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Big Data in Industry 4.0 and 5.0 for Operational Efficiency and Decision-Making

Dila Ram Bhandari[1], Prakash Shrestha[2]* and Gopal Man Pradhan[3]

[1,2] Nepal Commerce Campus, Tribhuvan University, Nepal

[3]Bhaktapur Multiple Campus, Tribhuvan University, Nepal

ABSTRACT

Today's smart manufacturing is influenced by two distinct paradigms: Industry 4.0 heralds the shift toward process automation and digitization while Human centricity is emphasized in Industry 5.0. The entrance of Industry 4.0 has revolutionized the manufacturing and industrial sectors by integrating AI tools and data-driven approaches. A pivotal element of the transformation is the utilization of Big Data, which significantly enhances operational efficiency and decision-making processes. This paper explores the impact of Big Data on Industry 4.0, focusing on how it drives improvements in operational efficiency and supports informed decision-making. Through analysis of experience and current applications, the study demonstrates how Big Data analytics facilitates predictive maintenance, optimizes production processes, and enables real-time monitoring of systems. The findings highlight that leveraging large datasets allows for more precise forecasting, reduced downtime, and enhanced resource management. Furthermore, the paper addresses the challenges associated with Big Data integration, including data security, privacy concerns, and the need for AI analytical skills. By providing a nuanced understanding of these dynamics, the paper offers valuable insights for industries aiming to harness the full potential of Big Data within the Industry 4.0 framework.

Keywords: Big Data, Digital revolution, Industry 4.0, Industry 5.0.

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1. INTRODUCTION

Massive technological developments are transforming and accelerating modern industry. The goal of Industry 4.0 [1] is to enable such a high level of networking, automation, digitalization, and intelligence that it is unclear what function humans' play in industrial operations. The fourth industrial manufacturing revolution is dubbed "Industry 4.0." Industry 1.0 introduced steam power, Industry 2.0 introduced electricity, Industry 3.0 introduced automation and information technology, and Industry 4.0 aims to accelerate the firm's transition to smart manufacturing [2]. Industry 4.0, a massive digital revolution defined by the use of Big Data and Artificial Intelligence (AI) to support autonomous learning systems, is the convergence of physical and digital worlds. With insights into achieving operational excellence through data analysis and integration across all important functional domains, this evolution has transformed manufacturing and production. Industry 4.0 has transformed the way businesses conceive, manufacture, and market their products. Artificial intelligence (AI), machine learning, cloud connectivity, and the Industrial Internet of Things (IIoT) are rapidly being used to link production processes.

Businesses continue to generate an increasing amount of data each year [3]. This data encompasses data volume (measured in bytes), data generation velocity (measured in speed), and data variety (measured in the number of various forms) [4]. The use of both structured and unstructured data, including photographs and video formats, has increased as a result of so-called "big data" [5], which has been branded a game changer in the way businesses operate across multiple industries [6].

The massive amount of data generated by Industry 4.0 serves as the foundation for the analysis and extraction of critical information. This study employs the SWOT dimensions framework to give both a positive and negative perspective on the topic, demonstrating the impact of big data analytics in industry 4.0 situations. The newest technology innovation in manufacturing, dubbed as "Industry 4.0," seeks to increase efficiency in a flexible and

effective manner. This radical shift is redefining the way manufacturers work, and it is being driven by a number of technological developments such as cloud computing, the Internet, big data analytics, and artificial intelligence. Because big data analytics provides valuable insights for smart factory management, it has been identified as a major component of Industry 4.0. Big Data and Industry 4.0 have the potential to alter industrial processes in a variety of ways, including automation, process optimization, resource use, and much more. It follows that it is critical to achieving sustainable development. However, to stay up with this AI, an individual must be very talented and experienced in diagnosing and fixing any real-time problem. Such issues can be as minor as a minute alteration in the data generated, which can have a long-term impact on their surroundings, including their life. Big Data analytics is a tough topic of research due to the continuously increasing rate of data collection.

The current global geopolitical crisis, as well as related hybrid threats (hybrid wars) such as massive cyberattacks posing a threat to cybersecurity, wars (such as Russia's aggression against Ukraine), and related humanitarian and refugee crises, have a significant impact on global industry and economics, particularly Industry 4.0 and smart manufacturing [7] [8] [9] [10] [11]. Human engagement is envisioned in Industry 4.0 because the world requires a significantly higher level of process resilience, production sustainability, and quality decision making. This is why the Industry 5.0 concept is growing increasingly popular. Unlike Industry 4.0, Industry 5.0 seeks to address emergent resilience issues created by automation while also attempting to restore human control over industrial processes [12] [13].

According to [14], the big data analytics industry would rise at a 29.7% CAGR to $40.6 billion by 2023. The demand for Big Data analytics professionals will increase in parallel with the market's growth. It is critical that Big Data analytics, one of Industry 4.0's tools, be integrated into science and art education. The current rate of change is particularly disruptive, with exponential shifts observed. Educational institutions are unsure how to include Industry 4.0 resources in university teacher preparation programs, as well as the arts, sciences, and social sciences. It also explores how big data is used in various industries such as social media, banking, education, remote sensing, and healthcare.

2. PILLARS OF INDUSTRY 4.0 AND INDUSTRY 5.0

The Fourth Industrial Revolution (Industry 4.0) has transformed the way we produce and consume goods and services. It is distinguished by the use of cutting-edge technology such as big data analytics, artificial intelligence (AI), and the Internet of Things. Production processes are becoming more agile and efficient as a result of the increased automation and connectivity that these technologies provide in the manufacturing industry. Industry 5.0 is a new era that follows Industry 4.0, although its tenets and concepts are vastly different. Customization and innovation are already taking precedence in industrial production in 5.0. Industry 5.0 has huge potential to transform how organizations work today. It's clear how Industry 4.0 and 5.0 differ from each other. The first focuses on automation and technology. The second is concerned with the foundations of technology as well as pushing for social change and human resources. The UN's 2030 Sustainable Development Goals (SDGs) are also closely tied to Industry 5.0. This is how industry activities are carried out with the goal of promoting sustainability and making better use of the planet's resources. Table 1 summarizes the key differences between Industry 4.0 and Industry 5.0.

Table 1: Key differences between Industry 4.0 and Industry 5.0

Features	Industry 4.0	Industry 5.0
Focus	Automation and connectivity	Human machine collaboration
Goals	Efficiency, agility and productivity	Sustainability, resilience and social responsibility
Technologies	IoT, AI, big data analytics	IoT, AI, big data analytics, human centered design, SDGs
Benefits	Reduced costs, improves quality, faster time to market	Increased job satisfaction, improved safety, reduced environmental impact

Source: [15].

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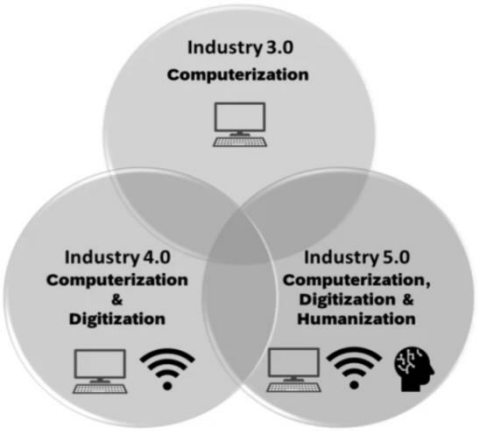

Figure 1. The key differential factors of Industry 3.0 Vs 4.0 Vs 5.0 : Source: [16].

3. BIG DATA FOR APPLICATIONS IN FACTORY 4.0

Big Data serves as the cornerstone for Industry 4.0, enabling dramatic advancements in manufacturing and production environments. The industry's future is continually being determined by its ability to drive efficiency, innovation, and competitiveness; this demonstrates the inextricable link between data analytics and the fourth industrial revolution. By using cutting-edge computing tools to enormous data sets, big data analytics can uncover crucial insights such as correlations, patterns, trends, and preferences. As a result, firms may make better choices.

The concept of an Industry 5.0-level cyber-physical system-of-systems recognizes the growing importance of system resilience and the ability to manage accidents involving safety and security [17]. The ability of a system to run sustainably and safely in the face of disruptions is known as resilience, and it requires certain interactions between low-level automation, autonomous AI components, and humans. [17] presents a framework that promotes resilience in which human operators make the initial judgments, followed by AI-powered autonomous control components, and finally low-level automated controls. Big data is essential to today's networked, intelligent industries. The automation and efficiency gains seen in Industry 4.0 are largely due to big data's ability to process and extract value from huge information networks. Without big data analytics, it would be difficult to construct more effective, independent, and intelligent manufacturing systems. Manufacturers, like other industries, use big data analytics, but their primary goal is to improve production processes and supply chain efficiency through the analysis of data from IoT platforms and smart sensors. This strategy increases output by discovering the hidden variables that cause production bottlenecks while minimizing expenses and waste. The Internet of Things (IoT) has grown into the Internet of Systems, thanks to big data insights, indicating a substantial shift toward more intelligent and interconnected systems.

- **Self-Service Systems**: Intel's smart industrial equipment, for example, uses real-time data analysis to find trends and issues, greatly cutting reaction times and saving a large amount of money.
- **Predictive Maintenance**: This method reduces unplanned downtime by using analytics to prioritize maintenance tasks.
- **Automated Production Management**: This involves using sophisticated robotics and software to manage machinery and analyzing historical and current data to minimize the need for human intervention in manufacturing.
- **Strategic Business Insights**: Market prospects and business directions are informed by big data analysis.

4. DATA IN THE BUSINESS

The well-known saying, "In God we trust, all others bring data," is attributed to [18]. Deming (2000) had a critical role in Japan's economic recovery following WWII. He was associated with the fourth concept: measurement and data analysis. Finally, this helped to improve the organization's overall performance. Even today, this notion applies to all types of business and business-related situations. Apart from experience, many businesses have no idea how well their firm is doing or, more importantly, how they can continue to improve it. One key component, or raw material, is required for Industry 4.0. Unlike items that can be seen with the human eye, such as oil, iron ore, or any other

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component, this basic substance is invisible and intangible. All that is involved is "data," a distinct relationship between connected industries. Businesses may make use of data by using the correct tools, methodologies, and technologies.

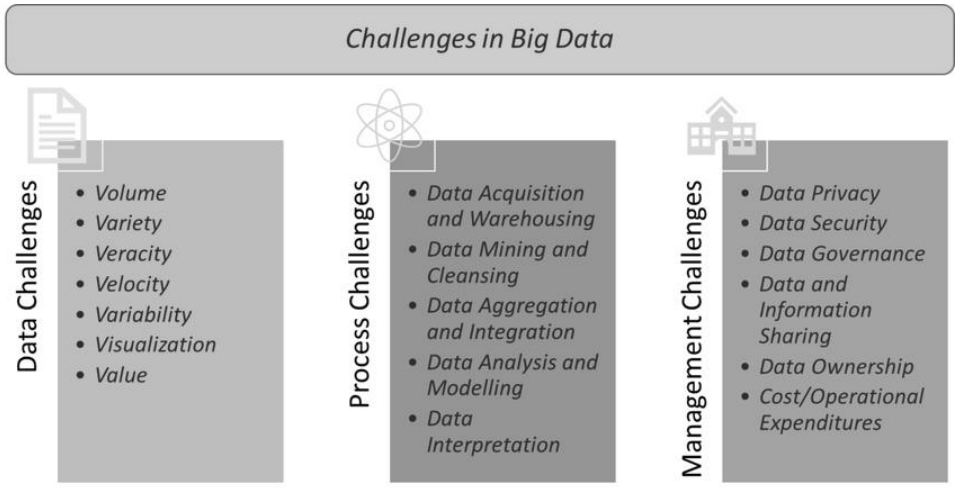

Figure 2. Challenges associated with Big Data: Source: [19].

According to Craig Mundie, a senior counselor to Microsoft's CEO and former US President Barack Obama, "Data are becoming the new raw material for business."An industry pioneer was questioned, "How do you deal with all of the unstructured data that comes from social media, audio, chats, sensors, videos, emails, images, and blog posts?". According to the pioneer, this data contains a plethora of valuable information that can be evaluated to reveal insights that can be used in commercial decision-making. Working with such unstructured material is difficult since it requires a high level of knowledge. People utilize social media to discuss and share their feelings. This means that firms can easily determine how people perceive their brand. It just gives us an idea of what other people are saying about us. Is there anything valuable that we could use to reposition our brand, business, or offering? Heat maps are built from in-store videos to show where customers spend the most time. The merchandise placed in specific regions can then be identified with the location, allowing for more strategic inventory planning. A large technology company uses product photographs to discern between genuine and counterfeit products. The detection of fraud is now possible. These are all examples of big data analytics in action. As a result, unstructured data has numerous applications. However, there are many challenges associated with Big Data (Figure 2)

5. BIG DATA ANALYTICS PROCESS

The most important thing to understand is how "data analytics" is used in different sectors. Each situation starts with a business concern. What are they made of? Industries collect a lot of information. What does the data show? Are there any striking similarities? Making decisions is challenging in industries where the conditions are unpredictable. Are industries capable of predicting and forecasting the future? Get ready! Maximize is the catchphrase. Industries are unable to combine data points, identify segments, water every rose in the garden, or streamline strategies.

Large data collections, easily accessible hardware infrastructure, information management software, and sophisticated analytical skills have all contributed to a watershed point in data analysis history. Because of these interrelated breakthroughs, humans today have the incredible ability to study data sets of unprecedented volume, diversity, and velocity in a more timely and cost-effective manner than in the past. This body of knowledge isn't trivial or theoretical. It is a genuine endeavor to advance and an excellent opportunity to significantly improve effectiveness, output, income, and profitability in any field. This allows the organization to learn more about its operations and form conclusions, preparing it to face the future with confidence!

6. DATA SCIENCE AND ITS APPLICATION IN RETAIL AND RETAIL E-COMMERCE

Retail e-commerce is forecast to expand to $6.54 trillion by 2023, while global retail sales are expected to exceed $30 trillion at a flat growth rate of approximately 4.5%. E-commerce will account for 22 percent of all retail sales by 2023. In this section, we will look at both the retail and e-commerce sectors. Today, in the market, the customer comes first.

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Businesses must always be one step ahead of their customers. Retail data gives retailers the knowledge and insight they require to remain relevant, successful, and competitive. As a result, businesses will gain a greater understanding of their consumers' behavior, habits, needs, wants, and purchasing patterns. As a result, businesses will be able to offer their customers a compelling and innovative buying experience. Analyzing customer data and segmenting it based on purchasing, demographics, and behavior can help retailers decide which things are popular and in demand. This will make it easier to make decisions and organize promotions.

7. FUTURE AND CHALLENGES

Big data, AI, machine learning, cloud infrastructure, and other cutting-edge retail techniques such as e-commerce delivery, food-tech enterprises, mobile phone retail, QSRs, and completely outsourced supply chains are just a few of the rising technologies that are currently in demand. The most important question at this moment is, "Why have traditional companies not been able to keep up with these modern developments?" Managers in these established businesses frequently argue that the claims made by these breakthrough technologies are overblown, and they remain skeptical of them. Data analytics skills are mostly limited to reporting and business intelligence. The few analytics providers who could have addressed this gap, on the other hand, are skeptical that analytics can be utilized in their organization for anything other than tactics, and they lack commercial acumen and awareness of the challenges that modern retailers face.

Combining data from modern digital sources, such as sensors in homes, hotels, and other corporate buildings and equipment, with historical data sources, such as company reports and transaction histories, is a daunting task. Because changes in the underlying data structure may be difficult to update on trained models, new data formats and types necessitate special consideration. Personalized services and data privacy and intrusion are provided based on customer-specific data and transactions, which walk a fine line between intrusive and useful.

According to [20], "the customer" is a collection of distinct groups that are always growing and cover multiple areas. With the rise of smartphones and the internet, competition in the retail industry is no longer limited to the local store but now extends across multiple channels. Even while highly successful organizations were among the first to employ analytics, many copycat stores simply have a basic understanding of its benefits.

Furthermore, as companies deal with their volume growth ambitions with prices and margins while attempting to build their "Omni" presence across channels, seldom realizing the importance of each, the growing conflict on pricing, discounts, and range between traditional retail, e-commerce, and modern retail is increasing pricing and margin pressure on businesses [21]. Although lower prices may benefit the final consumer in this conflict, margin pressure is building across the value chain. This poses the question: "Will analytics be the solution?"

8. DATA SCIENCE FOR BANKING, FINANCIAL SERVICES AND INSURANCE

Prior studies state that about 85% of the massive amounts of financial data collected have been created in the last two years alone. Furthermore, as previously stated, the scale of data is expected to grow rapidly with the continued use of mobile technologies and IoT. The financial services industry simply cannot afford to leave those massive amounts of data unexploited in the face of expanding and evolving customer needs, as well as increased competition from Fintech enterprises [22]. Thus, to get a competitive advantage and optimize client knowledge, banks and insurers should embrace data science. Identifying the shift in customer behavior for individualized service:

- As more people use digital devices, more consumer data may be easily collected, which was not the case in the days before computers and in-person interactions. The gathered information might be used to develop a customized service that was offered during face-to-face interactions.
- Consumers feel at ease utilizing digital channels for stock purchases and bank activities. Before purchasing any stocks or goods, customers use their mobile devices to conduct searches; these digital footprints are also recorded. These days, the financial industry also uses social media to market its goods and insurance premiums to consumers.
- At this point, customers are starting to demand more.
- Correct information that is tailored to their own needs, as opposed to a general suggestion. By integrating multiple data footprints of the specific customer along with like-minded customer data, this could be achieved.

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9. STATISTICAL METHODS IN BUSINESSES

We can use statistical methodologies and analytics techniques [23] to outline the scope of the data, divide the data structure into modules, condense the data representation, explain using tables, graphs, and visuals, assess statistical inclinations and likelihood, and draw relevant conclusions. These analytical tools eliminate the unnecessary complication that the remaining data causes, allowing us to deduce the underlying inference from the data. These strategies and tactics can be used to assess a wide range of data kinds, including text, photos, audio or speech, videos, qualitative, quantitative, and visual data.

The fundamental questions that qualitative data seeks to answer are "why," "what," and "how." Scaling is used in conjunction with quantitative methodologies to address each of these issues. Numerical data consists exclusively of numbers, expressed as decimals or points. Data collection and analysis methods have evolved in recent years. Rich text-based data from social media platforms is converted to numbers before being evaluated. Images used for recognition or classification are converted into color and pixel-based integers, which are then analyzed. A video is essentially a collection of interconnected picture frames that are treated similarly to images. Before being examined, speech and sounds are translated into waves and frequencies, which can then be converted into numbers.

There are numerous techniques for data analysis, depending on the business issue or topic at hand, the type of data, and the volume of data collected [24]. All of these strategies are based on data mining, which involves gathering relevant information, deriving conclusions, and converting those conclusions into decision-making criteria. The next sections will discuss various statistical approaches and analytics strategies used in supply chain, human resources, sales & marketing, and other corporate domains.

10. CONCLUSION

This paper raises an old and timeless “robots vs. humans” issue (particularly “efficiency and ubiquity vs. humanism and responsibility”) in the new “Industry 4.0 vs Industry 5.0” context. Big Data applications play an important part in the advancement of Industry 4.0 and 5.0, improving operational efficiency and decision-making processes. The combination of advanced analytics and data-driven intuitions allows companies to optimize production workflows, predict maintenance requirements, and improve supply chain management. Enterprises that leverage the potential of real-time data can reach unprecedented levels of automation, precision, and responsiveness, eventually generating innovation and competitive advantage.

Furthermore, combining Industry 4.0 and 5.0 with Big Data results in a more flexible and agile manufacturing environment capable of making quick decisions based on detailed data analysis. Big Data has the potential to totally revolutionize business processes as technology improves; consequently, firms must employ these tools to remain competitive in a rapidly changing market. The Industry 4.0 + Industry 5.0 hybrid assumes that collective (hybrid) intelligence will be the driving force behind decision-making, whereas the Industry 4.0 concept anticipates a significant amount of automation in the decision-making process, and the Industry 5.0 concept [25] assumes that people will play the primary role in the decision-making process. Finally, Industry 4.0 and 5.0's successful use of big data increases operational effectiveness while also revolutionizing decision-making, paving the way for more intelligent and resilient industries.

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* Corresponding Author: **mrprakashshrestha@gmail.com**

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