual quality control for manufacturing firms. As these enterprises often own conveyor belts in various operations, this solution can solve the challenge of automatically detecting and tracking anomalies in fast-moving production lines without interrupting the processes. AWS has demonstrated this use case applied to various food processing lines (bakery, confection, eggs, tomatoes, cookies, etc.) and many other manufacturing industries, namely automotive, electronics, steelmaking and pharmaceutical industries [61].

Companies can also utilize this solution in cases of detecting complex objects or foreign materials of different shapes, colors or transparency features (for example, glass or plastic) by fine-tuning hyperparameters for better localization of objects [93]. A highly reputed frozen pizza company in Sweden, have used ***Amazon Lookout for Vision*** system to make sure that their pizzas were adequately topped with cheese and a variety of toppings, depends on the product types. The implemented CV solution has enabled the firms to efficiently identify defects and assure quality for new products while minimizing operational impacts [94].

3.2.2 Cloud computing and big data analytics in supply chain management

A major drink and brewing company operating in more than 50 countries faced siloed information and operation, overlapping research efforts, and challenges in embracing innovation due to their geographically dispersed nature. The company needs a centralized infrastructure for greater collaboration across the organization. With a huge volume of data generated every day from various departments (including production, sales, marketing, logistics, and human resources, etc.), cloud services allow them to collect data into a single platform for analysis (almost) without limits thanks to the petabyte scale (1 petabyte = 1024 terabytes = 2^{50} bytes).

The company turns to Microsoft Azure for building a global analytics platform (shown in Figure 3.3) as a potential solution, thanks to their expertise and the long-term cooperation. Firstly, ***Azure Data Factory*** orchestrates and manages data pipelines from various sources and destinations across their supply chain. For example, from barley crops/fields data of growers, agronomists, to personal information of each customer. After ingestion, data from different departments and regions is stored in ***Azure Data Lake Storage*** and ***Azure Blob Storage*** depending on formats and purposes. Alternatively, data can also be ingested from real-time data sources e.g. Radio Frequency Identifications (RFIDs) in the company's warehouses, by utilizing Azure IoT services such as ***Azure IoT Hub*** and ***Azure Stream Analytics***. Then ***Azure HDInsight*** is utilized to prepare data for analysis involving tasks like reading data from storage, processing data, and writing output to data stores. ***Azure Synapse Analytics*** is an analytical data store geared towards processing data to optimize it for advanced analytics, reporting and visualization services e.g. ***Power BI***, ***Azure Machine Learning***.

The company leverages these technologies to keep track of beer pallets from breweries through the wholesalers and to retailers in order to optimize inventory, minimize out-of-stock events, and more precisely forecast future customer consumption trends. Additionally, the company utilizes analytical findings to make more accurate estimation of the pricing and availability of barley throughout farms across the world, and such insights are shared with farmers so that they may adjust their chemical usage to optimize resources efficiency, productivity, profitability and sustainability. Conclusively, the company has gain visibility throughout their worldwide business by aggregating data into a centralized secured platform with the help of cloud services. This enables the company to make improvements and increase efficiency across their supply chain [95].

An international farmer-owned dairy company that is attempting to use cutting-edge technologies to keep track of every stage of its supply chain, from farm to fridge, also faced challenges regarding their large and heterogeneous data collection from various sources, resulting in an undisciplined infrastructure filled with duplications and inconsistencies.

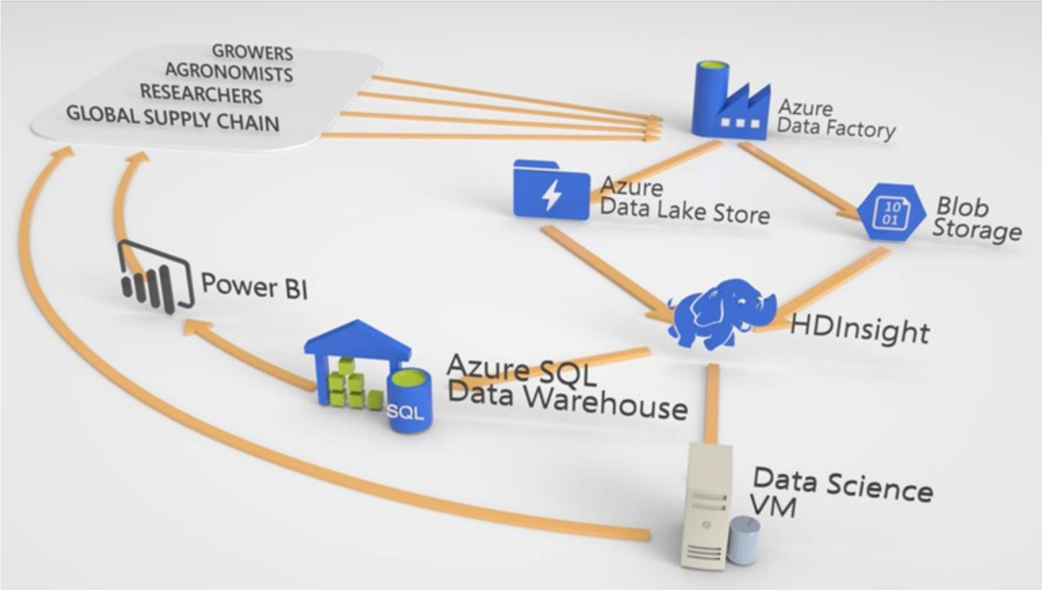


Figure. 3.3 Global analytics platform architecture [95]

The company recognized the necessity of a centralized data foundation to make greater use of their available resources and move their businesses forward in an effective manner.

One challenge is that their data and applications were established in a very siloed approach. Another challenge is that SAP data is enormous but only serves the financial aspect. They need much more external data from dairies and processes, which the current platform could not handle. So, they want to move to Azure Cloud and make both SAP and non-SAP data live and work together on the cloud. The on-premises non-SAP data is ingested into ***Azure Data Factory*** and stored in ***Azure Data Lake Store Gen2*** as raw data. ***Azure Databricks*** is utilized to cleanse and transform the stored data for further processing in data stores, such as ***Azure Synapse Analytics***. Since its introduction, ***Power BI*** has been the go-to front-end tool for reporting and visualization across the organization. The company is integrating real-time data retrieved IoT data from their farms and production facilities using ***Azure IoT Hub***.

The new foundation allows the company to use ML model to forecast the accurate milk production for the coming months based on several external factors rather than only based on experience. It enables the integration of data from diverse sources, including SAP, to deliver a more comprehensive picture of the whole supply chain, which was utterly impossible before. This also allows the firm to better identify the sources of waste generation and optimize their waste management practices, ultimately contributing to a more sustainable manufacturing process [96].

3.2.3 Cloud computing enabling IoT for predictive maintenance

A major industrial machinery manufacturer of stamping presses produces components at all scales for various industries ranging from small electronics to automotive. Alongside selling products to their customers, the manufacturer aims to provide services together with the equipment due to their long lifespans. Therefore, the company has developed a monitoring system by utilizing IoT. However, this technique only helped them respond faster to maintenance concerns that had already happened. Back then, their maintenance measure was primarily preventative, which typically required regular intervals for replacements without taking the actual condition of the machines into account.

Being aware of the time and cost inefficiency of this approach and taking advantage of the existing IoT infrastructure, the company has upgraded the system where data from each machine are collected and securely stored on cloud storage, then processed by various algorithms and ML models with ***Azure Machine*** environment for predictive maintenance. With a user-friendly drag-and-drop interface, ***Azure Machine Learning*** enables the company to develop learning models effortlessly and easily select algorithms and modify criteria, facilitating parameter testing and evaluation. These insights are then visualized with ***Power BI***.

The company can now assess machine performance, identify patterns that may signal possible faults or maintenance needs in real-time, and estimate the remaining useful life. Or in other words, the new predictive maintenance system not only detects maintenance issues in real-time but also predicts when those issues are likely to occur, which optimizes the frequency of inspections/replacements and, as a result, helps customers to reduce maintenance costs [97].

Another case shows how IoT and cloud-based solutions have changed an industrial parts and services provider that delivers their products to various industries such as metalworking, mining, aerospace and energy. The status checking of their machines and process tracking were initially performed manually. The machines were typically shut down for cleaning and setup throughout the day, making status-checking tasks troublesome. Because the person checking them needed to do more than simply observe if the machine was running, they needed to understand exactly what the machine was doing and for how long it had been operating. Those manual practices were restricting manufacturing capability.

Through their modernization strategy, the company realized that their on-premises infrastructure could not handle the large amount of data produced by their modern factories nor provide the analytical resources necessary to extract insights from it. They turned to Azure, which offers instant scalability, high availability, and excellent performance. The plant is now producing at an entirely new level by investing in IoT and cloud services for data analytics, AI, and ML. Collecting data is no more a human task, the factory's machines are linked to Open Platform Communications (OPC) servers, which send the data via ***Azure IoT Edge*** to ***IoT Hub***. Additionally, the manufacturer utilizes ***Azure SQL Database*** for temporary data storage and ***Azure Stream Analytics*** for transferring data while processing it during transit to its intended destination. For long-term storage and analysis, they use ***Azure Data Lake*** to extract data for further analytics and train ML algorithms with ***Azure Machine Learning***. All the visualizations at the plant are powered by ***Power BI***, which draws data from ***Azure SQL Database*** (shown in Figure 3.4).

By implementing modern technologies and solutions, the company can uncover valuable insights that would otherwise remain hidden behind numbers. With the assistance of ***Azure Machine Learning***, correlations in data can be identified, and new business opportunities can be revealed. These advancements also bring the potential to enable predictive analytics and proactive decision-making for machine maintenance, waste reduction, and even more promising prospects toward production efficiency and sustainability [98].

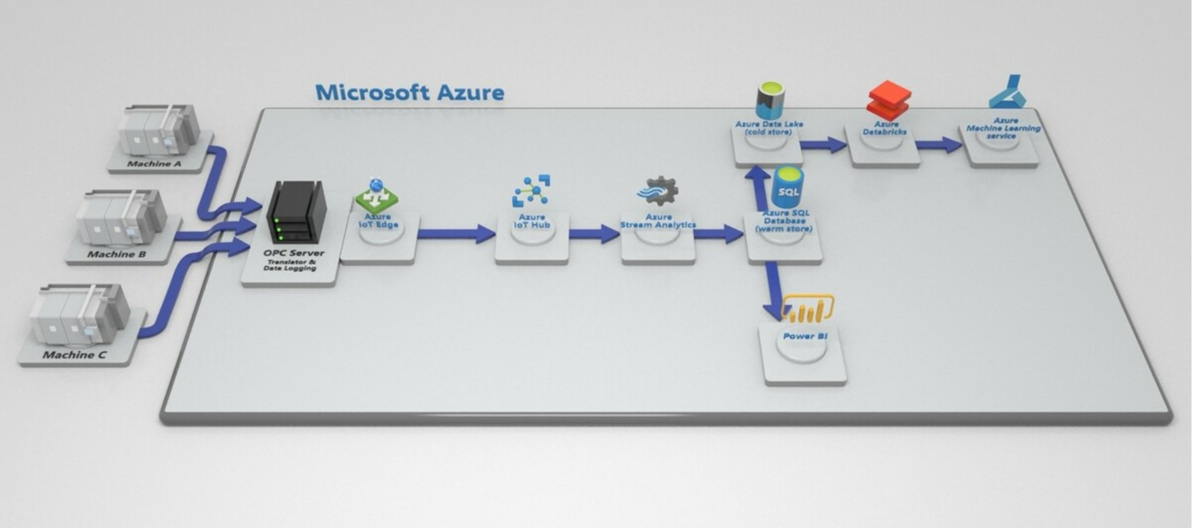


Figure. 3.4 IoT system architecture of the company case [98]

3.3 Analysis of three cases

Through case studies from industrial benchmarks mentioned in Section 3.2, it is suggested that cloud computing is an enabler of digital transformation that has empowered and facilitated businesses to adopt and leverage the power of modern technologies, such as ML, CV, IoT, and others, by providing the necessary infrastructure and services to support these innovations.

Analyzing those cases illustrates nature of the problems, application areas, and existing assets are collectively considered when defining suitable cloud services, which highlights the relevance of the conceptual model developed in Section 3.1.

Given that, the defined services, along with their key features and components would vary from case to case. Those key features and components are needed to be in place in the architecture of a specific cloud-based solution to ensure their efficacy, as showcased in the following sections.

3.3.1 Case #1

In case #1 from Section 3.2.1, the company has combined their existing camera system and CV with ML to automatically detect defects/anomalies via video feeds while freeing the workforce from such demanding and prone-to-error tasks. As fast-moving products/objects of interest go through inspections, the ML model can recognize any defective details that potentially jeopardize the quality standard or cause productivity or safety concerns.

In fact, an ML platform requires a considerable amount of computing power and storage capacity for training and processing data, which are not always accessible by most manufacturers or non-IT businesses across industries. Besides, investing in ML is hugely capital-intensive, not to mention that infrastructure maintenance is substantially costly. Alternatively, companies may leverage ML through cloud services without the processing hardware and heavy upfront investment that has previously been necessary for ML deployment. ML is provided as a cloud service offering users the flexibility to bring in their own models, existing assets, and infrastructures. Those services also remove the heavy lifting of the ML process with low-code and no-code solutions. As a result, the need for high technical expertise is no longer a significant concern in ML deployment, which facilitates them to become increasingly accessible to businesses.

In addition, when handling a vast number of products, one of the primary hurdles in incorporating ML and CV for quality control is the high cost and high latency incurred in transferring and processing video streams in the cloud. The company, in this case, is also constrained by limited bandwidth, which exacerbates this issue. Therefore, running the system at the edge, or in other words, on local devices and sending the output to the cloud for further analysis is preferable. This approach enables visual inspection of product defects at low latency and helps avoid high network bandwidth consumption.

After analyzing the company's case, several critical components corresponding to the conceptual model elements were identified to shape the cloud-based anomaly detection architecture using ML and CV at the edge, as shown in Figure 3.5. These components are:

- Camera system.
- Edge device adds CV models to those installed cameras. This model can be a self-built or a pre-built model provided by AWS or third parties.
- Scalable storage service to which images processed from the video stream and images of anomalies are sent. Those data are later fed into ML for model training.
- ML service on the cloud where the ML model is trained and deployed to the edge device.
- Notification and visualization services.

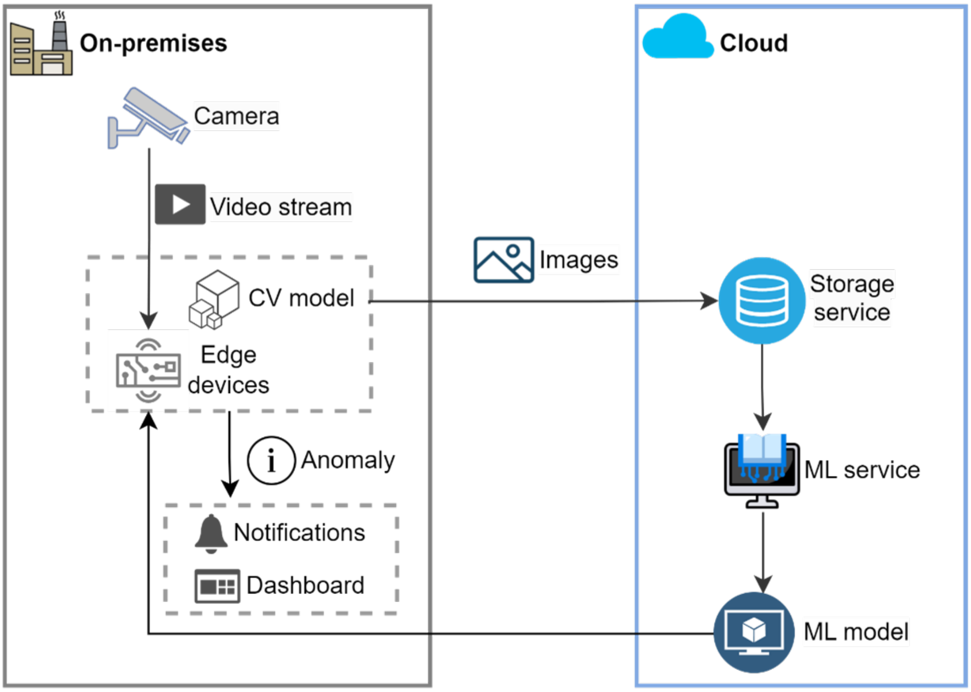


Figure. 3.5 ML and CV at the edge architecture for quality control

3.3.2 Case #2

The two cases in Section 3.2.2 demonstrate how cloud services have enabled big data analytics in supply chain management. Both companies strive to monitor and trace every stage of their supply chain, from “farm to fridge”. However, they have encountered a common problem due to disparate systems and data scattered across their networks, resulting in overlapping and inconsistent data. Both companies are leveraging modern technologies to develop a centralized data platform that gathers massive data from different sources and transforms it into actionable insights.

Dealing with and making use of vast amounts of data, including IT data from systems like ERP, OT data from sensors on manufacturing equipment, and historical data, is a complex undertaking. It requires integration with multiple data sources, scalable and secure data storage, large-scale data processing, advanced analytics capabilities, etc. Previously, companies needed to invest significantly in IT infrastructure and dedicate extensive expertise to implementing, operating, and maintaining it. Cloud services, on the other hand, now offer a straightforward way to satisfy these specific requirements. By adopting cloud services, companies may obtain greater insights into their supply chain operations, enhance performance, boost customer satisfaction, and increase profitability.

To enable an efficient big data analytic process, several components (Figure 3.6) needed to be in place as follows:

- The data source is a prerequisite part of a big data analytic platform which could be application data, static files or real-time data acquired from IoT devices, etc.,
- Data integration service helps to create and manage data pipelines that move and transform data from data sources to desired destinations.
- Real-time data ingestion service to capture and store real-time data, for instance, from IoT devices
- Real-time processing service processes ingested real-time data by filtering, aggregating, or preparing data for further analysis.
- Scalable data storage service receives and securely stores ingested data.
- Big data processing services include batch processing of big data and optimized data databases for handling both real-time and batch processing workloads.
- Data analytics and reporting service analyzes data for the derivation of meaningful insights to empower users to make better-informed decisions. It is usually used in coupled with modeling and visualization services such as self-service Business Intelligence (BI), analytical notebooks, etc.

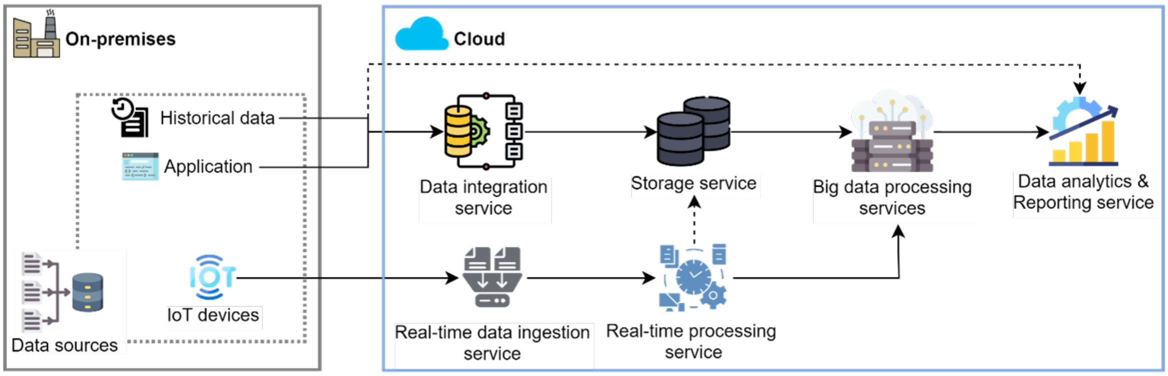


Figure. 3.6 Big data analytics architecture for supply chain management

The data flow and cloud services utilized in different use cases can vary depending on multiple factors, including the intention of the case, the existing infrastructure, types of data, and more. For example, the beverage and brewing company chose ***Azure HDInsight*** over ***Azure Databricks*** as the big data processing service, although the latter used by the dairy company is known for its user-friendliness. This decision was based on the company's existing infrastructure, including the big data framework Hadoop, which ***Azure HDInsight*** supports. Another difference in the data flow is due to differences in data source characteristics. For instance, in the dairy company case, SAP data is directly sent to ***Power BI***, whereas SAP data of the brewer is ingested, stored, and processed by multiple services prior to being sent to ***Power BI***.

3.3.3 Case #3

Maintenance issues, such as legacy maintenance approach with manual status checking of machines and process tracking or scheduled replacements without considering the actual condition of the machines, are significant concerns for the two companies mentioned in Section 3.2.3. They initially implemented IoT to automate real-time data collection for individual machines to address these problems. Eventually, they shifted towards predictive maintenance by uncovering valuable insights hidden within the data, enabling predictive analytics and proactive decision-making.

Upon considering the current capabilities of IoT systems, it becomes evident that relying exclusively on them presents numerous limitations. One significant limitation is the constrained processing capabilities, which make analyzing complex data or handling large datasets challenging or even impossible to perform on local devices. Another significant constraint is the limited data storage, which can restrict the amount of data that can be stored. It may result in incomplete/fractured historical data, affecting the accuracy of predictions and trend analysis. Integrating IoT with cloud services can overcome many of these limitations due to unlimited, scalable storage and processing power for advanced analytics, data-driven insights with ML capabilities, etc., in the cloud, enabling the company to have a more efficient and effective predictive maintenance strategy.

The solution shown in Figure 3.7, which combines IoT devices with cloud services, requires several components to be in place. These are listed as follows:

- Industrial machinery/equipment and attached IoT devices.
- Communication protocol facilitates connectivity between connected devices and target systems/services.
- Real-time data ingestion service to capture and store data from connected devices.
- Real-time processing services either process ingested data by filtering, aggregating, or preparing data for further analysis.
- Scalable storage services receive and securely store ingested data.
- Analytics services provide tools for users to extract semantics insight from data.
- ML service with a user-friendly drag-and-drop interface enables building models easier.
- Visualization and reporting services.

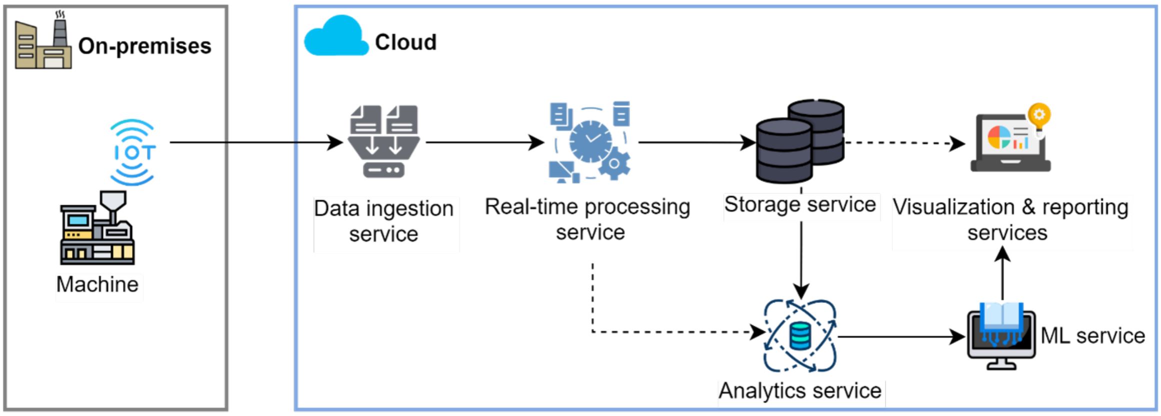


Figure. 3.7 IoT and cloud services architecture for predictive maintenance

This architecture (Figure 3.7) learned from two companies in Section 3.2.3, can be customized by modifying data flow patterns to suit different use cases, companies' requirements, and other factors. For example, processed data from ***Azure Stream Analytics*** (Real-time processing service) can be directly sent to ***Azure Synapse Analytics*** or ***Azure Databricks*** (Analytics service), bypassing ***Azure Data Lake Storage Gen2*** (Storage service). Another scenario involves sending data stored in ***Azure Data Lake Storage Gen2*** directly to ***Power BI*** without going through ***Azure Synapse Analytics*** or ***Azure Databricks*** and ***Azure Machine Learning***. These alternatives demonstrate the flexibility and adaptability of cloud services in meeting diverse needs and use cases. Likewise, when evaluating current assets, OPC Unified Architecture (OPC UA) was used as a communication protocol in the company case, which ***Azure IoT Hub*** (Data ingestion service) does not natively support. To address this, ***Azure IoT Edge*** was utilized to convert OPC UA data into a format that is compatible with ***Azure IoT Hub***. This difference in approach may result in variations compared to other architectures. Organizations can optimize their predictive maintenance solutions and maximize the benefits of IoT and cloud integration by tailoring the data flow and architecture to their specific requirements by considering their existing assets/ infrastructures.

3.3.4 Summary

Analyzing various industrial benchmarks demonstrates the application of cloud-based solutions in different areas and how it enables disruptive technologies to address several manufacturing challenges and meet business needs. These challenges range from labor-intensive, time-consuming, and error-prone manual product inspections to the lack of supply chain visibility due to scattered massive data or the need for a predictive maintenance program to deal with frequent and costly maintenance issues. It illustrates the wide range of possibilities and high potential of adopting cloud-based solutions within businesses. For instance, cloud-based CV and ML, initially used for foreign object detection to control product quality, can also be leveraged to detect defects or anomalies in equipment maintenance.

The most evident demonstration of the conceptual model for cloud adoption, as shown by the case studies, is that the manufacturing assets are pivotal and are significantly influential in shaping the solutions. For instance, the pre-existing camera system, a vast number of fast-moving products, and limited bandwidth facilitate the adoption of CV and ML. Likewise, the diverse data sources with varying types and formats from the company's IT and OT systems influence the selection of cloud services and data flow patterns when developing a centralized data platform. Similarly, a predictive maintenance solution was built and implemented using cloud-based ML to extract meaningful insights from under-utilized data generated by numerous IoT devices across the shop floors. This solution comprises a collection of diverse cloud services that depend on the characteristics of the IoT systems, types of communication protocols used, and so on. Depending on the features of the existing assets, suitable cloud-based solutions are defined or customized to align with them optimally. It enables companies to effectively utilize cloud services while unlocking their full potential.

The adoption of cloud services brings myriad benefits to companies, which are reflected across different application areas.

- In quality control, cloud solutions provide real-time automated detection of deviations in quality with CV at the edge and more in-depth quality-related data analysis with advanced analytics tools such as ML. By leveraging these insights, manufacturers can improve processes, reduce errors, and minimize the waste of raw materials and finished goods, thereby enhancing sustainable manufacturing practices.

- In supply chain management, cloud solutions boost visibility throughout the supply chain by providing a centralized data platform for collecting real-time data and generating actionable insights. It enables manufacturers to make informed decisions to optimize inventory, improve resource utilization, and minimize waste, all of which are crucial in improving sustainability ratings. For example, the adoption of cloud solutions opens up the potential for developing “green tracking” services. These services can be incorporated as a significant element of sustainable supply chain management. They can monitor and track perishable produce throughout the supply chain. They can also estimate the optimal transportation route to minimize fuel consumption and carbon emission of such activity.
- In predictive maintenance, cloud-based solutions with IoT and ML capabilities allow manufacturers to anticipate equipment failures before they occur, avoiding costly downtime, extending the lifespan of equipment, and better planning maintenance activities to reduce unnecessary inspections and spare parts waste. This optimized use of resources significantly contributes to sustainability performance.

In conclusion, adopting cloud solutions in various areas of manufacturing, as demonstrated in industrial benchmarks such as quality control, supply chain management, and predictive maintenance, collectively contributes to sustainability performance. By assisting in minimizing waste, optimizing resource usage, enhancing efficiency, etc., cloud solutions enable manufacturers to enhance their sustainability efforts and improve their competitiveness in the market. These sustainability improvements span environmental, economic, and social aspects. They include reduced environmental impact through waste minimization, improved economic performance through efficiency gains, and enhanced social responsibility through resource conservation.

Chapter 4

Developing a hypothetical cloud-based manufacturing concept for the food manufacturing industry

Given the inherent diversity within the manufacturing sector, the food manufacturing industry has been selected as an exemplary industry for this study, mainly due to its simplicity and my personal experience in this field. Additionally, despite its relatively simple operational processes, the sector embodies many challenges common to the broader manufacturing sector. This chapter aims to illustrate how the conceptual model for cloud service adoption presented in Section 3.1 can be leveraged to address the challenges faced by the food manufacturing industry.

The chapter starts by discussing the current challenges that the industry is facing. Next, a hypothetical company is introduced with specific configurations and is also challenged by the previously mentioned issues. Due to practical constraints associated with gathering real-world data, a hypothetical case study offers an effective alternative. Constructing a hypothetical scenario would remove these constraints and provide more flexibility to explore and demonstrate the cloud adoption process which, in turn, allows for more focused research.

Finally, cloud-based solutions are proposed for that hypothetical food manufacturer by referencing findings from the benchmark analysis in Section 3.3 combined with the conceptual model, providing an optimal approach to address the challenges it is facing.

4.1 Food manufacturing industry

The food manufacturing industry is a significant part of the global economy and plays a key role in supplying the world with safe, nutritious, and affordable food products. In the European Union (EU) economy, the food industry is the leading manufacturing industry in terms of turnover, value creation, and employment [99]. Likewise, in Norway, it is the sector that has employed by far the largest workforce, contributing 19% of the value added and 26% of the total operating profits to the Norwegian industry in 2018 [100].

The sector does not simply contribute to eliminating hunger but also aids the global community in achieving crucial progress on all 17 Sustainable Development Goal (SDG) of the United Nations [101]. For instance, in the context of SDG 2 (Zero Hunger), the food manufacturing industry is responsible for securing a continuous and stable food supply. A sufficient amount of food would provide adequate nutrition to people of all ages to achieve good health and well-being (SDG 3). In addition, manufacturers help address deficiencies of micronutrients by fortifying food products with essential micronutrients, for instance, basic commodities like flour and milk are commonly fortified with vitamin D in higher latitude countries like Norway. These are just a few examples, but they could highlight how the food manufacturing industry is essential to economic growth, food security, public health, and other achievements toward the SDGs.

The food manufacturing industry primarily processes raw materials such as livestock or produce into intermediate or final consumption food products, as defined by [102]. The finished goods produced in these plants are typically sold to wholesalers or retailers across geographical regions for distribution to end customers. As a result, the value chain of the sector includes several key stages, each of which adds value to the final products and is described as follows:

- Agricultural production: raw materials such as crops, livestock, dairy, etc., are produced at this first stage.
- Processing/manufacturing and packaging: raw materials undergo transformation into food products and are subsequently packed for delivery.

- Distribution and retail: a network of wholesalers, retailers, and transportation services are typically involved in distributing packaged goods.
- Consumption: food products are purchased and consumed by end consumers. Feedback from customers is vital since they may drive changes across the value chain from agricultural production output to preferred processing methods.

4.2 Challenges of the food manufacturing companies

Given the integral part of everyday activities and the economy, the food manufacturing industry faces numerous challenges that some resemble those of other manufacturing industries while some distinguish it from others. These issues range from complicated raw materials management to stringent regulatory compliance on food safety, high product quality demand, and sustainable production practices [103]. In addition, recent global crises have highlighted the vulnerabilities of the food manufacturing supply chain, demanding immediate industry adaptation and resilience [104]. This section explores the challenges food manufacturing companies encounter, highlighting the complex interactions of factors that must be navigated to ensure operational efficiency, profitability, and, most importantly, the delivery of secure, high-quality food products.

Despite the myriad of problems within this setting, the study is narrowed down to three particular application areas that resemble the challenges identified within a broader manufacturing context in Section 2.3. This focus allows for a more thorough examination of the unique characteristics of the food sector, providing a more concrete context for further analysis. Three specific challenges inherent to the food sector are consecutively demonstrated in the following paragraphs.

Maintaining the highest levels of product quality and food safety is one of the most fundamental and complex challenges facing food makers nowadays.

- Authorities impose stringent standards for food processing and packaging because of their direct effects on public health [105]. This enforcement requires meticulous quality control to be performed at each stage of production. This consists of screening for defects, ensuring that the final products meet specific specifications, and, most importantly, guaranteeing that they are safe to eat.

- Quality control in food manufacturing often necessitates complicated processes such as detecting microbial contamination, monitoring freshness, and managing allergen cross-contamination. Furthermore, variability in raw materials due to seasonality, weather, pests, and diseases introduces another level of complexity that is unique to the food manufacturing industry [106].
- Given the diverse nature of materials and processes and all the rigorous quality control measures, a lapse in these procedures may pose a safety risk and lead to product recalls. These may cause significant financial and reputational damage to any involved producers [27]. Therefore, robust quality control measures are integral in this industry to ensure the safety, integrity, and consistent quality of food products.

The food manufacturing industry is distinguished from other sectors by its unique and intricate supply chain structure.

- The supply chain's inherent vulnerability can be attributed primarily to the perishable nature of food products and their diverse distributed sources. Appropriate storage, refrigeration, and timely transportation of these products are critical in ensuring that they remain in optimal condition throughout their journey across stakeholders in the supply chain. Even the slightest disruption or delay can result in significant financial loss and substantial waste. This underscores the criticality of efficient and streamlined processes at every part of the supply chain to ensure food safety, quality and quantity [107][108].
- Globalization has added a new layer of complexity to the food supply chain, as it now spans multiple nations, regions, continents and even the entire world. In contrast, the global reach has undoubtedly brought about several advantages, including but not limited to increased product diversity and cost reduction [107][109]. The supply chain is also more vulnerable to interruptions, whether from political instability, trade conflicts, military warfare or a global pandemic like COVID-19 [107][110][111].

- On top of the global problems above, companies nowadays are faced with challenges within themselves, such as managing a flood of data coming from many different sources. They have had a hard time developing a unified strategy due to the wide variety of data sources, different technologies and siloed operating divisions. Furthermore, firms often fail to properly make good use of BI analytics. They may have difficulty getting the correct data, resulting in the under-utilization of these tools to effectively innovate and enhance their business as desired. Overall, these problems may make it difficult for many organizations to manage their supply chain successfully.

Maintenance issues are another common challenge in manufacturing, where operations depend heavily on machines and equipment.

- Unplanned downtime caused by unexpected equipment breakdowns causes operational interruptions, production delays, missed delivery timelines, and sometimes contractual penalties, resulting in reduced efficiency and financial losses. In the context of food manufacturing, these issues become even more pronounced. Because production plants operate under stringent hygiene and sanitation standards, any breakdown could also lead to food spoilage and contamination, compromising food safety standards. In addition, frequent deep-cleaning procedures are necessary to maintain these sanitation standards, which often results in more equipment downtime. Additional downtime in the food manufacturing company might also be caused by product changeover. Significant adjustments to the processing machinery are typically required when the product's recipe, packaging, or production schedule has to be altered to suit new product lines. As a result, overall efficiency may suffer due to these alterations.
- Therefore, it is essential for food manufacturers to effectively manage and minimize the downtime caused by sanitation, product changeover and maintenance. In this high-volume, low-margin industry, food manufacturers must meticulously plan these activities to reach the right balance between hygienic conditions, required product changes and minimal downtime, and appropriate overall productivity and efficiency. Given that many businesses in the food manufacturing industry

emphasize achieving minimum downtime in their operations. Sanitation and product changes are inevitable but may be arranged during non-peak hours to avoid inactivity. But if issues related to maintenance aren't fixed in a timely manner or aren't addressed properly, they might lead to significant unplanned downtime that hampers the manufacturing process more than anything else.

The food manufacturing industry is facing an array of sustainability concerns in the context of the increasing population and the rising food consumption as a result.

- Tasked to satisfy this rising need, however, must not come at the price of the planet's ecological well-being, this industry has been working towards discovering methods to increase output while lowering its environmental impact. This includes managing energy consumption, water usage, waste generation, and greenhouse gas emissions. Sustainable sourcing of raw materials, reducing packaging waste, and transitioning to renewable energy are all significant concerns in its path to sustainability.
- In fact, as mentioned in Section 3.3.4, each challenge of the food manufacturing industry is intertwined with sustainability. Proactively addressing these issues is a crucial step towards more sustainable food production. Resolving supply chain issues, for example, may decrease food spoilage, waste, and carbon footprint via transportation. Optimized maintenance strategies may reduce downtime and result in more efficient use of time and resources. Efficient quality control activities can avoid product recalls and hence prevent food waste. As a result, the route to sustainability is inextricably linked to the industry's operating efficiency, waste management, and quality control procedures, rather than just adopting separate eco-friendly activities. Solving these issues will ensure that the food sector can better supply the current global food demand without jeopardizing future generations' ability to do the same.

However, the food manufacturing industry is distinguished by a comparatively low degree of innovation, which may compromise its future growth and sustainability path [112]. Multiple elements of digitalization, e.g., cloud computing, IoT, AI, ML, big data analytics, digital twins, etc., are applicable across industries, including the food manufacturing industry [35][113]. Because of the complex characteristics that the food industry features, such as seasonal demand fluctuations, increasing regulatory/quality restrictions, complicated production planning, and the vast scale of production and manufacturing, it is distinctively positioned to capitalize on the advantages of digitalization [113].

4.3 Hypothetical food manufacturing company and its configuration

In order to offer an efficient and comprehensive analysis, a hypothetical company of a chicken processing facility was created for this thesis, relying only on data and ideas obtained from real case studies [114][115][116][117][118]. Several practical considerations influenced the decision-making process of creating this company. Firstly, gathering real statistics from actual companies may be an extensive and time-consuming task due to numerous practical constraints, e.g., data confidentiality and sensitivity. This obstacle may be efficiently overcome by creating a hypothetical scenario, allowing for a more focused and efficient study. Second, personal experience in the poultry processing sector offers some details to this case, enhancing the real-world applicability of the conceptual model. Finally, in addition to the simplicity of the operations of a poultry processing plant, it embodies many of the challenges common to the broader manufacturing sector, such as the need for high product quality, optimized operations, efficient supply chain management, etc. Hence, making it an ideal example for demonstrating the utilization of the previously developed conceptual model for cloud adoption.

We will explore a hypothetical poultry processing company operating 6000 birds per hour within a “farm-to-fork” model, which is facing some of the challenges mentioned above.

Broilers (young chickens) are either raised on company-owned farms or purchased from external farms. The company has several farms where sensors and RFID tags are deployed as a part of standard farming practices. Each bird is assigned an RFID tag that contains unique identification information, such as farm name, age, weight, breed, etc. External farms which the company cooperate with are required to deploy the necessary technologies as a business condition. This ensures that all suppliers meet the company's high standards for quality and traceability.

The broilers are transported and received at the processing plant, and the RFID tags are scanned to confirm their identity. The birds are unloaded from the trucks and placed into holding pens where they would wait to be processed. The broilers are about to go through a production line that includes several stages, as demonstrated in Figure 4.1.

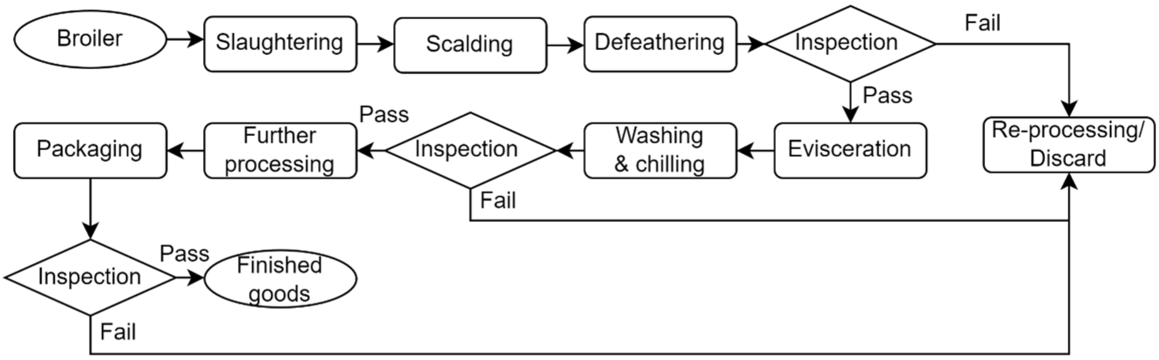


Figure. 4.1 Poultry production line of the hypothetical company

The first step after receiving the broilers is slaughtering, which is done using a mechanical system. The birds are hung upside down by their feet on a conveyor belt, which carries them through a stunning process that renders them unconscious. Once the birds are unconscious, their throats are slit to drain the blood. The birds are then immersed in a scalding tank (hot water) to loosen their feathers and then moved to a feather-plucking machine. After this stage, human inspectors are tasked to check the birds for defects such as skin tears, tumors, missing parts, abnormal color, bruises, broken bones, missed feathers, and other visible defects. Any birds with defects shall be removed from the line and sent for reprocessing or discarded.

The bird's internal organs are then removed during the evisceration procedure. Following evisceration, the birds are washed in cold water, chilled to a safe temperature, and inspected for any remaining defects. The birds are subsequently transported for additional processing, such as weighing, grading, distribution, deboning, or cutting into pieces like breasts, wings, thighs, etc.

The birds are then packed in bags, trays, or cartons and tagged with product information and RFID tracking data. There is an additional quality control station at the end of the processing line where the final products are supposed to be thoroughly inspected by a team of trained inspectors who would perform a final visual inspection of the products to ensure that they meet the required standards for quality, safety, and appearance. If any defects are found, the affected products shall be removed from the line and either reprocessed or discarded.

The chicken packages are then stored in temperature-controlled chambers until they are ready to be transported to retailers or other distribution sites. The transportation providers have to guarantee that the goods are shipped under specified conditions. They adhere to utilizing different IoT devices, such as Global Positioning System (GPS) trackers and temperature sensors, to collect data on temperature and route from transport trucks or containers and transfer it to the manufacturer.

The products are then transported to the retailer's warehouse or store, where they are received and stored under similar controlled conditions. Retailers are responsible for monitoring the temperature of their storage facilities to ensure that the products are kept at the appropriate temperature to maintain quality and safety. Sellers place orders for the products depending on their needs to the manufacturer. The producer may use this data to monitor demand trends, adjust production schedules, and guarantee sufficient resources to satisfy demand.

The company has been facing several problems, as stated below:

The processes in the factory plant are a combination of fully automated, semi-automatic and manual processes. There are three manual inspection stages during the whole process, which are labor-intensive, time-consuming, and error-prone. In addition, human inspectors are also subject to fatigue and may miss defects due to the repetitive nature of the work. Evidently, the company has experienced several recall incidents before due to foreign objects and faulty labeling. These resulted in brand damage, expensive retrieval and disposal of affected products and other financial losses.

The existing IoT infrastructure features sensors that are pre-installed on equipment and machines at the time of purchase. It captures real-time data and recognizes patterns and trends in machine behavior, allowing the organization to respond more quickly to any problems or failures. However, this infrastructure is limited in its ability to predict when equipment failures or maintenance issues are likely to occur. As a result, unplanned downtimes are still happening, and maintenance costs remain high.

The company's data is scattered across various sources, from IoT devices and RFID software used by different farms, through IoT devices of transportation partners, to monitoring and control systems of the plant itself and customers' demand from distributors/sellers. Those data are stored in different formats, on different platforms, and in different locations, creating challenges in integrating them with the existing ERP system for better operational visibility. Without a centralized data foundation, having a holistic view of the entire supply chain or gaining actionable insights from this data is also impossible. It hinders the company from proactively approaching unforeseen circumstances or identifying areas for improvement or optimization.

4.4 Cloud-based solution for the hypothetical food manufacturer

Figure 4.2 illustrates a tri-directional relationship between the developed conceptual model for cloud adoption in manufacturing, the industrial benchmarks, and the application of the model to define suitable cloud-based solutions for the hypothetical food manufacturing company.

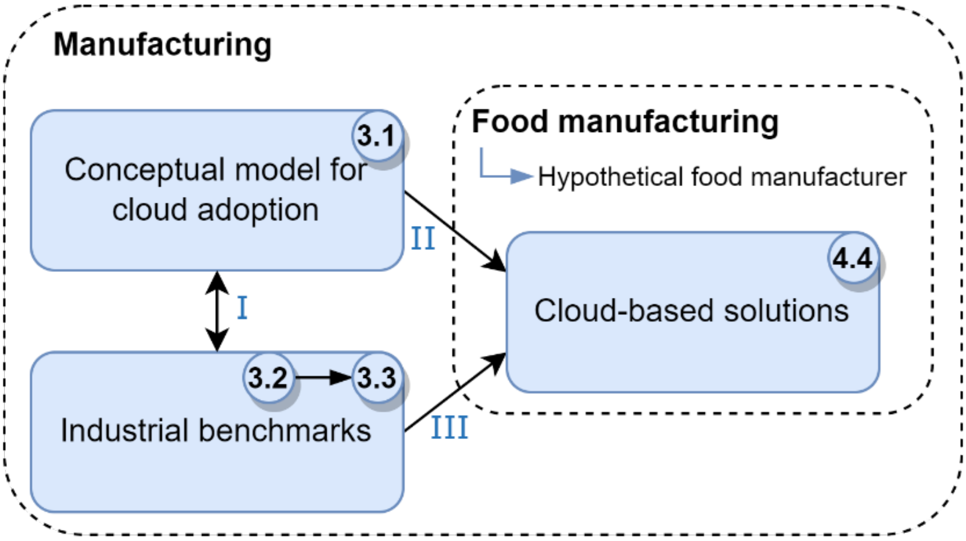


Figure. 4.2 Integrated view of cloud adoption for hypothetical food manufacturer

- The first connection (I) presents the relationship between the developed conceptual model and the industrial benchmarks. Despite being philosophically described in Section 3.1, the conceptual model for cloud adoption in manufacturing is not solely a theoretical framework. It is closely linked with real-world industrial benchmarks (Section 3.2), highlighting the model's relevance and applicability in identifying the most suitable cloud solutions for navigating manufacturing challenges.
- The second relationship (II) emphasizes the role of the developed conceptual model, which serves as a foundational blueprint for finding best-fit cloud solutions in this particular scenario. It demonstrates the conceptual model's flexibility and adaptability to various manufacturing contexts.
- The third connection (III) underscores the impact of the industry benchmarks on shaping the tailored cloud-based solutions for the hypothetical company in the food manufacturing industry. The key features and components of cloud solutions, as determined by analyzing those benchmarks (Section 3.3), serve as crucial reference points in developing customized solutions. This reflects the practical value of the industrial benchmarks and their potential applicability in diverse manufacturing scenarios.

Considering that, by aligning the conceptual model for cloud adoption, key features and components of cloud solutions with the industry's specific challenges, application areas, and pre-existing assets (as depicted in Figure 4.3), the food manufacturer can effectively utilize cloud-based solutions to gain better insight into their operations, thereby facilitating accomplishing higher product quality, enhanced efficiency, reduced downtime and more sustainable growth.

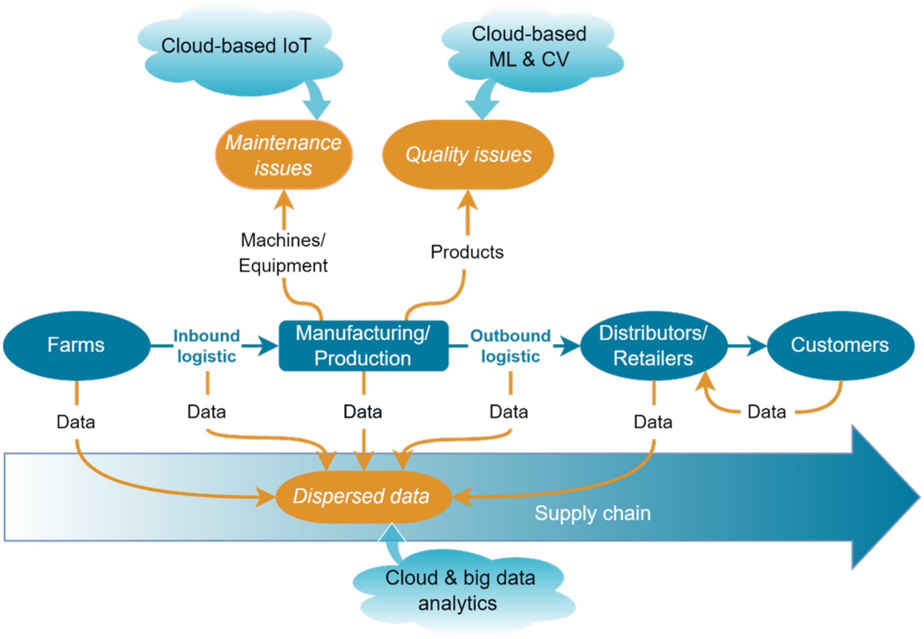


Figure. 4.3 Cloud services adoption for the hypothetical food manufacturer

The previous section identifies challenges within food manufacturing, then a hypothetical food manufacturer possessing tangible and intangible assets is created. These assets include broilers received from farms, machines used in most stages of production, IT systems such as the ERP system, RFID software, and OT systems of machines with built-in IoT devices, etc. In addition, data from farms and customer demand/orders from distributors/retailers are also parts of these assets. By acknowledging and understanding these assets, we can identify the opportunities and limitations when integrating cloud solutions into the existing ecosystem. It is one of the significant elements mentioned in the conceptual model.

Alongside defined configurations, this hypothetical company also illustrates three critical challenges prevalent in food manufacturing. The first is the significant quality concerns related to products causing expensive recalls and reputation damage as foreign objects, defects, and anomalies are discovered in products due to inefficient manual quality inspection procedures. The second problem pertains to production downtime, which results in substantial losses. The existing monitoring systems equipped with IoT only visualize the machines' current statuses. It allows maintenance personnel to respond quickly to issues that have already occurred but fail to predict what is about to happen. The manufacturer's third challenge is massive data dispersal, which hinders them from the visibility of supply chains to make better decisions. By mapping the identified needs and challenges to specific application areas, such as quality control, supply chain and maintenance, we clearly understand the transformative solutions that cloud services could offer.

Following a deep dive into the core factors of the conceptual model and insights drawn from Section 3.3, I underscore the key features and components of cloud solutions that could be customized to meet the needs, challenges, application areas, and assets of the food manufacturer, as illustrated in detail in tables below.

Table 4.1 Key features and components of cloud-based solutions for quality control

Application area	Cloud-based solution	Key features	Components
Quality control (Foreign object detection, anomaly detection)	CV and ML at the Edge	- Low latency and bandwidth efficiency with edge computing - Scalable, reliable and secured data storage - ML capabilities with minimal ML expertise required - Real-time monitoring and alerts	- Cameras (video stream) - Edge device (include CV model) - Storage service - ML service - Visualization and notification services

The cloud-based CV and ML solution at the edge, demonstrated in Table 4.1, would address the challenge of labor-intensive, time-consuming, and error-prone manual inspection processes. This is achieved by automating the process, resulting in faster and more accurate outcomes than manual work.

A core requirement for this solution is the deployment of camera systems on the three inspection stages of the production line, capturing video streams of the processing activities. The data captured by these cameras would be processed in real-time by the edge devices with ML and CV models. A vital feature of this setup is the ability to provide low latency processing, which is critical for real-time detection of anomalies on chicken carcasses like abnormal color, bruises, broken bones, missed feathers, etc., at the first two stations, and spotting of faulty labeling or foreign objects such as pieces of glass, plastic at the end of the production line. With the support of real-time monitoring and alert functions, issues can be identified and rectified immediately, preventing defective products from reaching customers.

The integration of an ML service into the company's infrastructure would enable automatic learning and improvement from experience, as an innate functionality, without being explicitly programmed. Moreover, utilization of ML services in the cloud shifts the ML capabilities to the next level, which can significantly speed up the development, training, and deployment of ML models by taking advantage of not only the cloud's vast computational resources but also the ready-to-use tools and pre-trained models available on cloud ML platforms. Last but not least, a cloud storage service, a fundamental building block of the solution, serves the scalability, security, and reliability requirements to store video streams, processed images, and ML inference results.

Table 4.2 Key features and components of cloud-based solutions for predictive maintenance

Application area	Cloud-based solution	Key features	Components
Predictive maintenance	IoT and ML	- IoT device connectivity - Scalable, secure data storage capacity - Scalable real-time processing and analytics capability - User-friendly ML interface - Visualization and reporting	- IoT devices - Communication protocol - Data ingestion service - Data processing service - Storage services - ML service - Visualization and notification services

Because collected data only holds value when transformed into actionable insights, integrating existing IoT systems with a cloud platform realizes the full potential of this data. This integration leverages cloud resources' immense scalability and power, including real-time processing, analytics capabilities, and ML, as shown in Table 4.2. It considerably amplifies the predictive maintenance strategy's effectiveness through predictive analysis of equipment performance. Consequently, the company can strategically plan maintenance work and avoid unexpected downtimes, which could otherwise lead to significant production losses.

Pre-installed IoT devices on machines no longer work merely as a monitoring system for equipment status. They come equipped with communication modules that utilize standard communication protocols supported by the cloud's data ingestion service. As a result, IoT devices are compatible with cloud services, allowing collected data from IoT devices to be transmitted to the cloud efficiently.

Subsequently, a data processing service can handle this data in real-time, preparing it for ML applications. This processed data then needs to be stored securely in a scalable, cloud-based storage service. With ML, the company can formulate ML models based on historical data from the IoT devices, predicting potential failures rooted in patterns that might be too intricate for a basic monitoring system to detect.

In addition, these cloud platforms also provide a wealth of tools for visualizing and understanding this data. For example, the manufacturer can create comprehensive dashboards displaying the status of all their machines, their maintenance history, and even predictive insights into when they might need service or replacement. This data, accessible and comprehensible for decision-makers, helps gain better visibility over assets and operations, elevating operational efficiency and enhancing the maintenance process's effectiveness.

Table 4.3 Key features and components of cloud-based solutions for supply chain management

Application area	Cloud-based solution	Key features	Components
Supply chain management (Supply chain visibility, data analytics platform)	Big data analytics	- Integration of diverse data sources - Scalable, secure data storage capacity - Large-scale data processing for batch and streaming workloads. - Scalable analytics capability - Advanced analytics and reporting capabilities	- Multiple high-volume data sources (including historical data, data of applications, and real-time data) - IoT devices - Integration service - Storage services - Big data processing (batch & real-time) and analytics services - Visualization and notification services

Table 4.3 illustrates the features and components of a cloud solution where the combination of various cloud-based services fosters a unified platform that significantly reduces data management complexities. It also enables the company to gain a real-time holistic

overview of their supply chain, derive actionable insights, and streamline operations in response to customer demand changes, as well as other trends and patterns.

The data from diverse sources use different formats, protocols and are located in different places (such as IoT devices on farms, RFID tags on birds, sensors on machines, and ordering data from retailers); some could be on-premises, while others could be on the cloud. Using a cloud-based integration service, these dispersed datasets can be simply extracted, cleansed and transformed into a consistent format, regardless of their original forms or location.

Next, scalable and secure data storage capacity, provided by cloud-based storage services, is necessary to store the integrated data. These services essentially prepare data, ensuring the data is in the right place, in the proper format, and ready for advanced processing, analytics, and reporting purposes.

Furthermore, cloud-based analytics platforms come equipped with a suite of scalable processing services and advanced analytics tools. These services proficiently handle large-scale data processing for both real-time and historical workloads without the need to upgrade the existing IT infrastructure. They function as sophisticated data manipulators and preprocessors for advanced analytics, e.g., ML and predictive analytics, while also serving as big data analytics to provide valuable business insights. Lastly, BI services offer reporting capabilities to make sense of this large dataset. By leveraging the insights drawn from advanced analytics and reporting, the company can identify potential areas for improvement or optimization. This process can lead to heightened efficiency and substantial cost reductions.

Chapter 5

Capability mapping of third-party service providers for cloud adoption

In the current market landscape, third-party service providers have emerged as critical players in facilitating successful transitions to the cloud and supporting organizations in unlocking the full potential of digital technologies. They not only lend their technical capabilities to build technologically advanced solutions but also act as strategic partners to organizations on their cloud adoption journey. Accenture, Capgemini, Tata Consultancy Services (TCS), HCL Technologies (HCL Tech), and IBM have all been distinguished as leaders in Everest Group's PEAK Matrix for Cloud Services in Europe [119], as shown in Figure 5.1.

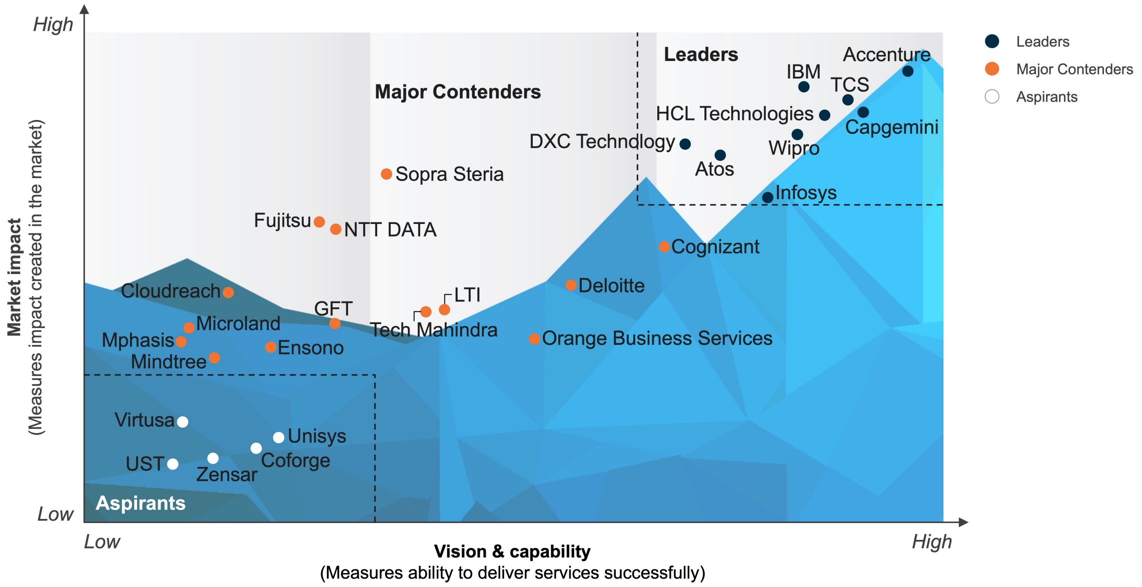


Figure. 5.1 Everest Group Cloud Services PEAK Matrix Assessment 2022 [119]

This section includes a summary of the important technical attributes defined in Section 4.4 and non-technical attributes for successfully adopting cloud solutions. We will investigate the published content of some leading third-party service companies to map their capabilities in both technical and non-technical attributes. In addition, taken as a representative for consulting companies, capabilities mapping of Capgemini is engaged with multiple discussions to determine if they can fulfill the technical and non-technical attributes to effectively facilitate the hypothetical food manufacturer in the process of adopting cloud solutions.

5.1 Key features and components of cloud solutions

Table 5.1 below summarizes the main key features and components of cloud-based solutions that address distinct challenges faced in three different areas of food manufacturing as described in Table 4.1, Table 4.2 and Table 4.3. This table includes key features (F) and associated components (C) that have been recognized as essential for successfully implementing and operating such cloud-based systems.

Table 5.1 Key features and components with notations

Key features	Components
[F1] Low latency & bandwidth efficiency with edge computing	[C1] Cameras [C2] Edge devices
[F2] Scalable, reliable & secured data storage	[C3] Storage services
[F3] Integration of diverse data sources	[C4] High volume data sources (historical data, data of application, real-time data) [C5] Integration services
[F4] Scalable big data processing & analytics capability	[C6] Big data processing (batch & real-time) & analytics services
[F5] ML capabilities with minimal ML expertise required	[C7] ML services
[F6] IoT device connectivity	[C8] IoT devices [C9] Communication protocols
[F7] Real-time monitoring & reporting	[C10] Visualization & notification services

5.2 Capability study of third-party service providers for cloud adoption

Table 5.2 shows how third-party service providers utilize different cloud services and other components to deliver the true potential of the cloud features outlined in Table 5.1. These services belong to different categories as mentioned in Section 2.5.1.1, for instance, compute, storage, database, analytics, ML and IoT services. While these applications are industry-specific, such as maritime, mining, transportation, retail, etc., they could be easily adapted or repurposed for the manufacturing industry, given the versatile nature of cloud technology.

Table 5.2 Technical capability study of third-party service providers for cloud adoption

References	Description	Technical features	Components
[120]	IBM and Promare have developed an AI-powered autonomous ship named the Mayflower Autonomous Ship. This vessel uses IBM's AI and edge computing technologies to navigate itself and make decisions at sea without human intervention. The ship's "AI Captain" uses IBM's CV to detect and classify maritime objects and avoid potential hazards. Local data processing on edge devices allows quicker decision-making speed and reduces bandwidth usage for data flow, especially critical during its transatlantic voyages.	[F1], [F5]	[C1], [C2], [C7]
[121]	IBM and Shell co-created the OREN platform, a centralized digital service and solution hub. OREN utilizes IBM Cloud Pak for Data for data ingestion, integration, and analysis to connect existing operational siloes and integrate fragmented technologies and disparate data. The platform also integrates IBM's in-house cloud-based AI-powered services software suites for industrial asset management, predictive maintenance and emission management, leading to operational efficiency and emission reduction across the supply chain.	[F2], [F3], [F5]	[C3], [C5], [C7]

Table 5.2 – continued from previous page

References	Description	Technical features	Components
[122]	Downer partners with IBM to develop and strengthen TrainDNA, a platform that revolutionizes train maintenance and asset management. The system is powered by IBM Maximo Application Suite, providing advanced analytics and asset monitoring in real-time with predictive maintenance capabilities for more than 200 trains across Australia. AI-driven analytics enable real-time tracking of train statuses and predictive maintenance, optimizing efficiency and service quality. The platform uses IBM MQ to handle all its big data integration. It also leverages IBM Cloud Pak for Data to improve data flow, analysis, and alarm triggers. Furthermore, the use of AI extends to include energy consumption optimizations and carbon footprint reduction of the fleet's operation.	[F2], [F3],[F4], [F5], [F7]	[C3], [C5], [C6], [C7], [C10]
[123]	Airbus and Accenture created a CV-based AI model to identify production faults during aircraft final assembly. The deep learning model also allows recognizing task completion, such as wings attachment, and automatically annotating it directly on video streams, resulting in greater insights and a more effective process. This solution increased the efficiency and accuracy of the aircraft manufacturing process and effectively detected any anomalies during installation.	[F5], [F7]	[C1], [C7], [C10]

Table 5.2 – continued from previous page

References	Description	Technical features	Components
[124]	HCL Tech helped a medical technology firm develop a sensor selection framework powered by Microsoft Azure to identify suitable sensors and communication protocols that can be retrofitted onto existing machines to collect relevant data. This data stream is processed in real-time by AI algorithms to predict maintenance needs and detect anomalies of critical machinery on the shop floor. The solution also enables real-time storage and visualization of data, coupled with real-time condition monitoring, alerts, and predictive maintenance. As a result, the client started to recognize enhanced OEE, reduced maintenance and inventory costs, and increased productivity.	[F2], [F5], [F6], [F7]	[C3], [C7], [C8], [C9], [C10]

Table 5.2 – continued from previous page

References	Description	Technical features	Components
[125][126]	TCS and Woolworths collaborated to develop a common data platform consolidating diverse data sources from their sales, finance, and supply chain departments. This platform served as a data lake for the entire business, providing a centralized and trustworthy data source. Utilizing Google's Dataproc, Google Cloud Storage, and BigQuery, the platform enabled the scalable processing, storage, and analysis of both structured and unstructured data in an efficient and cost-effective manner. This robust solution provided real-time insights into sales, marketing, finance, supply chain, and workforce trends using industry-specific analytics. TCS also applied both descriptive and prescriptive analytics by leveraging the market-dominant data and AI capabilities of Google Cloud. In addition to facilitating complex data visualization experiences with top-tier tools, the platform enabled real-time reports, interactive dashboards for in-depth analysis, and integration of pertinent data with existing tools. This comprehensive approach informed decision-making processes and unleashed business value from data to improve supply chain performance, more accurately foresee seasonal sales patterns, and contribute to achieving sustainability objectives.	[F2], [F3], [F4], [F5], [F7]	[C3], [C4], [C5], [C6], [C7], [C10]

The majority of third-party service providers, however, do not possess their own cloud platforms, their specialty lies in assisting clients in fully leveraging the adopted cloud-based solutions. This capability not only elevates their attractiveness to potential customers but also bolsters their competitiveness. Achieving this involves providing their clients with outstanding non-technical features complementing the above mentioned technical ones. These non-technical attributes may include, but are not limited to, the followings:

- ***Consultation and Advisory Services***: These providers have a deep understanding of the major cloud platforms and can offer expert advice to clients about which services to use and how to use them effectively. They can help clients navigate the complexities of these platforms and make the most of their capabilities.
- ***Training and Upskilling***: Extensive training programs for the client side can be essential to maximizing the benefits of the cloud solution. This may involve user training, technical training, and continuous instruction about new features and updates.
- ***Customer Support***: This should include prompt responses to inquiries or problems, 24/7 support for critical issues, and multiple communication channels (e.g., phone, email, and chat). This is the ongoing support provided after a solution has been implemented. It typically includes troubleshooting and resolving any issues that arise, providing updates and maintenance, and offering additional training as needed.
- ***Strategic Partnerships and Collaborations***: Third-party service providers may actively seek strategic collaborations and partnerships with technology providers, industry leaders, startups, and academic institutions. As a result, they could gain access to a greater range of expertise, novel solutions, and emerging technologies by developing solid relationships. This network may also enable them to stay ahead of market trends while bringing cutting-edge solutions to their clients.

Recognizing the immense value non-technical features can bring to their competitiveness, leading third-party service providers in the IT sector, such as Accenture, TCS, and HCL Tech, also develop and provide these attributes as a standard. As described in the following paragraphs, those features are not just good-to-have but have become the norm among leading firms.

- Accenture is a leading global professional services company acknowledged for its broad capabilities. It offers customers strategic business consulting and advisory services to help them acquire a competitive edge in the marketplace [127]. Accenture also provides continuous support services and training courses to improve their customers' IT skills and capabilities, allowing them to function at greater proficiency and provide more value to the company [128]. Furthermore, Accenture's extensive network of over 350 partners and suppliers adds value to its products. Accenture has the possibility to tap into a huge pool of talent and technology as a result of these agreements, ensuring the most relevant and effective solutions for their customers [129].
- TCS provides consulting services as part of its core offerings, including cloud consulting and cognitive business operations. TCS also delivers managed services across various domains, such as cloud services, cybersecurity, and mobility, handling everything from implementation to maintenance [130]. TCS has formed strategic alliances with cloud hyperscalers, enterprise software leaders, and various tech specialists to build an extensive and professional network of premier technology businesses to assist clients in their transformation and growth [131]. On the customer support front, TCS operates a global IT Service Desk providing support in 35 languages to their clients worldwide [132]. TCS Corporate Digital Academy includes a combination of virtual classrooms, self-paced learning modules, hands-on projects, etc. The platform aims to upskill and reskill not only employees but also corporate clients, their partners, and customers to meet the evolving demands of the digital age [133].
- HCL Tech offers collaborative cloud consulting services to their clients. They work closely with clients' business and IT teams, assessing processes, policies, user behaviors, and platforms to design a cloud strategy centered around business goals. Leveraging AI and cloud technology expertise, HCL Tech transforms client data into actionable insights to help mitigate risks and support decision-making [134]. Furthermore, they have a platform called HCLSoftware U that offers self-paced

training courses across their software portfolio [135] and a dedicated customer support portal offering a 24/7/365 service desk that acts as a single point of contact for all software and hardware needs, inquiries, and issues [136]. Moreover, recognized by major cloud platforms and software companies, HCL Tech has established strategic partnerships with industry leaders. These partnerships facilitate the provision of scalable, integrated cloud solutions that deliver exceptional results [137].

5.3 Capability mapping of Capgemini for cloud adoption

Capgemini has been selected as a representative third-party service provider in this study because of the opportunity to collaborate closely with them, which offers a unique insight into their operations and competencies. Capgemini, a leading player in the consulting, technology services, and digital transformation domain, serves as a quintessential third-party service provider that plays a crucial role in facilitating businesses, particularly those in the manufacturing industry, in their transition to cloud computing. Their broad portfolio of offerings and commitment to innovation and digitalization make them an ideal candidate for this study.

Following extensive conversations with various teams at Capgemini, it is clear that they possess extensive technical expertise and the necessary resources to deliver every key feature and required component. The Cloud & Custom Application (C&CA), Insights & Data (I&D), and Engineering (ENG) teams have all been designated as essential contributors to the projects, each bringing their own set of skills and expertise to the table. It is noticeable that cooperation among teams is crucial to guarantee optimal performance and timely delivery of these key features. The overlapping areas of expertise among these teams are a fascinating aspect of this joint effort, setting an environment for synergistic cooperation that enriches the projects' outcomes. At the same time, individual components of the platform are often handled by a group that has the most relevant expertise. The segregation of responsibilities offers a more streamlined operation and guarantees that every component is optimized by specialized knowledge and skills (Figure 5.2).

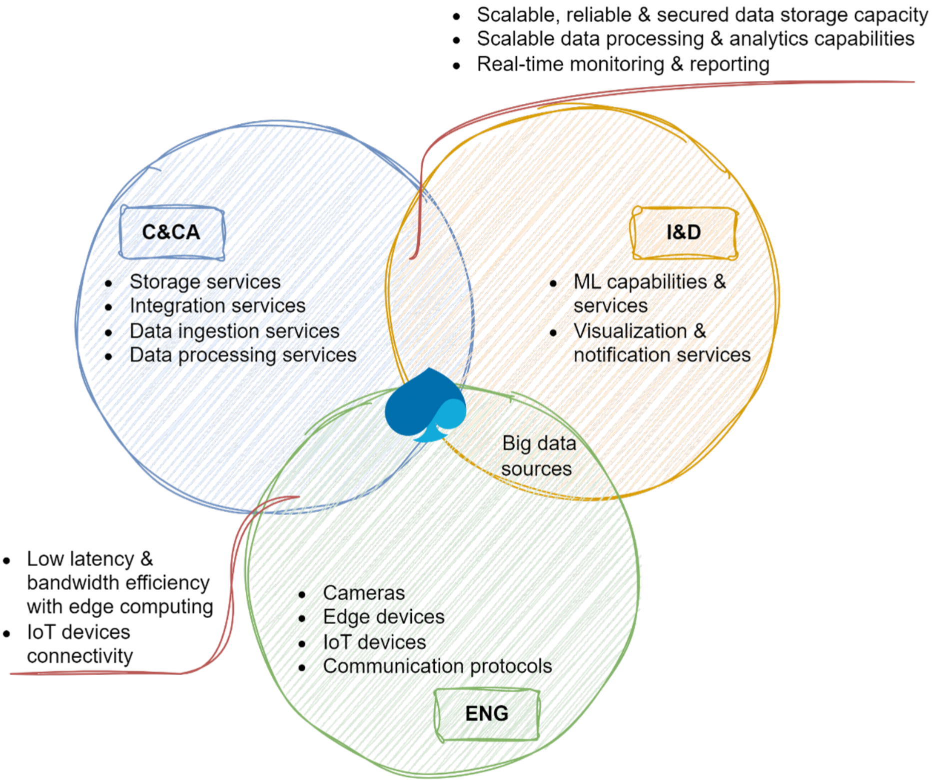


Figure. 5.2 Mapping Capgemini's collaborative dynamics

For the cloud-based solution using CV and ML at the edge to improve quality control via better foreign objects and anomalies detection, the C&CA and ENG teams will collaborate to align the cloud configuration with the hardware capabilities of the edge devices, ensuring low latency with limited bandwidth usage via edge computing. The ENG team will be in charge of contacting approved vendors for acquiring cameras, edge devices and other necessary hardware, while the C&CA team will establish smooth data transfer between the edge and the cloud. In addition, the C&CA team will work closely with the I&D team to offer scalable, reliable, and secure data storage, where they utilize storage services from their cooperated CSPs and configure them with input from the I&D on which data is critical and how to deal with it.

The I&D team is tasked with the utilization of ML services offered by CSPs. This team is professionally qualified to modify pre-trained models, which are made readily available within ML services, and tailor them to suit the particular use case at hand. This process involves training and fine-tuning these models based on the client's unique data set, guaranteeing that the ML functionalities are precisely delivered to their specific needs. It should be noted that this process requires minimal ML experience from the client's side. In cases where clients may lack such expertise, the I&D team is inclined to enhance their skills, enabling self-service and empowering clients to leverage AI tools and ML competencies in their routine activities.

The I&D team can also enable ML models for the predictive maintenance use case. These models aim to predict possible breakdowns in machinery, allowing for more timely and efficient servicing. First, the client's existing data needs to be analyzed and understood, then small Proof-of-Concept (PoC) projects will be launched to verify the potential benefits showcased via the use of ML on small data sets in these projects. This approach will effectively facilitate clients on their journey toward a data-driven business.

To enable predictive maintenance for various machines across the shop floor, the ENG team will address device connectivity by evaluating the compatibility of the existing IoT devices with the cloud platform and recommend/perform modifications or replacements wherever necessary. While newly fabricated equipment may usually come integrated with required components to enable IoT capabilities, older instruments may need retrofitting with additional upgrades or add-ons to become connected devices. The ENG and C&CA teams will collaborate to set up and configure data integration services, guaranteeing seamless communication of these physical devices with the cloud. The C&CA team will also configure data processing services for real-time data processing and analytics with input from the I&D team on data requirements, ensuring the processed data is aligned with the needs of the predictive maintenance ML model. It is essential to mention that these configurations are supported by a scalable and secure storage solution established by the C&CA and I&D teams, as described previously.

The C&CA team will take the leading steps in building a data platform by integrating data from various sources. Apart from securing the indispensable storage capacity, the

C&CA team will perform configurations of integration services and processing services, with the collaboration of the I&D team, which gives insight into data structures for proper integration and data requirements for the following analytics tasks. The I&D team will then act on the integrated data produced by the C&CA team. The collaboration between these two teams facilitates a comprehensive and rich understanding of the data, satisfying the smooth integration from diverse data sources and maximizing the utility and value of both the cloud services and the available data for advanced analytics.

The I&D team will also work alongside the C&CA team to provide real-time monitoring and alerts for more informed and data-driven decision-making. By taking advantage of visualization and notification services provided on the cloud, the C&CA team will be responsible for developing user interfaces and notification functions. Meanwhile, the I&D team will specify which information should be displayed in real-time and when alerts should be sent in response to the ML model's outputs.

Each functional team in Capgemini utilizes various components/cloud services, from several categories ranging from compute, storage, database, analytics services to ML, IoT services, mentioned in Section 2.5.1.1, in order to improve the technical features of cloud solutions. Even though they do not own these cloud services themselves, they combine their expertise, consultation and advisory capabilities with their established partnership and ecosystem for cloud services (from major CSPs such as Microsoft, AWS, Google, etc.) and hardware (cameras, edge devices, IoT devices, etc.) to deliver comprehensive solutions for their clients. In addition to delivering comprehensive solutions, Capgemini also offers other operational supports such as training and upskilling courses for their clients whenever necessary, as mentioned elsewhere previously. Furthermore, Capgemini is responsible for managing the operational aspects of their customers' cloud systems. This is continuous support after the implementation of the solution and includes delivering maintenance, updates, patches, additional coaching, etc. Alternatively, customers can raise tickets to support teams for any issues or inquiries in their day-to-day operations. Capgemini's support teams will respond promptly to these concerns, offering necessary assistance, troubleshooting, and resolution to ensure smooth operations and excellent customer experience.

Chapter 6

Recommendations for competitive performance of Capgemini for cloud adoption

Looking through Capgemini's capabilities and how they operate and deliver services, it is recognizable that there is a shift from a conventional consulting business model, which merely provides consultation services, to a value-adding business model. This model brings various changes, such as: shifting from transactional relationships only offering clients services and expert advice on specific projects to strategic partnerships where they deeply involve client long-term operations, support in post-implementation, assist in shaping strategic directions and drive innovations, etc. All leads to a higher level of client satisfaction and bidirectional longer-term engagements. Furthermore, to facilitate clients in effectively adopting and maximizing the potential of solutions, they now strongly underline knowledge sharing, educating and empowering client organizations to become more self-sufficient in managing their services, which is a significant shift from the conventional business model. Moreover, the new model also changes them from a solution provider to an ecosystem facilitator. Instead of merely delivering specific solutions to client problems, the value-adding business model takes a broader approach, allowing them to establish and foster networks of interconnected companies, technologies, and resources to deliver more comprehensive, holistic solutions. Such an approach facilitates effective client adoption of solutions and redefines the dynamic between consultants, their partners and clients, ultimately enhancing the value generated from the relationship.

This shift towards a value-adding business model inherently necessitates Capgemini to enhance its non-technical capabilities. By focusing on non-technical capability, Capgemini can complement its technical strengths and position itself as a comprehensive consulting partner that understands the unique business challenges of its clients and offers holistic, tailored solutions. It allows Capgemini to provide value beyond technical implementation, driving their clients' business transformation and sustainable growth. The following sections provide a series of recommendations to help Capgemini conquer this paradigm shift while maximizing its benefits.

Continuous Learning

Continuous learning is crucial in the rapidly evolving IT landscape, particularly regarding cloud technologies. Capgemini should invest in upskilling their expertise to stay on top of the latest trends, technologies, and practices in cloud solutions. Deepening their knowledge of industries is crucial to ensure that the innovative solutions provided to their clients can be effectively aligned with the industrial context. They could expand their research into the complexities in industries of interest and create a repository of industry-specific challenges, needs, and goals related to cloud adoption for comprehensive insights. This strategy would aid in identifying opportunities for improvement within those sectors, further enhancing their consultative approach and service delivery.

Reliable Partnership Ecosystem

As showcased in previous sections, it is known that Capgemini's services provided to their clients are tightly coupled with collaborative activities with their industrial partners who provide cloud services and hardware. This approach has some advantages, such as specialization of knowledge and skills, resource scalability and enhanced services offerings. On the flip side, this also poses cooperative risks such as dependency on external forces, coordination and communication challenges, and potential for conflicts of interest.

To mitigate risks and form reliable collaborations, the company first needs to ensure potential partners have the capabilities that match their requirements or expectations. It could be fulfilled by defining and communicating requirements clearly to those partners and assessing their expertise, technologies, resources, and track records, which can be achieved through background checks, reference checks, and past performance evaluations. Additionally, continuous evaluation is crucial to maintain high service quality.

Secondly, they need to strengthen the partnership with these firms to ensure effective and well-functioning collaboration by building trust through consistent and reliable behavior, honesty, and transparency, while maintaining open communication with their partners. On the other hand, it is also necessary for them to cooperate with multiple qualified suppliers. It allows Capgemini to have alternatives in case of disruptions with a particular partner. However, the number of partnerships should be strategically chosen to ensure the ability to manage these relationships effectively.

The last important aspect to consider is the necessity of fostering a strong partnership where both parties share mutual goals and objectives, ultimately benefitting both sides. This encourages the partner to work towards fulfilling the job to the full extent. For example, while working with a client who values the sustainability performance of their operations and products, Capgemini and their partners must have a shared objective of promoting sustainability. This can be considered a factor for Capgemini to choose their desired partners who implement eco-friendly practices and solutions into their day-to-day businesses.

Capgemini's services and collaborative activities with industrial partners present a unique blend of specialization, scalability, and enhanced service offerings. While offering numerous benefits, these collaborations also introduce risks such as dependency, coordination challenges, and potential conflicts of interest. By considering three aspects mentioned above, including capability matching, objective alignment, and partnership health, which are proposed by [26], Capgemini can mitigate these risks and strengthen its partnerships.

Sustainable Business Practices

With the increasing global awareness towards sustainability, it is imperative for companies like Capgemini to conduct a thorough review and revamp their sustainable practices. Despite having little to no in-house production capacity, they still can minimize their carbon emissions, increasing resource efficiency, and advocating for environmentally friendly programs within the organization through such activities like establish energy-efficient and renewable-energy-powered workplaces, expand virtual cooperation to minimize business travel and commuting, prolong the lifetime of computing devices to reduce e-waste, etc. Through this action, Capgemini would not only achieve alignment with global sustainability objectives but also establish a favorable reputation among its partners and clients. Capgemini has the capability to act as a driver in promoting and facilitating the implementation of sustainable practices by their partners. Capgemini may incorporate criteria for sustainability into their partner selection process and provide support and guidance on sustainable practices to both new and existing partners. Implementing this strategy can further strengthen Capgemini's reputation as a responsible and forward-thinking organization while also supporting the establishment of a sustainability-oriented network of partners.

Chapter 7

Discussion

The manufacturing industry is increasingly embracing the digital transformation process as it has the potential to yield considerable benefits in many aspects. Cloud computing forms the backbone of this transition, enabling other emerging technologies like IoT, ML, AI, and predictive analytics, thereby boosting productivity, reducing costs, and driving innovation. However, the cloud adoption process in manufacturing is not a simple task, demanding a comprehensive understanding of all aspects of manufacturers and finding the most appropriate cloud solutions. With their specialized knowledge and experience, third-party service providers can significantly aid in this transition.

The focus of this research was to study the possibilities of cloud adoption in the manufacturing context by proposing a conceptual model for cloud adoption and highlighting the essential role of third-party providers who guide and support manufacturers throughout the intricate journey of cloud adoption. To meet this main aim, the following steps are processed.

A conceptual model was developed, connecting manufacturing assets, business needs, and application areas to aid in identifying the most suitable cloud-based solutions. Industrial benchmark case studies were analyzed in depth, from which key features and components for successful cloud adoption are the main findings. The model was then applied to a hypothetical case in the food manufacturing industry as an example to identify the most notable features and components of the most suitable cloud solutions, demonstrating the practical relevance and effectiveness of the developed conceptual model for cloud adoption.

The role of third-party consulting companies was explored, especially Capgemini, mapping their capabilities to meet both the technical attributes (key features and components) of the previously identified cloud solutions and non-technical attributes. From these insights, recommendations for broadening Capgemini's capabilities and enhancing their competitive edge in the market were proposed.

7.1 Learning points

While working on this thesis, I have both broadened my knowledge and deepened my understanding of plenty of concepts. Those range from the manufacturing industry and its complex value chains to the digital transformation process coupled with numerous emerging digital technologies such as AI/ML, IoT, big data analytics, cloud computing, etc. Additionally, I also looked into the various trends, forces, and challenges shaping the current and future landscape of the manufacturing sector.

In the realm of cloud computing specifically, I delved into the intricate details of various cloud services, their unique features, the complexities involved in their adoption, and how they can be harnessed to enable other cutting-edge technologies to tackle numerous challenges manufacturers face. This not only allowed me to appreciate their unique features and functionalities but also to recognize their interconnections and the synergies they can create in a well-integrated technological ecosystem.

My understanding of the food manufacturing industry has also deepened, specifically in terms of its distinct configurations and processes and how it makes an excellent example of a practical application of the conceptual model for cloud adoption developed in this thesis.

Moreover, I have developed an appreciation for the pivotal role that third-party service providers play in today's business landscape. Through their diverse expertise and offerings, these providers deliver myriad values to their clients, which, in turn, underscores their growing importance in facilitating successful cloud adoption, digital transformations and driving business success in the modern era.

7.2 Main challenges

While writing my thesis, I ran across several practical challenges that ultimately shaped the direction and depth of my investigation. Limited data for analysis, particularly data relevant to the unique context of cloud adoption in the industrial industry, was one of the main challenges. The available information was often either too general or too shallow to properly analyze the dynamics and characteristics of cloud adoption in this industry.

In addition, I encountered technical challenges due to my modest expertise in cloud services and solution architecture. There has been a significant learning curve involved in acquiring the in-depth knowledge necessary for examining different cloud architectures and their applicability to different manufacturing needs, resulting in extensive self-study and research. Additionally, the continuous changes in cloud services made some older case studies outdated, complicating the process of fully interpreting their implications and keeping my research relevant and up-to-date. This complexity highlighted the importance of agility and continuous learning in technology research.

Furthermore, recognizing third-party service providers' capabilities presented its unique challenges. The purpose of the study was to shed light on the crucial role these providers play in promoting cloud adoption. However, precisely defining and mapping their roles, capabilities, and contributions proved challenging. The absence of specific case studies and examples exacerbated this complexity. Despite these difficulties, the study demanded a creative and open-minded problem-solving approach to generate useful and practical findings.

7.3 Further research recommendations

While the presented research provides a conceptual model that can serve as a solid foundation for cloud adoption in various industries beyond manufacturing, it is crucial to acknowledge that each industry has its unique context. Therefore, the model may necessitate customization and fine-tuning to optimally fit a particular sector. Hence, future research could extend into cross-industry studies, assessing the implementation and outcomes of cloud adoption across different sectors, including both manufacturing and non-manufacturing industries. Ideally, these studies would leverage real-life data to ensure the most accurate results.

Furthermore, future research could aim to develop strategies that provide a comprehensive approach for successfully adopting cloud technologies. Such strategies would need to address critical factors not extensively covered by the developed conceptual model in this thesis. These might include cybersecurity measures to mitigate risks associated with cloud adoption, change management considerations due to the significant organizational changes inherent in cloud adoption, and compliance with various policies and regulations.

This thesis primarily applies qualitative methods and discusses several benefits of cloud adoption. Therefore, future studies could delve deeper into a cost-benefit analysis, assisting manufacturers in comprehending the financial implications better. Additionally, future research could focus on a quantitative analysis of the impact of cloud adoption on manufacturing performance metrics, such as efficiency, productivity, cost savings, etc. However, it is vital to note that these analyses would require a relatively large amount of reliable data to be relevant.

Chapter 8

Conclusion

This thesis carries out an exploration of cloud adoption possibilities in the manufacturing industry, highlighting the transformative potential of cloud technologies and offering a roadmap for manufacturers to navigate this intricate journey. It contributes to both academic discourse around cloud adoption in the manufacturing industry and serves as a practical guide for manufacturing companies commencing their cloud adoption journeys. The developed model, designed to identify suitable cloud-based solutions tailored to unique manufacturing assets, business needs, and application areas; combined with insights from real-world cases and the roles of third-party service providers, provides a robust foundation for the successful implementation of cloud solutions in the manufacturing sector.

Through this research, a deeper understanding of digital technologies, especially cloud computing, their potential, and the complexities involved in their implementation has been acquired. Encountering practical challenges in both real-world and hypothetical scenarios yields insights into the realities of digital transformation in the manufacturing sector, specifically for cloud adoption. Despite myriad challenges, the derived insights from this research endorse the significant role and benefits of cloud adoption in manufacturing, thereby outlining a pathway toward a more sustainable, efficient, and digitally-empowered future for the sector.

Due to the dynamic nature of the manufacturing industry, coupled with continuous technological advancements and the relentless development and improvement of third-party service providers, numerous opportunities for future research are presented.

References

[1] United Nations. Manufacturing employment as a share of total employment, 2020. URL https://ourworldindata.org/grapher/manufacturing-share-of-total-employment.

[2] World Bank. Manufacturing, value added (% of GDP) | Data, 2021. URL https://data.worldbank.org/indicator/NV.IND.MANF.ZS.

[3] Deloitte. 2023 Manufacturing Industry Outlook. Technical report, 2022. URL https://www2.deloitte.com/us/en/pages/energy-and-resources/articles/manufacturing-industry-outlook.html.

[4] Matthias Kässer, Wolf Richter, Gundbert Scherf, and Christoph Schrey. How industrial companies can capture cloud technology's full business value | McKinsey. Technical report, February 2021. URL https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/clearing-the-air-on-cloud-how-industrial-companies-can-capture-cloud-technologys-full-business-value.

[5] AWS. Overview of Amazon Web Services - AWS Whitepaper. Technical report, 2021. URL https://d1.awsstatic.com/whitepapers/aws-overview.pdf.

[6] Google. Advantages Of Cloud Computing, 2023. URL https://cloud.google.com/learn/advantages-of-cloud-computing.

[7] Microsoft. What is a Private Cloud - Definition | Microsoft Azure, 2023. URL https://azure.microsoft.com/en-us/resources/cloud-computing-dictionary/what-is-a-private-cloud.

[8] Will Kenton, Gordon Scott, and Amanda Jackson. Manufacturing: Definition, Types, Examples, and Use as Indicator, September 2022. URL https://www.investopedia.com/terms/m/manufacturing.asp.

[9] U.S. Bureau of Labor Statistics. Industries at a Glance: Manufacturing: NAICS 31-33 : U.S. Bureau of Labor Statistics, 2023. URL https://www.bls.gov/iag/tgs/iag31-33.htm#prices.

[10] IDC. Worldwide Digital Transformation Investments Forecast to Reach $1.8 Trillion in 2022, According to New IDC Spending Guide, 2022. URL https://www.idc.com/getdoc.jsp?containerId=prUS49114722.

[11] Ewelina Gregolinska, Rehana Khanam, Frédéric Lefort, and Prashanth Parthasarathy. Capturing the true value of Industry 4.0. Technical report, April 2022. URL https://www.mckinsey.com/capabilities/operations/our-insights/capturing-the-true-value-of-industry-four-point-zero.

[12] ISO. ISO 55000:2014 - Asset management. Technical Report ISO 55000:2014(E), January 2014.

[13] Joe E. Amadi-Echendu, Roger Willett, Kerry Brown, Tony Hope, Jay Lee, Joseph Mathew, Nalinaksh Vyas, and Bo-Suk Yang. What Is Engineering Asset Management? In Joe E. Amadi-Echendu, Kerry Brown, Roger Willett, and Joseph Mathew, editors, *Definitions, Concepts and Scope of Engineering Asset Management*, Engineering Asset Management Review, pages 3–16. Springer, London, 2010. ISBN 978-1-84996-178-3. doi: 10.1007/978-1-84996-178-3_1. URL https://doi.org/10.1007/978-1-84996-178-3_1.

[14] Nicholas A. J. Hastings. *Physical Asset Management*. Springer London, London, 2010. ISBN 978-1-84882-750-9 978-1-84882-751-6. doi: 10.1007/978-1-84882-751-6. URL http://link.springer.com/10.1007/978-1-84882-751-6.

[15] Joe E. Amadi-Echendu. New Paradigms for Physical Asset Management, 2006.

[16] John Bell Rae and Alan K. Binder. Automotive industry - The modern industry | Britannica, 2023. URL https://www.britannica.com/technology/automotive-industry/The-modern-industry.

[17] Food Processing Technology. Them Co-operative Dairy Cheese Production Plant - Food Processing Technology. 2023. URL https://www.foodprocessing-technology.com/projects/them/.

[18] ArcelorMittal. Making steel | ArcelorMittal, 2023. URL https://corporate.arcelormittal.com/about/making-steel.

[19] M. Porter. *Competitive Advantage: Creating and Sustaining Superior Performance*. 1985. URL https://www.semanticscholar.org/paper/Competitive-Advantage%3A-Creating-and-Sustaining-Porter/f5d6857c5e18f546fed8ba6a5826619cdf55f6c7.

[20] Susan Lund, James Manyika, San Francisco, Jonathan Woetzel, Jacques Bughin, Mekala Krishnan, Jeongmin Seong, and Mac Muir. Globalization in transition: The future of trade and value chains. Technical report, McKinsey Global Institute, 2019. URL https://www.mckinsey.com/featured-insights/innovation-and-growth/globalization-in-transition-the-future-of-trade-and-value-chains.

[21] Francesco Ricciotti. From value chain to value network: a systematic literature review. *Management Review Quarterly*, 70(2):191–212, May 2020. ISSN 2198-1620, 2198-1639. doi: 10.1007/s11301-019-00164-7. URL http://link.springer.com/10.1007/s11301-019-00164-7.

[22] Øystein D. Fjeldstad and Knut Haanæs. Chapter 6: Value Creation, Business Models and Organization Design in a Digital World1. In *At the Forefront, Looking Ahead*, Books, pages 85–96. Universitetsforlaget, August 2018. ISBN 978-82-15-03140-8. doi: 10.18261/9788215031583-2018-07. URL https://www.idunn.no/doi/10.18261/9788215031583-2018-07.

[23] Teuvo Uusitalo, Padmakshi Rana, Maria Holgado Granados, and Marco Macchi. Sustainable Manufacturing: Challenges, Approaches and a Roadmap. In *Springer Series in Advanced Manufacturing*, Springer Series in Advanced Manufacturing, pages 27–41. Springer, 2017. ISBN 978-3-319-27797-4. doi: 10.1007/978-3-319-27799-8_3. URL http://dx.doi.org/10.1007/978-3-319-27799-8_3.

[24] Katri Valkokari and Padmakshi Rana. Towards Sustainability Governance in Value Networks. In Jayantha P Liyanage and Teuvo Uusitalo, editors, *Value Networks in Manufacturing: Sustainability and Performance Excellence*, Springer Series in Advanced Manufacturing, pages 43–63. Springer International Publishing, Cham, 2017. ISBN 978-3-319-27799-8. doi: 10.1007/978-3-319-27799-8_4. URL https://doi.org/10.1007/978-3-319-27799-8_4.

[25] WIPO. World Intellectual Property Report 2017 - Intangible Capital in Global Value Chains. Technical report, World Intellectual Property Organization, Geneva, 2017. URL https://www.wipo.int/publications/en/details.jsp?id=4225.

[26] Jakob E. Beer and Jayantha P. Liyanage. Integrated Performance Framework for Sustainable Manufacturing Networks. In Jayantha P Liyanage and Teuvo Uusitalo, editors, *Value Networks in Manufacturing*, pages 291–301. Springer International Publishing, Cham, 2017. ISBN 978-3-319-27797-4 978-3-319-27799-8. doi: 10.1007/978-3-319-27799-8_17. URL http://link.springer.com/10.1007/978-3-319-27799-8_17. Series Title: Springer Series in Advanced Manufacturing.

[27] Allianz. Product recall: Managing the impact of the new risk landscape. Technical report, December 2017. URL https://www.agcs.allianz.com/content/dam/onemarketing/agcs/agcs/reports/AGCS-Product-Recall-Report.pdf.

[28] World Manufacturing Foundation. 2022 World Manufacturing Report: Redesigning Supply Chains in the New Era of Manufacturing. Technical report, 2022. URL https://worldmanufacturing.org/wp-content/uploads/17/6-2022_World-Manufacturing-Report_E-Book.pdf.

[29] Emily Johnson. The True Cost of Downtime | Siemens Blog | Siemens, April 2023. URL https://blog.siemens.com/2023/04/the-true-cost-of-downtime/.

[30] Deloitte. Made-to-order: The rise of mass personalisation. Deloitte Consumer Review, 2019. URL https://www2.deloitte.com/content/dam/Deloitte/ch/Documents/consumer-business/ch-en-consumer-business-made-to-order-consumer-review.pdf.

[31] Oxford English Dictionary. digitalization, n.2, 1959. URL https://www.oed.com/view/Entry/242061.

[32] Erik Stolterman and Anna Croon Fors. Information Technology and the Good Life. In Bonnie Kaplan, Duane P. Truex, David Wastell, A. Trevor Wood-Harper, and Janice I. DeGross, editors, *Information Systems Research: Relevant Theory and Informed Practice*, IFIP International Federation for Information Processing, pages 687–692. Springer US, Boston, MA, 2004. ISBN 978-1-4020-8095-1. doi: 10.1007/1-4020-8095-6_45. URL https://doi.org/10.1007/1-4020-8095-6_45.

[33] Siddharth Shukla. Digital Transformation: Turning the Buzzword into a Reality, March 2022. URL https://webengage.com/blog/digital-transformation-turning-the-buzzword-into-a-reality/. Section: Cross-Channel Engagement.

[34] Päivi Parviainen, Maarit Tihinen, Jukka Kääriäinen, and Susanna Teppola. Tackling the digitalization challenge: how to benefit from digitalization in practice. *International Journal of Information Systems and Project Management*, 5:63–77, 2017. ISSN 2182-7788. doi: 10.12821/ijispm050104. URL https://revistas.uminho.pt/index.php/ijispm/article/view/3856.

[35] Digital21. Digitale grep for norsk verdiskaping Samlede anbefalinger. Technical report, 2021. URL https://www.regjeringen.no/contentassets/d018d0b1a7374cdf894b4cf7ff4fea81/digital21_endeligversjon.pdf.

[36] Shahar Markovitch and Paul Willmott. Accelerating the digitization of business processes. May 2014. URL https://www.mckinsey.com/~/media/McKinsey/Business%20Functions/McKinsey%20Digital/Our%20Insights/Accelerating%20the%20digitization%20of%20business%20processes/Accelerating%20the%20digitization%20of%20business%20processes.pdf.

[37] McKinsey. Smartening up with Artificial Intelligence (AI) - What's in it for Germany and its Industrial Sector? Technical report, April 2017. URL https://www.mckinsey.com/~/media/mckinsey/industries/semiconductors/our%20insights/smartening%20up%20with%20artificial%20intelligence/smartening-up-with-artificial-intelligence.ashx.

[38] Stuart Russell, Stuart Jonathan Russell, Peter Norvig, and Ernest Davis. *Artificial Intelligence: A Modern Approach*. Prentice Hall, 2010. ISBN 978-0-13-604259-4.

[39] Carlos López-Gómez, David Leal-Ayala, Michele Palladino, and Eoin O'Sullivan. Emerging trends in global advanced manufacturing: Challenges, opportunities and policy responses. Technical report, United Nations Industrial Development Organization, 2017. URL https://www.ciip.group.cam.ac.uk/reports-and-articles/emerging-trends-global-advanced-manufacturing-chal/download/UNIDO_FINAL_VERSION.pdf.

[40] IBM. What is Computer Vision? | IBM, 2023. URL https://www.ibm.com/topics/computer-vision.

[41] Ranjay Krishna. Computer Vision: Foundations and Applications. 2017. URL http://vision.stanford.edu/teaching/cs131_fall1718/files/cs131-class-notes.pdf.

[42] Eleanor M. Caves, Nicholas C. Brandley, and Sönke Johnsen. Visual Acuity and the Evolution of Signals. *Trends in Ecology & Evolution*, 33(5):358–372, May 2018. ISSN 01695347. doi: 10.1016/j.tree.2018.03.001. URL https://linkinghub.elsevier.com/retrieve/pii/S0169534718300521.

[43] Richard Szeliski. *Computer Vision: Algorithms and Applications*. Springer Nature, January 2022. ISBN 978-3-030-34372-9. Google-Books-ID: QptXEAAAQBAJ.

[44] Grand View Research. Global Computer Vision Market Size & Share Report, 2030, 2021. URL https://www.grandviewresearch.com/industry-analysis/computer-vision-market.

[45] Google Cloud. Visual Inspection AI Google Cloud | Solutions, 2023. URL https://cloud.google.com/solutions/visual-inspection-ai.

[46] Evan Ackerman. Covariant Uses Simple Robot and Gigantic Neural Net to Automate Warehouse Picking - IEEE Spectrum. January 2020. URL https://spectrum.ieee.org/covariant-ai-gigantic-neural-network-to-automate-warehouse-picking.

[47] Joel Janai, Fatma Güney, Aseem Behl, and Andreas Geiger. Computer Vision for Autonomous Vehicles: Problems, Datasets and State of the Art, March 2021. URL http://arxiv.org/abs/1704.05519.

[48] Kevin Ashton. That 'Internet of Things' Thing. *RFID Journal*, June 2009. URL https://www.itrco.jp/libraries/RFIDjournal-That%20Internet%20of%20Things%20Thing.pdf.

[49] IEEE Standards Association. Internet of Things (IoT) Ecosystem Study. Technical report, The Institute of Electrical and Electronics Engineers, 2015. URL https://web.archive.org/web/20180619094739/http://www.sensei-iot.org:80/PDF/IoT_Ecosystem_Study_2015.pdf.

[50] OECD. *The Next Production Revolution: Implications for Governments and Business*. Organisation for Economic Co-operation and Development, Paris, 2017. URL https://www.oecd-ilibrary.org/science-and-technology/the-next-production-revolution_9789264271036-en.

[51] Stan Schneider. THE INDUSTRIAL INTERNET OF THINGS (IIoT): APPLICATIONS AND TAXONOMY. In Hwaiyu Geng, editor, *Internet of Things and Data Analytics Handbook*, pages 41–81. John Wiley & Sons, Inc., Hoboken, NJ, USA, December 2016. ISBN 978-1-119-17360-1 978-1-119-17364-9. doi: 10.1002/9781119173601.ch3. URL https://onlinelibrary.wiley.com/doi/10.1002/9781119173601.ch3.

[52] K. Gordon. What is Big Data? *ITNOW*, 55(3):12–13, September 2013. ISSN 1746-5702, 1746-5710. doi: 10.1093/itnow/bwt037. URL https://academic.oup.com/itnow/article-lookup/doi/10.1093/itnow/bwt037.

[53] NIST Big Data Public Working Group Definitions and Taxonomies Subgroup. NIST Big Data Interoperability Framework: Volume 1, Definitions. Technical Report NIST SP 1500-1, National Institute of Standards and Technology, October 2015. URL https://nvlpubs.nist.gov/nistpubs/SpecialPublications/NIST.SP.1500-1.pdf.

[54] Wenhong Tian and Yong Zhao. 2 - Big Data Technologies and Cloud Computing. In Wenhong Tian and Yong Zhao, editors, *Optimized Cloud Resource Management and Scheduling*, pages 17–49. Morgan Kaufmann, Boston, January 2015. ISBN 978-0-12-801476-9. doi: 10.1016/B978-0-12-801476-9.00002-1. URL https://www.sciencedirect.com/science/article/pii/B9780128014769000021.

[55] Peter Mell and Tim Grance. The NIST Definition of Cloud Computing. Technical Report NIST Special Publication (SP) 800-145, National Institute of Standards and Technology, September 2011. URL https://csrc.nist.gov/publications/detail/sp/800-145/final.

[56] Professor of English Michael Collier and Robin Shahan. *Microsoft Azure Essentials - Fundamentals of Azure*. Pearson Technology Group, January 2015. ISBN 978-0-7356-9722-5. Google-Books-ID: R0EFCAAAQBAJ.

[57] Eric Simmon. Evaluation of cloud computing services based on NIST SP 800-145. Technical Report NIST SP 500-322, National Institute of Standards and Technology, Gaithersburg, MD, February 2018. URL http://nvlpubs.nist.gov/nistpubs/SpecialPublications/NIST.SP.500-322.pdf.

[58] Gartner, Inc. Magic Quadrant for Cloud Infrastructure and Platform Services. Technical Report G00756608, October 2022. URL https://services.google.com/fh/files/misc/gartner_magic_quadrant_cips_2022.pdf.

[59] Microsoft. Shared responsibility in the cloud - Microsoft Azure, June 2022. URL https://learn.microsoft.com/en-us/azure/security/fundamentals/shared-responsibility.

[60] AWS. Automated Quality Inspection – Amazon Lookout for Vision – Amazon Web Services, 2023. URL https://aws.amazon.com/lookout-for-vision/.

[61] Anant Patel. Amazon Lookout for Vision: Spot product defects using computer vision to automate quality inspection, 2021. URL https://pages.awscloud.com/Get-Started-with-Computer-Vision-for-Quality-Inspection-with-Amazon-Lookout-for-Vision_2021_0320-MCL_OD.html.

[62] AWS. Computer Vision Applications at the edge - AWS Panorama - Amazon Web Services, 2023. URL https://aws.amazon.com/panorama/.

[63] Banu Nagasundaram and Jason Copeland. Introducing AWS Panorama – Improve your operations with computer vision at the edge | AWS Machine Learning Blog, December 2020. URL https://aws.amazon.com/blogs/machine-learning/introducing-aws-panorama-improve-your-operations-with-computer-vision-at-the-edge/. Section: Amazon SageMaker.

[64] AWS. Cloud Object Storage – Amazon S3 – Amazon Web Services, 2023. URL https://aws.amazon.com/s3/.

[65] AWS. What is AWS IoT SiteWise? - AWS IoT SiteWise, 2023. URL https://docs.aws.amazon.com/iot-sitewise/latest/userguide/what-is-sitewise.html#why-use-sitewise.

[66] Microsoft. Data Factory - Data Integration Service | Microsoft Azure, 2023. URL https://azure.microsoft.com/en-us/products/data-factory.

[67] Microsoft. What is Azure Data Lake Storage Gen1?, February 2022. URL https://learn.microsoft.com/en-us/azure/data-lake-store/data-lake-store-overview.

[68] Microsoft. Azure Blob Storage | Microsoft Azure, 2023. URL https://azure.microsoft.com/en-us/products/storage/blobs.

[69] Microsoft. Azure Data Lake Storage Gen2 Introduction - Azure Storage, March 2023. URL https://learn.microsoft.com/en-us/azure/storage/blobs/data-lake-storage-introduction.

[70] Microsoft. Azure SQL Database – Managed Cloud Database Service | Microsoft Azure, 2023. URL https://azure.microsoft.com/en-us/products/azure-sql/database.

[71] Microsoft. Azure HDInsight - Hadoop, Spark, and Kafka | Microsoft Azure, 2023. URL https://azure.microsoft.com/en-us/products/hdinsight.

[72] Microsoft. Azure Databricks – Open Data Lakehouse in Azure | Microsoft Azure, 2023. URL https://azure.microsoft.com/en-us/products/databricks.

[73] Microsoft. IoT Hub | Microsoft Azure, 2023. URL https://azure.microsoft.com/en-us/products/iot-hub.

[74] Microsoft. IoT Edge | Cloud Intelligence | Microsoft Azure, 2023. URL https://azure.microsoft.com/en-us/products/iot-edge.

[75] Microsoft. Azure Stream Analytics | Microsoft Azure, 2023. URL https://azure.microsoft.com/en-us/products/stream-analytics.

[76] Microsoft. Azure Synapse Analytics | Microsoft Azure, 2023. URL https://azure.microsoft.com/en-us/products/synapse-analytics.

[77] Microsoft. Azure Machine Learning - ML as a Service | Microsoft Azure, 2023. URL https://azure.microsoft.com/en-us/products/machine-learning.

[78] Microsoft. What is Power BI - Power BI?, February 2023. URL https://learn.microsoft.com/en-us/power-bi/fundamentals/power-bi-overview.

[79] Norwegian Ministry of Local Government and Modernisation. Cloud Computing strategy for Norway. Strategy, June 2016. URL https://www.regjeringen.no/en/dokumenter/cloud-computing-strategy-for-norway/id2484403/. Publisher: regjeringen.no.

[80] Microsoft. What Is Cloud Computing? A Beginner's Guide | Microsoft Azure, 2023. URL https://azure.microsoft.com/en-us/resources/cloud-computing-dictionary/what-is-cloud-computing.

[81] Sean Marston, Zhi Li, Subhajyoti Bandyopadhyay, Juheng Zhang, and Anand Ghalsasi. Cloud computing — The business perspective. *Decision Support Systems*, 51(1):176–189, April 2011. ISSN 0167-9236. doi: 10.1016/j.dss.2010.12.006. URL https://www.sciencedirect.com/science/article/pii/S0167923610002393.

[82] Microsoft. Public Cloud vs Private Cloud vs Hybrid Cloud | Microsoft Azure, 2023. URL https://azure.microsoft.com/en-us/resources/cloud-computing-dictionary/what-are-private-public-hybrid-clouds/.

[83] John Reilly. Climate AI: How artificial intelligence can power your climate action strategy | MIT Global Change, November 2020. URL https://globalchange.mit.edu/news-media/jp-news-outreach/climate-ai-how-artificial-intelligence-can-power-your-climate-action.

[84] Che B. Joung, John Carrell, Prabir Sarkar, and Shaw C. Feng. Categorization of indicators for sustainable manufacturing. *Ecological Indicators*, 24:148–157, January 2013. ISSN 1470-160X. doi: 10.1016/j.ecolind.2012.05.030. URL https://www.sciencedirect.com/science/article/pii/S1470160X12002294.

[85] Capgemini Research Institute. Sustainable Operations: A comprehensive guide for manufacturers. Technical report, 2021. URL https://www.capgemini.com/no-no/wp-content/uploads/2021/06/Capgemini-Research-Institute_Sustainable-Operations_Web.pdf.

[86] Deloitte. Sustainable manufacturing From vision to action. Technical report, 2021. URL https://www.deloitte.com/content/dam/assets-shared/legacy/docs/industry/energy-resources-industrials/2022/gx-eri-sustainable-manufacturing-2021.pdf.

[87] OP US EPA. Sustainable Manufacturing, July 2015. URL https://www.epa.gov/sustainability/sustainable-manufacturing.

[88] Gordon L. Clark, Andreas Feiner, and Michael Viehs. From the Stockholder to the Stakeholder: How Sustainability Can Drive Financial Outperformance, March 2015. URL https://papers.ssrn.com/abstract=2508281.

[89] Betty Moy Huber and Michael Comstock. ESG Reports and Ratings: What They Are, Why They Matter, July 2017. URL https://corpgov.law.harvard.edu/2017/07/27/esg-reports-and-ratings-what-they-are-why-they-matter/.

[90] Edward Segal. Companies Are Falling Short Measuring Environmental Performance Against Goals: Report. *Forbes*, December 2021. URL https://www.forbes.com/sites/edwardsegal/2021/12/02/companies-are-falling-short--measuring-environmental-performance-against-goals-report/. Section: Leadership Strategy.

[91] Thomas Kopp and Steffen Lange. The Climate Effect of Digitalization in Production and Consumption in OECD Countries. January 2019. URL https://www.researchgate.net/publication/337425005.

[92] Audrey Timmerman, Farooq Sabir, James Wu, Elizabeth Samara Rubio, and Shreyas Subramanian. Computer vision-based anomaly detection using Amazon Lookout for Vision and AWS Panorama | AWS Machine Learning Blog, January 2022. URL https://aws.amazon.com/blogs/machine-learning/computer-vision-based-anomaly-detection-using-amazon-lookout-for-vision-and-aws-panorama/. Section: Amazon Lookout for Vision.

[93] Oleg Smirnov, Naresh Rajendra Shah, Marko Nikolic, and Ilya Katsov. Building a Visual Quality Control Solution with Amazon Lookout for Vision and Advanced Video Preprocessing | AWS Partner Network (APN) Blog, January 2023. URL https://aws.amazon.com/blogs/apn/building-a-visual-quality-control-solution-with-amazon-lookout-for-vision-and-advanced-video-preprocessing/. Section: Amazon Lookout for Vision.

[94] AWS. Amazon Lookout for Vision Customers, 2023. URL https://aws.amazon.com/lookout-for-vision/customers/.

[95] Microsoft. Anheuser-Busch InBev brews up game-changing business solutions with Microsoft Azure, September 2018. URL https://customers.microsoft.com/en-us/story/ab-inbev-consumer-goods-azure.

[96] Microsoft. Dairy company centralizes its data in Azure, gains flexibility and productivity, July 2020. URL https://customers.microsoft.com/en-us/story/827449-arla-foods-consumer-goods-power-bi.

[97] Microsoft. Komatsu Industries optimizes machinery up-time and predicts remaining useful life of components using Azure Machine Learning, November 2021. URL https://customers.microsoft.com/en-us/story/1426478534500305145-komatsu-industries-ja-japan.

[98] Microsoft. Kennametal pushes manufacturing into the future with IoT and Microsoft cloud solutions, May 2020. URL http://web.archive.org/web/20230202015958/https://customers.microsoft.com/en-us/story/774902-kennametal-manufacturing-azure-iot-power-bi.

[99] FoodDrinkEurope. Data & Trends of the European Food and Drink Industry 2022. Technical report, 2022. URL https://www.fooddrinkeurope.eu/resource/data-trends-of-the-european-food-and-drink-industry-2022/.

[100] Ivar Pettersen and Signe Kårstad. Mat, matindustri og verdikjeder 2020. Status og utvikling i norsk matindustri og verdikjeder for matvarer. Technical Report 7/67/2021, NIBIO, March 2021. URL https://nibio.brage.unit.no/nibio-xmlui/handle/11250/2735783. Accepted: 2021-03-26T14:29:42Z Publication Title: 86.

[101] United Nations. Food Systems Summit x SDGs, 2021. URL https://www.un.org/en/food-systems-summit/sdgs. Publisher: United Nations.

[102] U.S. Census Bureau. North American Industry Classification System (NAICS), 2022. URL https://www.census.gov/naics/?input=311&year=2022&details=311.

[103] Antonio Sartal, Diego Carou, Rubén Dorado-Vicente, and Lorenzo Mandayo. Facing the challenges of the food industry: Might additive manufacturing be the answer? *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*, 233(8):1902–1906, June 2019. ISSN 0954-4054, 2041-2975. doi: 10.1177/0954405418805611. URL http://journals.sagepub.com/doi/10.1177/0954405418805611.

[104] Daniel Aminetzah, Artem Baroyan, Nicolas Denis, Sarah Dewilde, Nelson Ferreira, Oleksandr Kravchenko, Julien Revellat, and Ivan Verlan. Global food shortage and security: New risks, August 2022. URL https://www.mckinsey.com/industries/agriculture/our-insights/a-reflection-on-global-food-security-challenges-amid-the-war-in-ukraine-and-the-early-impact-of-climate-change.

[105] WHO. Food safety, May 2022. URL https://www.who.int/news-room/fact-sheets/detail/food-safety.

[106] Deskera. Quality Control in Food Manufacturing: What You Need to Know, March 2023. URL https://www.deskera.com/blog/quality-control-in-food-manufacturing-what-you-need-to-know/.

[107] Deskera. Globalization and the Challenges of Managing Supply Chains in Food Manufacturing, March 2023. URL https://www.deskera.com/blog/globalization-and-the-challenges-of-managing-supply-chains-in-food-manufacturing/.

[108] Olumide Olajide Ojo, Satya Shah, and Alec Coutroubis. Impacts of Industry 4.0 in sustainable food manufacturing and supply chain. *International Journal of Integrated Supply Management*, 13(2/3):140, 2020. ISSN 1477-5360, 1741-8097. doi: 10.1504/IJISM.2020.107851. URL http://www.inderscience.com/link.php?id=107851.

[109] L. Manning and R.N. Baines. Globalisation: a study of the poultry-meat supply chain. *British Food Journal*, 106(10/11):819–836, October 2004. ISSN 0007-070X. doi: 10.1108/00070700410561414. URL https://www.emerald.com/insight/content/doi/10.1108/00070700410561414/full/html.

[110] Philip Garnett, Bob Doherty, and Tony Heron. Vulnerability of the United Kingdom's food supply chains exposed by COVID-19. *Nature Food*, 1(6):315–318, June 2020. ISSN 2662-1355. doi: 10.1038/s43016-020-0097-7. URL https://www.nature.com/articles/s43016-020-0097-7.

[111] OECD. Food Supply Chains and COVID-19: Impacts and Policy Lessons, June 2020. URL https://www.oecd.org/coronavirus/policy-responses/food-supply-chains-and-covid-19-impacts-and-policy-lessons-71b57aea/.

[112] Katarzyna Kosior. The advancement of digitalization processes in food industry enterprises in the European Union. *Zagadnienia Ekonomiki Rolnej / Problems of Agricultural Economics*, 371(2):28–46, June 2022. ISSN 0044-1600, 2392-3458. doi: 10.30858/zer/146782. URL http://www.zer.waw.pl/THE-ADVANCEMENT-OF-DIGITALIZATION-PROCESSES-IN-FOOD-INDUSTRY-ENTERPRISES-IN-THE-EUROPEAN,146782,0,2.html.

[113] Chris McNamara and Suzanne Kopcha. Industry Briefing: Digitalization in Food and Beverage. Technical report, August 2021. URL https://foodsafetytech.com/digitalization-in-food-and-beverage/.

[114] Beyond Finance. EXTREMELY GRAPHIC: Modern Poultry Processing Plant, Chicken Processing Machines, January 2019. URL https://www.youtube.com/watch?v=D8EFGwd7GUM.

[115] Marel Poultry. The world of poultry processing. Technical report, 2020. URL https://marel.com/media/enzhxgh4/world-of-poultry-processing-en.pdf.

[116] Noal Farm. How Poultry Farm Make Million Eggs and Meat - Inside Modern Chickens Farm - Poultry Farm Technology, July 2020. URL https://www.youtube.com/watch?v=T0E4VsR31hI.

[117] Tyson Foods, Inc. Tour of Tyson Foods Poultry Processing Facility, May 2020. URL https://www.youtube.com/watch?v=zxD6RBiw-fA.

[118] B. Watkins, Y.C. Lu, and Y.R. Chen. Economic feasibility analysis for an automated on-line poultry inspection technology. *Poultry Science*, 79(2):265–274, February 2000. ISSN 00325791. doi: 10.1093/ps/79.2.265. URL https://linkinghub.elsevier.com/retrieve/pii/S0032579119414685.

[119] Everest Group. Everest Group PEAK Matrix® for Cloud Service Provider 2022 – Europe - Focus on Accenture. Technical report, January 2022. URL https://dxc.com/content/dam/dxc/projects/dxc-com/us/pdfs/about-us/awards-and-recognition/everest/everest2/Everest%20Group%20PEAK%20Matrix%20for%20Cloud%20Service%20Provider%202022%20%20Europe%20-%20Focus%20on%20DXC%20Technology.pdf.

[120] IBM. Sea Trials Begin for Mayflower Autonomous Ship's 'AI Captain', March 2020. URL https://newsroom.ibm.com/2020-03-05-Sea-Trials-Begin-for-Mayflower-Autonomous-Ships-AI-Captain.

[121] IBM. Energy giant Shell eyes net-zero emissions, October 2022. URL https://www.ibm.com/case-studies/shell-plc.

[122] IBM. Predictive maintenance. Predictable trains., November 2022. URL https://www.ibm.com/case-studies/downer.

[123] Accenture. Co-creation for Smarter Manufacturing | Accenture, 2023. URL https://www.accenture.com/us-en/case-studies/technology/airbus.

[124] HCLTech. Predictive Maintenance Program for a medical technology company | HCLTech, November 2018. URL https://www.hcltech.com/success-story/iot-works/predictive-maintenance-program-medical-technology-company.

[125] TCS. Embracing data-driven retail to enhance customer experiences, May 2022. URL https://www.tcs.com/what-we-do/services/cloud/google/case-study/woolworths-data-driven-retail-enhance-customer-experience.

[126] TCS. Data and AI Services on Google Cloud to Fast Track Data Modernization, 2023. URL https://www.tcs.com/what-we-do/services/cloud/google/solution/data-ai-service-google-cloud-database-modernization.

[127] Accenture. Strategy & Consulting Services & Solutions | Accenture, 2023. URL https://www.accenture.com/us-en/about/consulting-index.

[128] Accenture. Telenor Norway to Accelerate Digital Transformation with Support from Accenture | Accenture, February 2023. URL https://newsroom.accenture.com/news/telenor-norway-to-accelerate-digital-transformation-with-support-from-accenture.htm.

[129] Accenture. Ecosystem Partnerships | Accenture, 2023. URL https://www.accenture.com/us-en/services/technology/ecosystem.

[130] TCS. TCS Consulting Services to Achieve Success in the Business 4.0 Era, 2023. URL https://www.tcs.com/what-we-do/services/consulting.

[131] TCS. Alliances & Partnerships, 2023. URL https://www.tcs.com/who-we-are/alliances-partnerships.

[132] TCS. Global Service Desk Solutions for Improving Customer Service | TCS, 2023. URL https://www.tcs.com/what-we-do/services/cognitive-business-operations/solution/global-service-desk.

[133] TCS. End-to-end Corporate Skill Development with TCS' Services, 2023. URL https://www.tcs.com/what-we-do/industries/education/solution/corporate-digital-academy-skill-development.

[134] HCLTech. Cloud | HCLTech, 2023. URL https://www.hcltech.com/cloud.

[135] HCLTech. HCLSoftware U, 2023. URL https://hclsoftwareu.hcltechsw.com/.

[136] HCLTech. HCL Software Customer Support portal - Customer Support, 2023. URL https://support.hcltechsw.com/csm.

[137] HCLTech. Strategic Alliances | HCLTech, 2023. URL https://www.hcltech.com/strategic-alliances.

Appendix A

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