IMPACT OF INDUSTRY 4.0 ON SUPPLY CHAIN MANAGEMENT: AN APPLICATION IN TO DAIRY SECTOR

by

Nijas Pampadiyil Hameedu Rawther

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APPROVED BY

I. Buljubasic

<Chair's Name, Degree>, Chair

RECEIVED/APPROVED BY:

<Associate Dean's Name, Degree>, Associate Dean

Dedication

I dedicate this research to my late mother and my father whose love, wisdom, and support continue to inspire me every day. To my family, thank you for your support and belief in me throughout my career. To all who have helped and motivated me to keep on, your faith has been my anchor.

Lastly, I dedicate this study to all my teachers, other students and researchers who are inspired to explore, learn, and make meaningful contributions to the field.

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ABSTRACT

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Nijas Pampadiyil Hameedu Rawther
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Dissertation Chair: <Chair's Name>
Co-Chair: <If applicable. Co-Chair's Name>

Industry 4.0 is the fourth industrial revolution that integrates advanced technologies into industrial and manufacturing processes to enhance efficiency, improve decision-making, and bring automation to processes. This research has been carried out to conduct a cross-comparison of the application of different Industry 4.0 technologies in the supply chain of the dairy industry in India and the Kingdom of Saudi Arabia (KSA). The research has been qualitative and conducted using interviews of the relevant personnel in the dairy industry of both countries. The sample size of the study consisted of 19 respondents: 10 respondents from India and 9 from the KSA dairy industry. The results of structured interviews have been analyzed using the thematic analysis technique.

The results of the thematic analysis helped generate four main themes and certain sub-themes under each category. In this regard, the main themes of the study included Industry 4.0 technologies used in the supply chain of the dairy sector, benefits of implementing Industry 4.0 technologies in the supply chain of the dairy sector, challenges of implementing Industry 4.0 in the supply chain of the dairy sector, and resilience brought by Industry 4.0 in the dairy sector supply chain. A further investigation has shown that the

main Industry 4.0 technologies used in the dairy industry supply chain consisted of Big Data, Internet of Things (IoT), RFIDs, Artificial Intelligence (AI), Machine Learning, Cloud Computing, Augmented Reality, Cyber Physical Systems, 3D Printing, and Robotics. The results have indicated that the application of these technologies is more prevalent in the Saudi dairy sector while Indian dairy is lagging. However, the main challenges included a lack of resources, inconsistent infrastructure, a shortage of skilled personnel, and others. Those who have implemented these technologies effectively reported smooth information sharing, real-time monitoring, timely response to disruptions, and an integrative environment which all lead to greater resilience. The cross-comparison of the two countries shows KSA leading ahead of India in the application of I4.0 technologies in the dairy industry, however, the application is limited in KSA as well.

The results of the study have added to existing literature on I4.0 in Dairy Industry while it also provides important implications for policymakers to enhance application of I4.0 to avail full potential of these technologies in dairy industry.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I:

INTRODUCTION

1.1 Research Background

With the manufacturing of spears during ancient times, to hunt animals, human beings have always been in a race to manufacture newer and improved tools for their better survival on the planet (Epicor, 2021). The new trends, ever-changing business environment, more demanding customers, and the need for agile and lean supply chains have diverted the attention of businesses to advanced technologies. Companies have started realizing the advancement and innovation in technologies can become a powerful strategic weapon that will help the companies to boost their sustainable performance-business (Shrivastava, et al., 2016). Technologies are used by various companies so that their business processes can be streamlined, and their operations efficiency can be improved by integrating all operational processes. And, now, companies are investing more in bringing innovative technologies that are linked with Industry 4.0 (Fatorachian & Kazemi, 2021).

This effort has resulted in a consistent improvement to the tools being manufactured over the years, however, the needs of people grew at an even faster pace. With these efforts Industry 4.0 was introduced for the refinement of ores for manufacturing of improved tools using wind and water powers. With time, Industry 2.0 was introduced to meet the growing need for technological improvements (Haradhan, 2019). It resulted in the discovery of electricity, and improved ways of communication and transportation, thus, all helped to improve the supply chain which spanned across countries and continents. Furthermore, Industry 2.0 resulted in the launch of production lines that resulted in increased production capabilities which were beyond imagination (StrNiekerk, 2019).

Later, Industry 3.0 was the era of recent technological innovations in which industry currently exists. It has resulted in bringing the internet and robots for industry and

changed the way operations are carried out (Lemstra and de Mesquita, 2023). For this purpose, information is digitally stored and moved while information from all over the world can be obtained in a moment. It has also resulted in making supply chains more complex where several modern technologies are used to move products from manufacturing to end customers (Dan, 2017).

The beginning of the industrial revolution was with the advent of steam power, waterpower, and the automation of production systems in 1784. The second revolution transformed the manufacturing system into a mass manufacturing system and used electricity for advanced assembly in the1870s. Computers were used to automate processes in 1970 which led to the third industrial revolution. Internet of Things (IoT) and Cyber-Physical Systems were used to integrate the system by bringing digitalization among devices. This change led to the evolution of Industry (4.0) also termed the fourth industrial revolution (Abdirad & Krishnan, 2021).

Industry 4.0 is an idea that emphasizes the automation of operations, innovative technologies, digitalization, and the exchange of data in real-time in the business world. The major goals of this concept is to transform traditional manufacturing into smart manufacturing by reducing lead time, increasing responsiveness, bringing agility and leanness to the supply chain, and enhancing the overall productivity of businesses (Jefroy, et al., 2022). This practical application of Industry 4.0 can make a significant positive impact on manufacturing, supply chain, and logistics by refining their performance and outcome. This emerging trend in supply chain management is a critical topic that needs more attention and research (Nagyova, et al., 2020).

The drastic change in communication and information technologies and their amalgamation in the supply chain have introduced the concept of Industry 4.0 and its impact on the supply chain in the business world. Industry 4.0 has increased the

competition within the organization because of the changing demands and preferences of customers and advancements in technologies (Ghadge, et al., 2020). It has become a necessity for organizations to adapt themselves and integrate with new challenges in an emerging business ecosystem. Operational models and frameworks are also influenced by this transformational change in the industrial world. For better performance and improved productivity, many companies have implemented new standards, principles, and technologies according to Industry 4.0. Different facets of society are positively influenced by Industry 4.0. The impact of this advancement in the business world is quite evident in domestic, social, and professional fields (Bag & Pretorius, 2021). This new paradigm is revolutionizing the world in countless ways e.g. smart cities, smart homes, offices, and even e-health are just a few instances of this revolution. The prominent impact of Industry 4.0 is on manufacturing as it is focusing more on smart manufacturing, procurement, business process management areas, and logistics. In today's competitive and dynamic world, it is indispensable to bring digitalization to the entire supply chain. Emerging technologies should be adopted in businesses' operations, and data flow should be managed in the value chain for effective and efficient management of the digital supply chain (Ghadge, et al., 2020). Industry 4.0 refers to the advanced level of digitalization for production, value chain, and business models. It provides IT solutions and networking to expand manufacturing and shrink manufacturing costs (Abdirad & Krishnan, 2021).

Over the years, there has been tremendous technological progress, especially in the form of Industry 4.0 which offers to build a resilient supply chain (Hägele, et al., 2023). In this regard, Industry 4.0 includes a combination of various digital and intelligent technologies that help to offer more profitable businesses and improved efficiency. Globally, governments have been increasingly investing in Industry 4.0 technologies to improve resilience (Choi, et al., 2022). Industry 4.0 has worked to bring autonomous

technologies where operations can be performed without human interaction. A better understanding of Industry 4.0 can be obtained through a comprehensive evaluation of the first industrial revolution and its impact on industries. It was started in the 18th century in England which helped different to become superpowers (Yen, 2020). It introduced the first steam engine which changed the supply chain of industries and boosted the production efficiencies of factories. However, the supply chain is not the only component that has been affected by the industrial revolution, rather different production functions were affected by it (Zeidan 2019). Then later on, the second, third and fourth industrial revolutions have all been focused on making improvements in existing ways of undertaking manufacturing operations and improving supply chain functions (Brkljac & Sudaraevie 2018).

The goal of every company is to have a modern and agile supply chain, because this transformed supply chain is more responsive, has automated systems and processes (receiving orders, transformation, and delivery to final customers), and is more transparent and flexible. Moreover, these modern supply chains are capable to working in vast and dynamic systems which can manage a high volume of data easily by following the principles of Industry 4.0 (Khan, et al., 2009). It is essential to embrace the concept that expedites the transformation of a traditional supply chain to a modern supply chain, to address dynamic conditions. Embracing Industry 4.0 will drastically change the performance of the supply chain because it focuses more on digitalization, automation, networking, and handling a high volume of information. It also empowers the employees to make decisions quickly under different circumstances. Integrating all elements and processes, connecting suppliers, manufacturers, and customers in real-time, and making the entire supply chain flexible are also the objectives of this concept. The major focus of Industry 4.0 is real-time integration and mobility; therefore, it proves to be a good framework for the modern supply chain (Galanakis, 2023).

Food items consist of a complex supply chain that is made up of various interconnected processes (Higgins, 2021). In recent times, the sustainability of food has been facing severe challenges in recent periods due to various factors mainly including the outbreak of COVID-19, climate change, and potential tensions. In such an environment, building resilient food chains are possible mainly with the help of implementation of advanced technologies (Galanakis, 2023; Hassoun et al., 2022a). One of the main sectors that is more vulnerable to global challenges is the dairy sector (Ioanna et al., 2022). Dairy products are considered as one of the main important sources of functional and nutritional components. The processing of dairy products and operating conditions have increasingly been studied by researchers to understand the safety and sustainability of highly perishable dairy products. However, the operators of dairy products always look for newer and innovative solutions for their products in this dynamic environment (Ribeiro et al., 2022). Thus, the sector is fact adopter of the fourth industrial revolution which is commonly known as Industry 4.0. The main components of Industry 4.0 include robotics, 3D printing, Artificial Intelligence (AI), Blockchain, The Cloud, Cybersecurity, the Internet of Things (IoT), Augmented Reality, Big Data, Digital Twins, and many others. The application of these technologies in the agriculture sector is often referred to as precision or smart farming, for food factories, it is known as 'smart factories' and for dairy sector, it is termed as Dairy 4.0. The concept of Dairy 4.0 is quite new, thus, no precise definition is available for it and there is little reference to the type of technologies used for this sector (Gehlot et al., 2022).

The main drivers of Industry 4.0 are BDA, CPS, IoT, and Cloud. A system that syndicates computing capabilities and communication with engineering and physical system is CPS (Cyber Physical System). A set of physical and cyber resources are included in CPS. They aim to achieve the desired tasks. It is considered a vital driver of Industry 4.0

as it links the virtual and physical worlds by connecting software and hardware at advanced levels. This advanced link results in advanced communication between machines, humans, operations, and products. CPS can be explained with an example CPS is a smart production line with advanced machines that enable the smooth productivity of goods by communicating with the components. The global environment is defined by IoT, which is another key enabler (Hassoun et al., 2022b). IoT (Internet of Things) means the center of connectivity for all the intelligent devices, systems, and processes of are through Internet. The innovation is considered an extension of the internet with ubiquitous connections, where internet-enabled objects and smart objects communicate with each other to make desired decisions by constantly giving feedback and valuable facts. Integration of smart technologies like actuators, sensors, and various other intelligent systems is done with the help of IoT. A paradigm shift has been noticed lately in managing a wealth of information. This shift is because 'cloud computing' as it allows to be sharing of borderless information and gives accessibility to everyone. High-tech computers are facilitating users with computing and analytical powers which results in the generation of BDA (big data analysis). A huge platform is created with such advancement, where big data generated from IoT is analyzed (Fatorachian & Kazemi, 2021).

Business must have transparent supply chains because the visibility of every stage of the supply chain from the first supplier till the end user will help the company to take the necessary action wherever required. As a result, the significance of implementing Industry 4.0 emerged, to achieve organizational goals with the help of smart manufacturing. Although countries focused on Industry 4.0 in 2011, SCM scholars have lately shown interest in Industry 4.0 and its impact on the supply chain. Industry 4.0 emphasizes real-time improvements in processes, production, security, energy consumption, and total cost. It is bringing automation and digitalization to every stage of

supply chain, especially in the manufacturing sector. Another addition to this concept was made in 2014 by diverting attention toward the interconnections between suppliers and consumers along with self-configurations (Chauhan & Singh, 2020).

Industry 4.0 is transforming a simple supply chain into a sustainable supply chain by reducing its negative environmental impact, eradicating all steps that are unnecessary in the production process, conserving energy, and increasing the period of equipment and tools used for operations. A new paradigm that has remarkably increased the process and production efficiency and companies' output is Industry 4.0. This emerging industry is considered a model for sustainable production practices in all areas. The logistics and transportation side has also significantly changed during this time. Road and railway tracks were changed during the Industrial revolution. Advanced technologies were used for building roads and steam engines, therefore, helping the transportation industry side to transform. Developed infrastructure leads to shorter lead times, and enhanced communication among suppliers, manufacturers, and end-users (Abdirad & Krishnan, 2021).

Industry 4.0 has become a recent trend in industries all over the world that has caused substantial changes in overall productivity. It started from the German Strategic Initiatives, it has become an important framework for industries in different countries including Asia, Europe, and the US. It helped to build new and advanced ideas (Tzanidakis et al., 2021).

Internet of Things (IoT), Cyber Physical Systems (CPS), Internet of Services (IoS), big data, cloud manufacturing, and robotics are promoted by Industry 4.0. It involves machines, production modules, automated machines, and products that are used in different areas like supply chain, operations, and management to become responsive in real-time. The techniques that apply to implementing Industry 4.0 for automation are Business

Analysis (BA), machine learning, dynamic optimization, artificial intelligence, and algorithms (Abdirad & Krishnan, 2021). Supply chains, business models, and processes in order are positively emerging because of Industry 4.0. Different terms have been used by researchers for Industry 4.0 in supply chain e.g. E-Supply Chain, Supply Chain 4.0, Digital Supply Network (DSN), E-Logistics, and Logistics 4.0. The four major elements of the supply chain procurement, operations, distribution, and integration are positively affected by the implementation of Industry 4.0. The productivity of companies has been drastically enhanced, and companies are fulfilling the demands of customers more conveniently with this new trend (Adbirad & Krishnan, 2021).

Supply Chain 4.0, also known as the digital supply chain, engages in constructing an innovative supply network that is responsive and resilient. The purpose of this evolution is to integrate the entire supply chain by incorporating the basic principles of Industry 4.0. The intended integration starts from the planning and execution, tracking of logistics, procurement 4.0, managing spare parts efficiently, smart warehousing, prescriptive supply chain analytics, and smart supply enablers. Connecting these elements to form an integrated and aligned system will largely benefit the business model of the supply chain in terms of leanness, agility, responsiveness, cost reduction, and productivity. According to various researchers, Industry 4.0 is showing remarkable potential impact on the supply chain as it is decreasing operational costs and other unnecessary expenses and simultaneously increasing agility. It is expected that Supply Chain 4.0 can decrease the total operation cost by up to 30%, decrease inventories by approximately 75%, and the lost sales by 75% (Gharaibeh, 2022).

The critical framework of activities constitutes the food industry that stimulates the production of dairy items for the population to regularly utilize. The managing directors and producers employ intelligent, trained, and skilled people who are ready to help the

organization by enforcing quality and ecological standards to ensure competitive advantage, economy of scale, economy of scope, agility, leanness, and robust operation. Physiochemical and mechanical operations work simultaneously in different phases requiring water and power reserves for producing dairy products in critical environments ensuring cost and the particular features. Lead time and market demand are two impact factors that have a direct impact on the operations of production lines in the dairy sector because of the perishable nature of dairy products. The dairy sector needs comprehensive real-time supervision, vigilance, and due diligence to timely track unsuitable circumstances, production defects, and quality that are not meeting standards apart from quality control tools and scrutiny (chemical and microbiological) because the entire production of dairy products depends on the skills of production staff (Konstantinidis et al., 2022).

Industry 4.0 emphasizes the learning of machinery, the cloud, and the blast of the internet to introduce a variety of new products and bring innovation. Dairy producers are also facing immense pressure from their consumers to introduce new and improved products and diversify their product line. The dairy industry with the utilization of Industry 4.0 technologies can create a boom in market. Industry 4.0 has already created new measure in processing of items and many industries have just realized the importance of this factor. The dairy producers have also developed an understanding of capitalization, increased their business, and gained a competitive advantage. Industry 4.0 can help the dairy industry in strengthening its global market as well (Tianhua et al., 2021). Dairy producers can also reduce costs with enhanced profitability and increased productivity with the adoption of Industry 4.0. The benefits of Industry 4.0 are real and long-term. Many industries have thrived for this revolution, but the dairy industry is still reluctant to adopt new means and

technologies. But to leap in to this ever-merging and changing market place the dairy industry has to jump into new era of science and technology (Schillings et al., 2021).

The major portion of the income generated annually in both urban and rural areas is from the dairy industry. Commercial dairy farms keep an up-to-date record of cows, their schedule of feeding and injections, and the amount of milk they produce by using RFID tags. This technology has helped the employees to work efficiently as it has enormously reduced the time required to record data for each cow and promote real-time monitoring of the milk produced, promoting corrective and necessary actions to maximize the production rates. In addition to this, smart production can connect the group of manufacturing plants to a system that will help businesses monitor the yield and performance of the dairy sector in real-time (Costa, Frecassetti, Rossini, & Portioli-Staudacher, 2023).

A promising strategy that can address all the challenges of integrated supply chain is embedding Industry 4.0 in supply chain management. This strategy will transform the entire supply chain through connections and comprehensive integrations that will result in a high productivity rate. Industry 4.0 will help businesses to smoothly run their operations without wasting resources and time (Fatorachian & Kazemi, 2021).

1.2 Research Problem

Dairy products are an important source of functional and nutritional compounds. The operating conditions of the dairy sector have been widely studied to understand the quality and safety practices of this sector; however, the operators or manufacturers are still searching for techniques and the latest technologies to find new solutions for their dynamic operations (Rudisail, 2021). With the arrival of Industry 4.0, the dairy sector has become one of the fastest adopters of new technologies, however, it is quite a newer concept for research that very few research publications have discussed. There is no mention of any definition of Industry 4.0 in the dairy sector or the technologies that are used in this sector

(Gehlot et al., 2022; Balaska et al., 2023). Bodo et al., (2022) have also reported that there are various studies discussing the application and readiness of Industry 4.0 in different manufacturing sectors, however, there is a lack of studies conducted in the Indian and Saudi Arabia dairy sector in this context.

In the current time, malpractices while processing, handling, and transporting dairy products, and consumption of these dairy products in the market can deadly affect human health. There is a drastic increase in the manifestation of dairy products-related scandals worldwide. It is observed that countries that developing are at more risk, especially India, Pakistan, and China. China faced a severe milk scandal in 2008 because more than 3 million people were affected by poor quality of dairy products. Food Safety and Standard Authority on India (FSSAI) conducted a study and showed that 68.4% of the milk in the country was not according to the desired legal standards. Incidences that are linked with milk and other dairy products are also observed in developed countries like the USA. There was a recall of 160 products in 2019 in the USA because of undeclared allergen. One-third of those 160 products was milk. Such issues have increased the need for tracking the milk and milk products. However, this need is not restricted to public health but also to environmental health, animal health, and farm labor welfare. The ability to track the transportation of milk and milk products through different channels from the production house to the end user is known as dairy traceability. Lack of coordination, communication among suppliers, producers, retailers, and end users, misinformation, and globalization have demanded an improved traceability system for the dairy industry. Application of Blockchain technology and the Internet of Things (IoT) are considered possible solutions for improving the supply chain of dairy products and tracing the agri-food supply chain system (Singh, Kamalvanshi, Ghimire, & Basyal, 2020).

Operations conditions that are critical for the processing of dairy products are widely studied to certify the good quality and well-being of these perishable dairy products. However, manufacturers of dairy products are looking for new techniques, technologies, and processes that will help them implement sustainable practices so that they can cater to the challenges and problems in the dairy sector with innovative solutions. The actors of the dairy industry are considered fast adopters of the last trends, technologies, and digitalization spurred by the emergence of the industrial revolution (Industry 4.0). The leading enablers of Industry 4.0 in the dairy sector are Robotics, Smart Sensors, Artificial Intelligence AI), Blockchain, Big Data, 3D Printing, Digital Twins, Cyber Security, Cyber-Physical Systems, and The Cloud. Applying these automated technologies in food factories and the dairy sector is often called "smart factories." Automation and Digital Technologies are highly adopted by the dairy supply chain, the implementation of Industry 4.0 technologies in the dairy sector is referred to as "Dairy 4.0". This term has been used in two researches recently, but there was no reference for this definition and enabling technologies. Therefore, this research aims to explore the impact and potential of Industry 4.0 in the dairy sector and highlight the latest trends and technologies (Hassoun et al., 2023).

Recent research has captured the value of I4.0 and its utilization in the supply chain (Gontarz & Sulich, 2020). However, there is a lack of comprehensive view in the existing literature about the potential of digital supply chains, especially in the dairy sector. This research will cover the advantages of supply chain 4.0 in the dairy industry.

There are many industries with low-margin commodities and the dairy industry is one of the traditional industries among them. An updated Vision 4.0 of the dairy industry is aimed at implementing communication and Information Technology (IT) as well as introducing aspects of operational achievement. The industry vision 4.0 in the dairy field

is solely represented by checks and balances in the production and maintenance of supply chains which include milking by robots, chemical and microbial testing during processing, and final packing with improvised data management. This helps timely omission of any faults and data history can help avoid particular mistakes in ongoing future production. Digitization of records helps scrutinize the supply and demand ratio and requirement of a particular dairy products area-wise. The benchmarks can be achieved by setting core objectives of making this industry self-sufficient by enhancing domestic production, effective cold chain, and consumer confidence, thus, meeting national industrial standards. The need for cold chains is main folds during the days of extensive utilization such as public and religious events of different natures which demands the industrialist maintain standards during which maintenance of cold chains is on top priority. Skilled employees and an automated supply chain could make efficient decisions in times of dire need and possess a great impact on the growth of the industry (Anon, 2018).

The major risk on the demand side is demand fluctuation which is considered as a main disruption. Similarly, forecasting errors are also seen as major disorders on the demand side in dairy sectors. These huge errors and problems in the dairy sector can affect the entire supply chain, thus contributing to major inefficient production problems. These devastating problems have become the main reason for changing the distribution channels which ultimately cause massive monetary loss and inefficiencies. Lack of problem technology in the dairy sector can also affect the quality of raw materials. This is observed as a huge risk supply risk by multiple researchers. The quality of milk and other dairy products is considered a critical supply-side risk. Inappropriate technologies and ordering mechanisms are also affecting the entire supply chain badly. Abrupt changes in technologies, equipment, and design are also imposing a lot of pressure on the supply side. Backward integration by competitors where suppliers are creating a monopoly, and various

organizations have to depend on them is also controlling supplies. Major common risks associated with traditional supply chains in the dairy sector are demand risk, supply risk, cost fluctuation, communication gap, unsustainable practices, delays, long lead time, and order-fulfillment issues (Zubair & Ahmad, 2015).

A framework and more research on digital supply chains in the dairy sector are needed to fill the research gap. There is a scarcity of research on the dairy sector, but possible resemblance can be observed in different sectors, keeping in mind some peculiarities. The dairy industry has thermal processes of the raw material and operations to transport dairy products e.g. milk. Another factor that is considered is maintaining the cold chain in an important part, especially in the stage of acquiring raw materials and ensuring the quality of dairy products (Arena et al., 2023).

The Indian dairy sector produces 23% of the total world's milk, making it the highest milk provider in the world. From 2014-15 to 2020-21, the milk production in the country increased at a compound annual growth rate of 6.2%. It indicates the increased potential of the sector that can be further polished with the use of latest technologies. With the application of cutting-edge technologies, data, and devices of the fourth industrial revolution, the speed of processing and production can be enhanced to a greater extent (Bag et al., 2021). Additionally, different untapped segments including value-added products, organic milk, and exports can be enhanced. For instance, milk has limited shelf-life but the introduction of powdered milk has brought greater revolution in this segment. Similarly, the application of different quality control tests can help to promote the sustainability and hygiene of dairy products. The application of Industry 4.0 can help to promote meeting the required standards to fulfill the demands of customers and all the regulatory requirements (Sinha & Mishra, 2023). A supply chain consists of many stakeholders who are involved in delivering goods and services from manufacturers to ultimate consumers. The main

components of the supply chain include raw materials and data. While transferring these components to consumers, they are always refined and transformed. Thus, there is a need to properly manage the supply chain. Pereira & Romero, (2017) have defined supply chain management (SCM) as controlling and managing various activities which are involved from logistics to manufacturing or operation so that the needs of customers can be met efficiently and more quickly. The other objective is to manage the supplier relationships effectively so that the costs can be reduced. Verwijmeren, (2017) has discussed that the current era supply chain has become quite complex since it spans across countries and even continents, thus managing such a supply chain has become quite difficult. Thus, the application of Industry 4.0 to manage supply chain operations is desired and is need of the hour.

Along with the demands of ecological stability, managing waste products and by-products of dairy has become a matter of sole importance in years on the go. The precise research is aimed at gathering the current up-to-the-mark technologies and new ideas required to reduce and better utilize the subsequent milk, cheese, yogurt, curd, and other dairy products used in daily life (Abdo Hassoun, 2024).

Thus, owing to the increased importance of Industry 4.0 for the dairy sector, the current research has been focused on the bridging the gap in literature while it will also make important practical implications.

1.3 Research Aim and Objectives

The research has been aimed at examining different technologies of the fourth industrial revolution that can be used and benefit the dairy sector. The main purpose is to get a deeper understanding of the modern technologies of Industry 4.0 and evaluate their impact on the resilience of the supply chain of the dairy sector. The fast-track digitization and introduction of modern procedures and practices in industry is placing a very

constructive image on society of this era as it contributes towards economic uplift. The dairy sector, in precise, includes time-bound and concentrating procedures. So, it has become critical to apply new digitized processes and solutions to enhance efficacy and meet standard requirements from day to day. An intelligent-based algorithm on mechanical and AI versions is discussed in this work at the end which will recognize milk products in the manufacturing frame.

In this regard, the main research objectives for the proposed research have been categorized as under:

- To investigate the Industry 4.0 technologies used in SCM of dairy sector.
- To evaluate the application of Industry 4.0 in SCM of the dairy sector of Kingdom of Saudi Arabia and India.
- To understand the challenges posed to the SCM of dairy sector for implementation of Industry 4.0.
- To recommend different solutions for practical application of the fourth industrial revolution in SCM of the dairy sector in Kingdom of Saudi Arabia and India.

1.4 Research Questions

The main research question of this study includes the following:

How does Industry 4.0 impact the resilience of supply chain management of the dairy sector in India and Kingdom of Saudi Arabia?

To address this research question, the following sub-questions have been formulated:

- How has Industry 4.0 affected the supply chain of the dairy sector?
- How can the dairy sector bring resilience into its supply chain using Industry 4.0?

1.5 Research Limitations

This research has been directed to investigate the impact of Industry 4.0 technology on supply chain resilience of the dairy sector. Thus, the results do not belong to overall industries but are confined to one specific industry. Furthermore, the research has also been conducted within the dairy sector of Kingdom of Saudi Arabia and India, thus, the findings may be generalized to only those countries with similar environments and conditions and may not apply to every geographical region.

1.6 Research Structure

This research has been organized in the form of different chapters where each specific chapter has been dedicated to including specialized information. In this regard, different chapters of this study and their relevant information include the following:

- Chapter One: Chapter One of this study contains information about the research background, aim, and objectives, research questions, and the rationale for conducting this research. Moreover, it also highlights the contributions of this study and the main limitations to it;
- Chapter Two: The second chapter is all about a review of the past literature. In this regard, it has investigated the main principles of Industry 4.0, its importance, technologies that make up Industry 4.0, and its application for different supply chain functions, while finally, it has discussed the impact of Industry 4.0 in the supply chain of the dairy sector.
- Chapter Three: The third chapter contains the complete methodology to conduct this research. In this regard, it has discussed the research design, research philosophy, research approach, research type, methods of data collection and analysis, sample size, sampling technique used for this research.

- Chapter Four: The fourth chapter has been dedicated to containing detailed findings of this research. With the help of research results, the research objectives and research questions have been answered.
- Chapter Five: The fifth chapter of this study which includes the analysis of the results, discussion, and the achievements of the four objectives.
- Chapter Six: The sixth chapter is the last chapter of this study with the overall summary of the whole research while recommendations have also made based on the results of the study and a future course of research has been proposed.

CHAPTER II:

REVIEW OF LITERATURE

2.1 Overview

Over the years, information technology (IT) has brought greater revolution which has resulted in radical changes in all aspects of life (Lu, 2017). The interconnection of machines and information sharing has been rising. With this, the future of factories will be driven by human-robotics interconnection using Cyber-Physical-Systems. It will result in radical changes in Industrial processes with the introduction of intelligent devices. The issues at factories will be solved with minimum of no human involvement. Such interconnected communication of machines at production and operations is known as Industry 4.0 (Mittal et al., 2018). Initially, the phenomenon of Industry 4.0 was restricted to only manufacturing concerns but gradually, it has included service providers as well (Lio et al., 2017).

The literature on industry 4.0 has no conclusive definition yet, there are four key features of the system unanimously derived from the literature (Müller et al., 2018).

First of all, the production systems based on Industry 4.0 work on vertical networking. This is formed using Cyber-physical systems (CPSs) which allow factories to quickly respond to customers' requirements. Smart factories lead to greater customization. With this, both autonomous and maintenance management is possible. It works by interconnecting products and resources while materials can be obtained as and when needed from anywhere. The production functions that have problems are automatically recorded (Pietro et al., 2017).

Secondly, the system has horizontal integration facilitated by a global value chain. The horizontal integration within smart factories is achieved under Industry 4.0 using

networks, strategies, and models. All this leads to achieving greater flexibility and provides a quick response to changing market demand.

Industry 4.0 also provides engineering support through the value chain. The production of new products is made using big data analytics which helps in bringing technical improvements as well as innovations in products.

Fourthly, industry 4.0 brings exponential growth and acceleration through the latest technologies, in this way, innovative technologies reduce costs, bring flexibility, and result in mass customization. This is all done using automated systems created by robots, artificial intelligence (AI), nanotechnologies, drones, and a variety of other technologies (Longo et al., 2017).

The paradigms in industry 4.0 can be categorized into three main heads including augmented operator, smart machine, and smart product (Weyer et al., 2015). Later Mrugalska and Wyrwicka, (2017) and Longo et al., (2017) also highlighted similar paradigms. In this regard, smart products include machines and products that are connected to the internet and controlled by software while sensors and microchips are installed in them (Kamble, 2018). These products inform machines about the required operations. These instructions may include what to produce, what quantity to produce, and where to produce for completion of manufacturing processes. In this way, the piece of work production is shifted from passive to active works under a smart system (Lu, 2017).

Secondly, the smart machine paradigm is a device that is equipped with cognitive computing or machine-to-machine technologies including machine learning or artificial intelligence. With the help of these technologies, machines can solve problems, provide reasons, make decisions, and implement them. With this, traditional production hierarchies are replaced by decentralized organizations (Mrugalska and Wyrwicka, 2017). Oztemel and Gursev, (2018) argued that sematic descriptions along with open networks allow the

system to communicate. It results in flexible communication and modular production lines (Pereira and Rmero, 2017).

Thirdly, the augmented operator helps the workers in the production system with technological support equipped with higher modularity and flexibility. By bringing knowledge automation, the augmented operator brings flexibility and modularity to the overall production system. These production systems provide workers with diverse tasks including verification, monitoring, and specifications of production strategy (Longo et al., 2017). Moreover, they also intervene in self-organized systems. In this way, it makes up user-focused systems where users can make decisions and solve problems (Gorecky et al., 2012).

2.2 Principles of Industry 4.0 Design

Oztemel & Gursev, (2018) have discussed 6 main principles that serve as foundation for industry 4.0 designs and implementation. These principles include real-time capability, decentralization, service orientation, interoperability, modularity, and virtualization (Lu, 2017). Later Kamble et al., (2018) conducted a systematic literature review and confirmed the role of these 6 principles in the implementation and the design of Industry 4.0.

A study on Industry 4.0 (The Fourth Industrial Revolution) by the I-Scoop consultancy, explains the concept of the smart factory by emphasizing the functional requirements that are used for smart manufacturing. These requirements highlight what can be produced with the help of existing technology and are based on six basic principles of Industry 4.0 (Koh, 2022).

In this regard, interoperability refers to the communication and understanding of two devices and the performance of functions. Information exchange and knowledge sharing capability is enhanced through it. The extent to which devices, applications,

software systems, and other entities can link and interact with other entities in synchronized way without the struggle from the end operator. This facility is linked with things like cross-functional collaboration, data transmission, and data access. Interoperability benefits the business in attaining advanced proficiency and a more holistic view of information (Lewis, 2023).

Thus, the interoperability feature facilitates communication, the connection between machines, and devices. For this, an automated diversified procedure is adopted. Lu, (2017) has argued that interoperability consists of four levels including technical, semantic, systematic, and operational. With the help of operational interoperability, it determines the standards, concepts, and relationships between different components of the system. Technical operability includes the platform and tools used for technical development, while systematic interoperability consists of methodologies, models, and standards. Finally, semantic operability ensures the different components in the system are engaged in an exchange of information that is understandable to everyone. Qin et al., (2016) have discussed that by using interoperability a trusted environment in a communication system is created which is helpful to quickly exchange information. Ultimately, cost saving is achieved with higher productivity levels.

The automated ability of systems to exchange and interpret information accurately is known as sematic interoperability. It is attained when the arrangement and codification of all data is uniform and constant along all systems that are involved in exchanging data. A crucial factor that is considered for the growth of modern technology is the exchange of data between It system, databases, and applications. It is beneficial for companies to maintain reliable interoperability in different ways like its lower maintenance costs that are linked with interoperable systems, giving more access to critical information to all

concerned stakeholders, sophisticated sourcing techniques to enhance the quality of data, and processing and converting data need less time and resources (Lewis, 2023).

The principle of virtualization is used for communication and monitoring of devices. This principle is based on the notion that machines can monitor the process by creating a virtual copy of the process and object. Kamble et al., (2018) have discussed that after detection of potential risks and failures, operators receive the signal, and they can take pre-emptive actions. Ultimately, the chances of errors are reduced, and the overall function operates smoothly (Brettel, et al., 2014).

The principles of decentralization argue that decision-making can be made independently rather than relying on centralized systems. Flexible production is adopted using customization. This reduces the control of the production line as the decision-making is made independent, which adds flexibility to operations. The principle of real-time capability involves immediacy for the collection and analysis of data for data transmission (Lee et al., 2017). This continuous monitoring of real-time data is important for detecting errors and making timely decisions. The service orientation leads to making users satisfied using the Internet of Services (IoS). Lasi et al., (2014) have discussed that all the devices are interconnected in the system which makes extension of products to services. By service orientation, it implies that the practical demands of customers are satisfied at the time of product design. It helps in giving a quick response to changing market conditions.

The principle of modularity implies that a device or its components are standardized. Thus, the expansion, replacement, and assembly can be done based on a modular system. With the help of modularity, changes in production capacities can be made with changing seasonal demand (Hansen et al., 2017).

2.3 Importance of Industry 4.0

Industry 4.0 is rapidly developing and so are theoretical and conceptual understandings. Industry 4.0 is becoming vital because the essential strategic component that is enhancing the manufacturing processes' efficiency and determining decisions regarding globalization strategies are linked with the implementation of Industry 4.0. Industry 4.0 has not had an ideal impact on businesses that are not evolving with time. Conversely, the apparent significance of Industry 4.0 on companies that have transformed their manufacturing by moving back and on the companies that have moved operations out and back are positively impacts by Industry 4.0 (Pansare, Yadav and Nagare, 2024)

Industry 4.0 is a revolution in the industry in terms of product design and operations in the overall supply chain. Various smart devices and smart factories help improve manufacturing operations in the form of cost reduction and adding flexibility and efficiency to operations. Dallasega et al., (2018) are of the view that Industry 4.0 revolutionizes the supply chain from product design to production to distribution of products. With the help of modularity, they are more equipped to manufacture customized products that meet the demands of customers. Pereira & Romero, (2017) has investigated that Industry 4.0 technologies have transformed the distribution of products and services against traditional means. For instance, by bringing digital market models, the physical barriers of distribution are reduced. Ibarra et al., (2018) have added that Industry 4.0 has also changed the skills requirements as well as the working environment in factories. This is because more robots are now working in factories for production purposes, thereby transforming the environment. In this new working environment, skilled workers in technical and social fields with interdisciplinary thinking are needed. For this purpose, employee education as well as training needs to be conducted at an extensive level so that they can be prepared for the application of new technologies (Pereira & Romero, 2017).

Industry 4.0 is more than investing in the latest technologies and tools to enhance manufacturing productivity. It is more about transfiguring the approaches through which your business operates and develops. With the help of this concept, the life cycles of products have been improved and so have the entire supply chains (procurement, sales, designs, quality, quantity, inventory, costumers, and field services). An up-to-date, relevant, and transparent view and information of production and business processes are shared with this industrial revolution (Toussaint, Krima, and Panetto, 2024). It helps a company to be more competitive by bringing transparency in the entire process, attracting younger workforces, strengthening the team, and providing more opportunities to outshine. It anticipates the potential issues and allows the company to address them timely before they cause huge disruption. Industry 4.0 is beneficial for business as it reduced costs, boosts revenue, and fuels development.

Sustainable development is possible using big data analytics and cloud computing since they help to reduce costs and achieve efficiency. Environmental sustainability can be achieved through tracing, detection, and sensing technologies which help in the reduction of waste and its efficient disposal. Other wearable and risk-mapping technologies work in hazardous workplaces to ensure employee safety, thus social sustainability is achieved (Bur et al., 2018).

2.4 Technologies Used in Industry 4.0

Industry 4.0 is an integrated, optimized, and adapted process that involves big data, algorithms, and high technologies. Bahrin et al., (2016) argued that technologies are core to Industry 4.0 since they ensure the interconnectedness of devices including processors, software, and sensors. In this regard, five main types of technologies are most commonly referred to under Industry 4.0 including: cloud, Internet of Things (IoT), 3D printing, big

data analytics, and robotics. Moreover, there are emerging technologies of artificial intelligence (AI) digital twin, Machine Learning (ML), and 5G (Yang et al., 2017).

The most trending topic in academic and professional fields is Industry 4.0. This has a multifaceted technology architecture of operation system. Therefore, implementing industry 4.0 technologies effectively is a subject of research. These technologies are separated into two dissimilar layers. The first layer is known as the "Front-end technologies" of I4.0, which transform the activities of manufacturing based on evolving technologies (smart manufacturing) and how smart products are offered (Dalenogare et al., 2018). The different ways of delivering raw materials and products visa smart supply chain, and emerging technologies used by workers in new ways to perform their activities (Stock et al., 2018). This technology layer is called "front-end technologies" because the four "smart" dimensions are associated with the needs of operations and the market. The front-end layer is dependent on another layer "base technologies" which include technologies that give connections and intelligence for for-end technologies. The concept of Industry 4.0 is enabled by this last layer, creating evolution in the industrial stages. Front-end technologies are linked to integrated manufacturing systems with the assistance of base technologies (Frank, Dalenogare, and Ayala, 2019).

Base technologies are considered the second layer of Industry 4.0 technologies. Internet of Things (IoT), cloud services, big data, and analytics are the composition of base technologies (Tao et al., 2014) The reason for considering their base is because they exist in all dimensions and various technologies of such dimensions. The possibility of interconnections and the provision of intelligence of new, manufacturing systems are because base technologies leverage the Industry 4.0.

2.4.1 Internet of Things (IoT)

Computer devices, digital and mechanical machines, objects, or individuals having UIDs (Unique Systems) are connected by a system named the Intern of Things (IoT). This technology has made the transfer of data easier by assigning internet protocol addresses to different networks or man-made objects in a connected manner (Laghari et al., 2021).

It is an emerging technology within the ecosystem, It helps in bringing efficiency and reliability and improved productivity using a variety of intelligent machines, human-machine collaboration, and advanced analytical capacities. To help the functioning of smart factories, virtual networks are created using IoT (Xu et al., 2018). Moreover, the collection and transmission of real-time data are also facilitated by IoT. Thus, stakeholder collaboration and remote manufacturing are enhanced. Yang et al., (2017) have postulated that coordination and collaboration of information flow as well as products is made possible. Furthermore, by reducing centralization the system performs the automatic analysis and takes decisions which helps in enhancing the responsiveness towards market changes (Wang et al., 2014).

A physical object having sensors for smooth communications with systems is referred to as the Internet of Things (IoT). The IOT given access to the physical world to monitor and control itself digitally. The power to connect constantly visa IoT, combined with analytics and data, creates new openings for businesses to bring innovation in products and services and increases the efficiency of operations. The most significant trend in transforming businesses and economics digitally is the emergence of IoT. A multinational company McKinsey has estimated that the value potential of the IoT network could reach $12.6 trillion by 2030 (Levy and Boer, 2024). This estimated total value potential encompasses the value caught by consumers and the total customers for the products and services of IoT. With the help of this technology, downtime can be reduced drastically,

create opportunities for new business models, enhances the experience of customers, and makes the company more resilient. The COVID-19 era made companies use digital management tools and constant connectivity to respond quickly to market demands by regulating the capacity of production and remote operations simultaneously. IoT is used to align organizations, businesses, and technology spheres by making connections possible in real time (Levy and Boer, 2024).

2.4.2 Big Data Analysis

In this era of increased globalization and digitalization, data analytic capabilities play a prime role in achieving competitive advantage. Lee et al., (2017) argued that owing to increased data analytic requirements, organizations are engaged in increased data interpretation and algorithm development, Bahrin et al., (2016) discussed that big data analytics help to collect, store, and retrieve data from multiple sources that can be used for real-time decision-making. Manufacturing organizations largely use big data analytics to monitor their operations. Moreover, with the help of predictive analytics, the defects can be identified and predicted. Lee et al., (2017) postulated that the quality of data as well as good analysis skills helps derive the required results for business. Kamble et al., (2018) have, however, highlighted that leveraging intelligence skills to ensure confidentiality and consistency is a big challenge for organizations.

Big data is considered an asset for companies after the tremendous development of information and communication technologies (ICTs). The big data is categorized into 5Vs: volume, velocity, veracity, variety, and value (Version, 2018). The magnitude of data is referred to as volume, which is increased exponentially, and is posing challenges to the aptitude of existing devices used for storage, the speed through which data is generated and delivered, processed in batch, real-time, close to real-time, or streamlined (Tan and Lee, 2015). The significance of the quality of data and trust level, because the sources of plenty

of data have somehow uncertainty and unreliability, are emphasized by veracity. The fact that heterogeneous sources like the Internet of Things, online social networks, sensors, and mobile devices can be used to generate data in structured, unstructured, and semi-structured formats refers to variety. Finally, the process of revealing underexploited values from Big Data to support future decisions is referred to as value. The rigorousness of Big Data Analytics among these 5Vs, is value and veracity. They are more important because, with data analysis, other BD processing aspects like storage, management, and collection will create value (Huang et al., 2015). Advanced analytical techniques are involved to extract treasured knowledge from a lot of data, facilitating data-driver decision-making.

2.4.3 Cloud

It is computing technology. Mitra et al., (2017) state that cloud computing includes various data centers where data storage and computations are made which helps reduce costs and improve productivity. Supported by virtualization technology, it helps in resource pooling, sharing, flexibility, and dynamic allocation to users Xu et al., (2018) have highlighted that the most efficient data sharing is made possible through cloud computing, and even complex problems are resolved. Organizations using cloud-based computing can better implement Industry 4.0 since it helps service orientation and modularization in manufacturing concerns. Branger (2015) have also provided that manufacturing concerns are shifting towards Industry 4.0 based on cloud computing.

A new service-oriented business paradigm based on cloud concepts and methods in known as cloud manufacturing. Academia and Industry have given great attention to this concept since its inception (Liu and Xu, 2016).

A rising paradigm that is significantly contributing to the success of Industry 4.0 is cloud-based manufacturing (CBM). A networked manufacturing model where the diversified distribution manufacturing resources are given demand access to form short-

term, reconfigurable cyber-physical production lines with improved efficiency, reduce the total production cost, and variable-demand customer-generated tasking leads towards optimal resource allocation. Advanced cloud-based manufacturing sector (Thames and Schaefer, 2016). Cloud-based design and manufacture (CBDM) is also a new paradigm similar to cloud-based manufacturing and is linked with a more product realization process where all systems and sources are aligned and integrated into a cloud computing model. Mishra and ray, (2010) defined CBDM as a product development model that promotes innovation and more rapid production with reduced manufacturing cost through crowd-sourcing and social networking platforms joined with shared service pools of manufacturing and design components and resources. The goal of CBDM is to enhance cloud-based manufacturing by synchronizing it with cloud-based design and social development (Thames and Schaefer, 2016).

2.4.4 3D Printing

3D printing uses large volume of material to manufacture final products which reduces the assembly cost of units during manufacturing> Oztemel and Gursev, (2018) provided that it uses an additive manufacturing technique which is helpful to support Industry 4.0 in the form of allowing small batches of products that are lightweight and customized, thus, providing businesses with competitive advantages. Earlier Chen and Lin, (2017) signaled that 3D printing leads to smart and lean manufacturing. However, they have further provided that 3D printing may contain certain challenges including availability of limited material and also limited accuracy. Due to this, 3D printing under additive technology is at the inception stage. With the removal of such issues, 3D printing can form a substantial part of Industry 4.0.

2.4.5 Robotics System

Robotics has been increasingly used in organization, especially for manufacturing concerns. These are flexible, and autonomous and also contain learning capability. They can collaborate and communicate with each other and are known as collaborative robots. The factories where robots work is known as smart factories. They are used in assembly lines for the distribution of materials and are known as smart factories. They are used in assembly lines for the distribution of materials and are known as programmable arm robots (Pir et al., 2017). It helps in significant reduction of cost. For safe work, safety eye devices are installed in robots. As the safety eye examines any fault in system, the robot stops working until the fault is removed (Muller et al., 2017). Extensive capabilities in the manufacturing sector are provided by one of the important technologies of Industry 4.0 robotics. This technology aims to automate the process, to perform tasks accurately at reduced cost. Production of quality products is mainly because of robotics while sustaining the value of current collaborators schemes (Javaid et al., 2021). The primary result of implementing Industry 4.0 is the development of smart factories with the help of advanced robotics, massive data, solid safety, and various other latest technologies to become cost-effective, powerful, competitive, and safe. Robotics is considered ideal for the collection of mysterious manufacturing-related data as their operations are closer to the component. The technology enables companies to perform complex hazardous jobs, promote automation, maintain high temperatures wherever required, and work non-stop for a longer period in assembly lines. High-level tasks are performed by robots by using artificial intelligence in intelligent factories. The advancement and development in robotics have enabled them to make decisions and learn from experiences in different ongoing activities (Chen et al., 2021).

The automated service that has replaced humans in reproducing the work in Robotic Process Automation. Software robots and Artificial intelligence workers are used to automate the system partially or entirely to perform the desired repetitive tasks precisely. The instructions for each task are provided by the developer. (Van der Aalst, Bichler and Heinzl, 2018) state that "RPA is an umbrella term for all the tools that make their operations on the user interface of other computer systems (Ribeiro et al., 2021).

2.5 Industry 4.0 and Supply Chain Management

A supply chain consists of many stakeholders who are involved in delivering goods and services from manufacturers to ultimate consumers, the main components of the supply chain include raw materials and data. While transferring these components to consumers, they are always refined and transformed. Thus, there is a need to properly manage the supply chain. Pereira & Romero, (2017) have defined supply chain management (SCM) as controlling and managing various activities which are involved from logistics to manufacturing or operation so that the needs of customers can be met efficiently and more quickly. The other objective is to manage the supplier relationships effectively so that the costs can be reduced. Verwijmeren, (2017) has discussed that the current era supply chain has become quite difficult. Thus, the application of Industry 4.0 to manage supply chain operations is desired and is the need of the hour.

The automated production of goods and services as well as the automated supply and delivery of raw materials and goods without involving humans is done with Industry 4.0. The emergence of Industry 4.0 is transforming the old exchange in manufacturing technologies and processes with the assistance of cyber-physical system (CPS), cloud computing, industrial internet of things (IIoT), artificial intelligence and cognitive *Vogel-Heuser and Hess, 2016). Industry 4.0 has predominantly decentralized the decision-making power, and system elements (e.g. logistics and operations) have started making

autonomously targeted decisions. Digital and smart manufacturing are interconnected, communicate up-to-date information, and utilize information to further take intelligent actions back in the real world (Hofmann et al., 2019).

A new phase of development in supply chain management is SCM 4.0, in which the flow of physical goods, services, information, and cash flows in the business world is highly automated and permeated with the latest digital technologies.

The components and effects based on) Vogel-Heuser and Hess, 2016) of Industry 4.0 are cyber-physical systems (CPS) based on service orientation and the internet of services, decentralized decisions by multi-agent systems and CPS, interoperability between devices and human and resources virtualization, process optimization due to supple automation, integration of data of different disciplines, cloud giving access and security to the data of distributed data storage like block chain.

Stank et al., (2019) investigated the ways to alter the supply chain model and frameworks through digitalization by following the DDP (digitally dominant paradigm) to explore how the established relationships and concepts are influenced in supply chain management. Analytics centers' role was explored by (Handfield, Jeong, and Choi, 2019) to check how they could cater to specific functional needs like procurement.

Supply chains can either partially or fully automate the supply chain by training the staff with adequate knowledge about the role and function of supportive technologies along with robotic solutions, Operations, inbound and outbound logistics, procurement, and all other processes are rapidly trying to be automated to increase transparency and efficiency and can be cost-effective for the organization (Hofmann et al., 2019).

2.5.1 Industry 4.0 and Planning

Planning considered to be one of the most important steps in the overall SCM since it sets out the direction and good planning can balance the demand and supply

requirements. Ashodian (2016) has provided that, planning includes all strategies from raw material procurement to manufacturing and delivery of products in a way that resources can be utilized in the most optimized manner and lay down the future strategy. Popa, (2013) has argued that smart technology may not be directly relevant to planning or scheduling. However, it impacts through data collection and exchange of valuable information. In this regard, the big data helps to evaluate and analyze information. Such analysis helps determine the most suitable and feasible processes for production operations. The system provides specifications for the time to complete each process and sequence of production. The intelligent machines in the system help managers to process and exchange information throughout the chain. With this, the managers can select the most optimal plan even in complex and diverse situations. Also, the alternative plans provided by the system are quite helpful to resolve the problems as they occur and thus, speed up the process. The automatic learning of machines can learn new knowledge and provide information about plans for changing market conditions. Thus error-free and up-to-date information is quite helpful to resolve problems and make the planning and scheduling process quicker. Furthermore, it provides flexibility to planning operations so that in case of any problem in operations, alternative plans can be adopted. Meissner & Aurich (2019) have also emphasized that for workers, alternative plans must always be prepared so that they can quickly revert to those plans. The use of AI and big data helps to process the data within no time and with complete precision. It allows understanding of various aspects including transportation of raw materials, performance of machinery and continuously changing market conditions.

A value-adding process that defines when, how, and what to buy, produce, and deliver so that businesses can easily meet the customers' demand with their manufacturing capabilities is known as production planning and control (PPC). PPC needs focus on complex customer demands, the operational environment, strategic environment, and

explore different supply chain opportunities, thus it should be adaptive, integrative, and dynamic (Bueno, Godinho Filho, and Frank, 2020). The digital capabilities of I4.0 can provide new chances to evolve for PPC. The real-time optimized value networks were established and sustained by the German conceptualization of Industry 4.0 (Habib and Chimsom, 2019). The prime part of the manufacturing system is PPC, which is vulnerable to changes with the arrival of Industry 4.0 technologies (Cattaneo et al., 2018). Digital technologies can transform the managerial functions of planning by automating and integrating them. Vertical integration of digital and physical production environments by involving cyber-physical systems and digital twins can affect the traditional tasks of PPC (Bueno, Godinho Filho, and Frank, 2020). The integration and synchronization of machine-to-machine approaches for ordering, ERP, and manufacturing execution systems can transform the PPC (Kopp, Howaldt, and Schultze, 2016).

Apart from the time component, product planning software selects a machine that matches the capacity of the manufacturing system. The system decides which machine will be used for the pre-defined operation for production which is considered as the first criterion. Technological time, preparatory time, and auxiliary time are the times of operations that are controlled first. The total time for the series of ordered products is calculated and the total needed quantity of products is also noted, which is the second criterion. These are connected to optimize the use of machines and to make timely decisions, this can be referred to as “just-in-time scheduling”. The digitalization concept helps the company to reduce manufacturing costs, lead time, and gain economy of scale by using advanced algorithms for digital planning (Trstenjak and Cosic, 2017).

2.5.2 Industry 4.0 and Procurement Functions

Industry 4.0 can significantly impact the procurement processes. Different technologies of Industry 4.0 including big data and IoT help to connect different

stakeholders and even departments in the overall supply chain (Rathore, 2018). The procurement departments in today's changing market conditions have to work in a tougher situation since the amount of raw material needed can quickly change with changes in market conditions. In such a situation, Industry 4.0 has revolutionized the procurement department with procurement 4.0 technology. These technologies often include:

- Cloud technology: It connects the suppliers and the manufacturers to make their decisions on raw materials based on market requirements.
- Augmented reality (AR): AR technology is helpful to acquire information which is helpful to meet the needs of customers. This technology works by providing real-time information like the availability of raw materials, their need for different departments, and the raw material in movement. All this information can be obtained with just a single click. It is helpful to reduce labor and costs and ensure accurate information about raw material availability.
- Additive manufacturing (AM): additive manufacturing is more concerned with manufacturing operations, however, both manufacturing and procurement processes are interconnected, thus, AM affects the procurement process as well. The use of 3D printing under additive manufacturing techniques is helpful to reduce the raw material needed for operations.
- IoT: IoT keeps track of raw materials in operations, automates the procurement process, and reduces problems in manufacturing operations. It mitigates disruptions in the supply chain. It empowers

machinery to make decisions. This support to making timely decisions in supply chain management.

In this way, industry 4.0 is likely to transform the procurement processes. The organizations engaged in Industry 4.0 are more integrated into manufacturing operations.

The components of Industry 4.0 are included in Procurement 4.0 (P4.0) where all supply chain upstream partners are connected through a shared network that has enabled prompt and dynamic cooperation and coordination beyond organizational boundaries (Althabatah, Yaqot, and Menezes, 2023)> The purchasing challenges are overcome by embracing P4.0 techniques in the operating model of the entire supply chain. The utilization of cutting-edge technologies like big data, e-procurement, the Internet of Things, 3D printing, artificial intelligence, modularity, and additive manufacturing has made this emergence in procurement possible. Industry 4.0 has altered every aspect of the value chain by empowering procurement managers to maximize their operations and boost their capabilities of decision-making to increase the effectiveness and efficiency of procurement operations including distribution, inbound and outbound logistics, supplier sourcing, warehousing and customer satisfaction (the prime purpose of supply chain). Moreover, these automated technologies have the potential to make significance contribution to increase production, reduce cost, reduce lead time, attract more customers, reduce errors especially bullwhip effect in the supply chain (Jahani et al., 2021). The three components of I4.0 that are playing a pivotal role in procurement are connectivity, advanced analytics, and automation. These components can make the procurement process automated and analytical tools can be used to support decision-making processes (Nicoletti, 2017). Although procurement functions have been supported by information technology for many years, this holistic use in every phase of the procurement process is exclusive as it is transforming simple procurement into Procurement 4.0. It is believed that the procurement

process will be explored more in the future with more developments in technology. There would be an increased interaction between internal and external shareholders in P4.0, the generation of more reliable data by offering up-to-date information through advanced analytics, and different ways of analysis to support decision-making processes (Althabatah, Yaqot, Menezes, 2023).

2.5.3 Industry 4.0 and Manufacturing Operations

Like procurement, manufacturing is also categorized as one of the most significant parts of SCM. IBM, (2020) has highlighted that organizations are more concerned with reducing production costs, shortening the production period, and manufacturing high-quality products to better satisfy their customers. Industry 4.0 helps make manufacturing decisions quickly and undertake flexible operations. Different industry 4.0 technologies including real-time monitoring, big data, IoT, and additive manufacturing allow the production processes to be conducted in smart factories which digitalize the overall operations and thus, the supply chain activities can be performed excellently, All the manufacturing aspects including procurement of raw materials, processing of information, and distribution of final goods are improved under it.

It is helpful in the selection of the best quality raw material and its timely reach to the factory. The digitalized and automated production procedures instead of manual operations improve the quality and quantity or production. Moyne, (2017) has proved that the use of advanced analytics which involves use of mathematical tools for different procedures and practices help reduce costs, save time, cut flaws, and meet the needs of customers in a better way. Using advanced analytics, the managers are enabled to understand the factors that result in greater production and improved quality. Hozdic, (2015) has discussed that advanced analytics can provide greater help in complex situations and achieve results way better than competitors.

Additionally, additive technologies work to further improve the production processes. It is helpful to manufacture even complex items directly from raw materials. Different additive manufacturing techniques including 3D printing and Cad have been positively impacting manufacturing operations; however, the advantages of these techniques have not been fully realized (Zijm et al., 2019). 3D printing is also helpful in stabilizing durability with the material amount used for the product.

2.5.4 Industry 4.0 and Inventory Control

Inventory management is related mainly to cash flows; thus, it is difficult to manage, inventories may be of different types including raw material, work in process, and finished goods inventory. Any delay in these three types of inventories can have a bottom-line impact on shareholders as well as consumers (Wagner et al., 2017). A successful business works in a way that its sales are maximized while inventory stocks are minimized. Good inventory management helps businesses reduce their waste and avoid the problems of understocking and overstocking. The integration of Industry 4.0 helps in achieving efficiency in warehouse and logistics operations which is turn leads to overall delivery times (Tao et al., 2014). Hoey, (2019) has provided that Industry 4.0 helps in the improvement of SCM through better inventory controls. With the help of IoT and other sensor technologies, the tracking and automated analysis of inventory becomes easier for supply chain managers. In technical terms, industry 4.0 affects inventory management in the following ways:

- Inventory processing: the buying and selling process is digitalized which helps in automatically fulfilling the products. Based on available information on demand and supply, new orders can be placed automatically with the suppliers. Lackey, (2019) has discussed that such a system is also

helpful to predict the demands of customers in terms of quality and quantity needed.

- Inventory classification: for the effective management of inventory, the managers use different classification systems including ABC classification where inventory is arranged according to quality from high to low value. Thus, the products according to their value and location can also be collected (Yuan, 2020).
- Parameters of Inventory System: inventory lead time is an important parameter for inventory management. The time taken by suppliers to inform about inventory requirements is very important and it determines the efficient manufacturing operations. Industry 4.0 determines the location of products and their demand which helps in reducing the lead time. In case of a delay in transportation, the system automatically updates information to everyone in the supply chain and thus the ordering and carrying costs and selling price all is adjusted accordingly (Wang et al., 2014).
- Review of inventory Systems: inventory systems may be continuous or periodic. Due to higher costs, businesses normally use a periodic inventory system. In such a situation the implementation of Industry 4.0 provides continuous information thereby converting the system from a periodic inventory system to a continuous review of inventory. Thus, the evaluation and review of inventory can be made possible continuously (Xu et al., 2018).

With the help of Industry 4.0, an optimization of the inventory system using the R&D model is created. It allows for deep data analysis which helps in adjusting inventory requirements and hence the supply processes are optimized.

2.5.5 Industry 4.0 and Delivery System

The delivery of products is an important component of SCM. Quicker delivery time is important for modern supply chains that are spread across countries. With the help of Industry 4.0 an automated supply chain is created through connected machines. Big data analysis determines the most optimal inventory route. With time, supply chain operations are getting very complex. However, modern analytical systems are empowered to determine the deadlines for product delivery in different scenarios (Melnyk et al., 2018). The major focus of Industry 4.0 is on delivery optimization instead of delivery time. The modern and efficient means of transportation can still result in delays due to circumstances unpredicted. One shipment of raw material if delayed can have a significant impact on overall operations of the business (Gunal et al., 2019).

However, prediction of all possible obstacles may not be possible, yet the supply chain can be planned too uninterrupted. Adonis, (2021) has highlighted that the modern GPS helps the transporters to inform about the best available route. Industry 4.0 provides an immediate update on routes using big data analytics and AI technologies. Additionally, simulation activities can be performed to evaluate the time needed to resolve the issues for different obstacles faced during the transit (Cotrino et al., 2020). The simulation can be performed for malfunctioning transportation trucks, weather and traffic problems. Both supplier and buyer must have access to information which is made possible through cloud sharing. It helps to not only monitor the progress, but also assist with different tools to resolve the obstacles (Ivanov et al., 2016).

The transportation system can be fully automated using self-driving technologies and drones. Gunal et al., (2021) have discussed that companies like Amazon have started using these technologies. This can be achieved with the help of augmented realities (AR)

and Virtual realities (VR) technologies assisted by AI technology. All the deliveries can be integrated into one system, which is easily accessible to both supplier and buyer.

It implies that Industry 4.0 has been revolutionizing the delivery systems. The use of IoT and cloud networks helps gather and share real-time delivery data. However, the real benefits of this technology can be achieved if all stakeholders are committed to cooperating and sharing the information (Khurram et al., 2017). Thus, collaborative relationships are formed between stakeholders. Industry 4.0 can work best under a collaborative system.

Industry 4.0 has implemented automation within and outside the manufacturing sites by integrating the processes and system of the supply chain. Sourcing, operations, and delivery are now interlinked, making synchronization promising. A huge change in delivering physical goods is witnessed with the advent of Industry 4.0. Smart deliveries are now possible with the help of big data analysis tools to timely deliver products to users. The complexity in delivery time and products can be tackled with these analytical tools by bringing transparency (supply chain visibility), and integrity control (the right product to be delivered at the right time, place, cost, and in the right quantity and condition). Fleets can be used to re-balance the workload for market-coordinated delivery. These coordination schemes can consider unforeseen circumstances in the distribution network like extreme weather conditions (snow, fog, and rain). Industry 4.0 has made deliveries through different distribution networks easy and transparent (Cruz-Mejia, Marquez and Monsreal-Barrera, 2019).

2.6 Industry 4.0 in Supply Chain of the Dairy Sector

There is a huge waste of food and agricultural products every year making up one-third of the overall production. This rate of wastage varies across countries in terms of low, medium and high-income countries. In this regard, it has been observed that the losses of

food products in medium and low-income countries mainly occur at an early stage if supply chain while in high-income countries, it occurs at the consumption stage (Lamping et al., 2022), Post et al., (2021) have investigated that in low and middle-income countries, food losses are mainly attributed to financial restrictions, poor infrastructure, and lack of technical knowledge. On the other hand, in high-income countries food losses result from a lack of stakeholder coordination in the supply chain and also due to consumer behavior.

With time, food wastage has become a global issue creating social, environmental, and economic issues. Industry 4.0 technologies provide solutions to problems in the food supply chain. The dairy sector, especially the production of yogurt has limited application of intelligent systems, thus, the production is governed by automated cells that are supported by predefined recipes and values. Slob et al., (2021) have conducted a systematic review of 427 articles where application of Industry 4.0 technologies was observed for illness detection, quality, and milk production purposes. The results of the study provided that machine learning is used to detect milk quality disorders.

The zero-defect manufacturing (ZDM) approach has been increasingly used in production processes as an extension of the existing quality control technique of Six Sigma. In dairy production, poor-quality raw materials like milk, and yogurt lead to poor-quality product production. ZDM offers solutions to meet the quality requirements assisted with AI technologies and help meet the standards for quality control. The dairy sector uses Machine Vision (MV) technology in diverse ways. These technologies help in tracking and detection within the production line. These tracking and detection technologies include Kanade – Lucas – Tomasi (KLT) feature tracking which is quite helpful in reducing the number of scans used in the production process (Stachowicz & Umstatter, 2020).

Xie at al., (2021) have investigated that neutral network models and machine vision technologies are used for detection of bones in Salmon fish, the data expansion and region

segmentation are helpful to take 3120 different types of images. This is further supported by the data compression algorithm which helps to provide different quality images.

Fotios et al., (2020) have discussed that the concepts and principles of Industry 4.0 are applied to the supply chain in the agriculture sector. However, Liu et al., (2018) have provided that the concept of Industry 4.0 is tough, applied to the agriculture and dairy sectors, yet the digitalized production systems in these sectors are hardly connected. Thus, the digital interconnection in the agricultural sector is missing. Ghadge et al., (2020) have discussed that the potential to transfer the ideas and technologies of Industry 4.0 for agriculture farming goes far beyond Industry 4.0. It is interesting to note that Industry 4.0 is heading towards Industry 5.0 while researchers and scientists are naming agriculture and farming technologies as Agriculture 4.0. However, there is no pre-stage to Agriculture 4.0 like Agriculture 1.0, agriculture 2.0, or agriculture 3.0. The industry 5.0 technologies are likely to be more people and environment-oriented paying greater focus on sustainability of the environment and people, thus, it will also observe a rapid transition towards 5.0 technologies.

Electronic devices have been increasingly used in dairy farming, especially in the areas of milking, feeding, and resting. The use of computer systems in dairy farms started in the 1980s for controlling and monitoring of dairy herds. Gradually, the automation of processes started mainly because of the repetitive nature of work and increasing human workload. These mainly included automatic milking, bedding, feeding, and cleaning systems. Smart dairy farming using algorithms, sensors for animal identification, heat detection, milk quality observation, animal location, and calving detection started after the automation of dairy farming (Tzanidakis et al., 2021). One such breakthrough occurred in the 1990s when all individual steps for milking were automated from cow identification, under cleaning, milking flow controlling, removing milk clusters, and checking for quality

of milk. In this way, dairy farming presents a perfect ground for the implementation of Industry 4.0 technologies (Schillings et al., 2021).

Dairy farming provides suitable circumstances for networking mainly because of the fixed spatial structure. It also helps in acting control centers inside barns; however, due to a lack of uniform data as well as radio standards, there are difficulties in using sensors on cows. They can only be used for animal identification. Networking within the value chain presents another challenge. It is because the data networks are not powerful, especially in rural areas, thus, direct access to the data networks is often not possible (Lokhorst et al., 2019).

The products of dairy farming are usually not sold directly to consumers but to food producers, thus, there is a long supply chain in the dairy sector which is benefited by Industry 4.0. The food producers need homogenous quality and products over time. The product features also remain unchanged, thus, there is little flexibility in dairy farming. Krueger et al., (2020) have discussed the parameters that offer opportunities to implement Industry 4.0 In the dairy sector.

In this way, the dairy sector offers greater potential for the application and implementation of Industry 4.0 technologies. Most of the machines are placed in a fixed location and are connected visa cable. There may be WIFI connectivity for mobile machines. The processes in the sector are quite standardized and are repetitive in nature. Natural factors like weather have a lesser impact on the dairy sector than on agriculture. Furthermore, the tools and techniques of Industry 4.0 are also applicable to small-size dairy sets (Balhara et al., 2021).

Maffezzoli et al., (2022) have, however, argued that the digitalization and automation in the sector is quite high, yet the stakeholders are not largely interconnected. This serves as one of the biggest obstacles to the achievement of Industry 4.0 results. This

aspect needs greater action (Cabrera et al., 2020). The use of sensors, especially with cows, is helpful since a cow can tolerate the sensors attached to it body while it also stays for a longer time in barns. On the other hand, the sensors for other animals are attached to the building following the idea of IoT to connect a digital network of dairy farms. However, the application of these sensors is at a lower or initial stage in the world for the dairy sector (Goller et al., 2021). Also, the existing state of dairy supports little data connection and exchange which results in a lack of information transparency. The on-ground automation and learning are also negligible because the stakeholders are largely unable to connect output data with process data. The lack of interconnectedness and lower application of sensors restrict animal welfare and health protection. Thus, the stakeholders need greater knowledge and training to meet the needs for the application of Industry 4.0 (Raj et al., 2020).

2.7 Theoretical Framework

Supply chain management is perceived to be one of the most important components to enhance business competitiveness not only in international but also in domestic markets. A resilient supply chain helps business achieve new levels of competitive advantages and agility in business operations. This is closely linked with the resource-based view (RBV) theory in which the author, Barney (1991) has postulated that companies can develop their agility and greater adaptability to changing customer's needs using come competitive resources or processes. Dubey et al., (2018) have argued that a business should have heterogeneous resources, which are properly allocated and are non-imitable, putting the business ahead of its competitors. Walker et al., (2015) have discussed that the businesses, to be competitive and perform ahead of their rivals, are trying to enhance their collaboration and coordination with their partners both upstream and downstream i.e., throughout their supply chain. In this way, companies work together with their suppliers to timely meet the

needs of their customers and deliver the required products and services. In this way, the investment of resources to develop an agile supply chain and relationship with suppliers is crucial to place the business apart from its competitors (Shibin et al., 2017). This is where RBV plays its part. The current study has been aimed at enhancing the supply chain performance using key 4.0 technologies that can serve it to achieve resilience and make competitive performance. RBV has received increased importance in the literature on supply chain management arguing that sustainability in supply chain operations can bring competitive advantage with the use of the right type of resources and advanced technologies (Nishant et al., 2016).

2.8 Chapter Summary

This chapter has been aimed at providing a comprehensive literature review on the main research problem and its related concepts. In this regard, it started with elaborating on the principles of Industry 4.0 design while the importance of Industry 4.0 is also provided. The chapter has discussed the main industry 4.0 technologies including big data analysis, cloud, 3D printing, robotic systems and others. The application of Industry 4.0 technologies in different phases of the supply chain including planning, procurement, manufacturing, and inventory control have been discussed. Finally, the need and application of Industry 4.0 technologies in the dairy sector have been discussed. In this regard, it has been highlighted that the fourth industrial revolution is highly important for all sectors including the dairy sector with the help of the latest automation, robotics, sensors, and other technologies. However, the literature has highlighted globally, there is less application of these technologies in the dairy sector mainly because of lack of awareness and training. It requires investigating the problem in detail in the Indian and Saudi Arabia dairy sectors using the lenses of RBV theory. The next chapter has been focused on establishing the key methodology to undertake this research.

CHAPTER III:

METHODOLOGY

3.1 Overview of the Research Problem

Research problems are the area of concern, or it can be a particular problem to be resolved, or difficulty to be eliminated. In other words, it is also the research gap that is to be addressed. The current research has been aimed at investigating the important application of Industry 4.0 technologies in the dairy sector for the resilience of its supply chain in India and The Kingdom of Saudi Arabia. The Indian dairy sector produced 23% of the total world's milk, making it the highest milk provider in the world. From 2014 -15 to 2020-21, the milk production in the country increased at a compounded annual growth rate of 6.2%. It indicates the increased potential of the sector that can be further polished with the use of the latest technologies. With the application of cutting-edge technologies, data, and devices of the fourth revolution, the speed of processing and production can be enhanced to a greater extent (Bag et al., 2021). Verwijmeren, (2017) has discussed that the current era supply chain has become complex since it spans across countries and even continents, thus managing such a supply chain has become quite difficult. Thus, the application of Industry 4.0 to manage supply chain operations is desired and is the need of the hour. Owing to the increased importance of Industry 4.0 for the dairy sector, the current research has been focused on bridging the gap in literature while it will also make important practical implications. In this way, the study has been targeted to investigate in detail the workings of the supply chain of the dairy sector and the ways Industry 4.0 technologies have impacted it. For this purpose, an authentic research methodology is to be adopted that

can comprehensively investigate the impact of Industry 4.0 technologies in the supply chain of the dairy sector of India and Saudi Arabia.

3.2 Operationalization of Theoretical Constructs

By operationalization, it means converting the research variables into measurable observations. Though, certain concepts or variables can easily be measured like the height of someone, the age of people, and others. To measure such variables, research has formulated certain ways and methods which help researchers to quantify them and measure them. With the help of the operationalization of key variables, the researchers can effectively collect data.

The current study is qualitative in nature; thus, a quantification of the study variables is not needed. However, for qualitative analysis, they have been operationalized. In this regard, the main variables of the study and their operationalization of study purpose include the following:

3.2.1 Industry 4.0 Technologies

Industry 4.0 consists of the fourth industrial revolution and the related technologies. It helps in collecting as well as reviewing real-time information between different points in a supply chain. In this way, they help to enhance productivity, efficiency, and speed of information sharing, and improve *improve the overall supply chain processes. These technologies mainly consist of big data, artificial intelligence, big data, IoT networks, automation, and robotics. These technologies are integrated into manufacturing as well as other processes to help improve productivity, reduce costs, and improve overall performance. For this study, Industry 4.0 technologies included all sets of technologies used in the supply chain of dairy farms to improve resilience.

3.2.2 Supply Chain

A supply chain consists of different sequences or processes that are helpful for the improvement of distribution and production functions. The supply chain is also defined as the network of people, resources, processes, and technologies used to create or distribute a product. In the context of this research, the supply chain has been studied in the context of dairy farms and processing plants for the supply of their products. In this regard, industry 4.0 technologies have been included to investigate how they affect the resilience of the supply chain mechanism of dairy farms and process plants in India and Kingdom of Saudi Arabia.

3.3 Research Purpose and Questions

This research has been aimed at examining different technologies of the fourth industrial revolution that can be used and benefit the dairy sector. The main purpose is to get a deeper understanding of the modern technologies of Industry 4.0 and evaluate their impact on the resilience of the supply chain of the dairy sector.

The main research question of this research includes the following:

How does Industry 4.0 impact the resilience of supply chain management of the dairy sector in India and Kingdom of Saudi Arabia?

To address this research question, the following sub-questions have been formulated:

- How has Industry 4.0 affected the supply chain of the dairy sector?
- How can the dairy sector bring resilience into its supply chain using Industry 4.0?

To address the aim and research questions of this study, the following research methodology has been used:

3.4 Research Design

The research design is aimed at answering research questions. It establishes how the research questions can be effectively answered. It should be well planned since a good research design ensures the achievement of research objectives effectively. Thus, the very first step in formulating the research design is to consider the research aim and objectives i.e. how the research objectives are to be approached (Creswell, 2011).

3.4.1.1 Qualitative Research

Qualitative research is directed to collect and analyze non-numerical data to get an enhanced understanding of the research problem. With this type of research, an in-depth understanding of the research problem can be made which helps generate new ideas. Qualitative research is useful in a way that it does not rigidly decide the ideas and pattern of research beforehand while the data collection is also made in a natural setting which helps in the generation of new ideas (Smith, 2015). Qualitative research design normally answers the particular questions starting with 'How' and 'What'. This type of research is largely conducted in social sciences since qualitative designs are always not helpful in answering the research questions. Qualitative research studies can be conducted using observations, survey, focus groups, interviews, and using secondary research methods. The common criticism associated with qualitative research design is that they are normally subjective in nature which can affect the results of study while the data collection in the qualitative approach is also labor intensive (Robinson, 2016).

3.4.1.2 Quantitative Research

In comparison, a quantitative research design is based on numbers. It collects data numerically while the analysis is also carried out in the form of numbers so that measurable results can be obtained. In other words, it focuses on quantifying the information. It follows a structured approach to conduct research. In this regard, the research questions of

quantitative research are usually measurable and objective in nature. Furthermore, the variables of quantitative research are also measurable (Schwab, 2013). They can be dependent and independent variables, and the research is conducted to investigate the association or relationship between variables. Data collection in this type of research can be made using a variety of ways including experiments, surveys, quantitative observations, or also using quantitative secondary data. To ensure the consistency of results, standardized instruments like questionnaires or other scales are used (Bryman & Bell, 2015). Finally, the analysis of data for quantitative research is also carried out statistically. Quantitative research design is used in various disciplines including social sciences, market research, economics, and psychology.

3.4.1.3 Selection of Research Type for Study

Based on the aim and objectives of this study, a qualitative research type has been preferred over a quantitative study. It is because the application of Industry 4.0 technologies in the field of dairy sector supply chain is relatively new, requiring a further generation of new ideas and thoughts which possible under qualitative research design.

3.4.2 Research Philosophy

The next step is to consider the research philosophy where research philosophy is the belief about the methods of data collection and analysis for this research. The purpose is to convert things from believed to known. There are a variety of research philosophies mainly, they are categorized into positivism and interpretivism (Creswell, 2013).

3.4.2.1 Positivism

A positivist philosophy is based upon the fact that the knowledge must be true and positive which means a fact should be based on a logical reason that is derived using sensory experiences i.e. without making any interference with the studies phenomenon. It also implies that the observations should be repeatable (Ross, 2014). It is helpful to predict

future relationships “Positivism has a long and rich historical tradition. It is so embedded in our society that knowledge claims not grounded in positivist thought are simply dismissed as scientific and therefore invalid” (Hirschheim, 1985, p.33). It mainly focuses on reason and the measurement of facts; thus, it holds that anything that is not measurable may not be known in a certain and definite way. Thus, it rejects knowledge based on intuition, religious faith, and introspection. This approach is widely used in pure sciences. Thus, there has been greater debate about the suitability of this type of philosophy for social sciences. However, with time, various phenomena that were considered unmeasurable, have been categorized to be measurable with the changing research paradigms (Bryman & Bell, 2015).

3.4.2.2 Interpretivism

Comparatively, interpretivism implies that the facts may not be all true or positive rather they may be driven by faith, intuition, introspection, and other such methods. It is also known as anti-positivism and is based on the idea that the interpretation of reality is possible. The researchers under interpretivism hold that reality can only be understood completely and comprehensively through intervention and subjective interpretation (Schwab, 2013). In this way, the philosophy holds that reality can be known only by the experience of someone, thus it may vary from person to person. This philosophy normally uses observations or questioning to generate deep insights into research phenomena. In this way, it has a close association with qualitative data collection methodology. This philosophy is mainly used in social sciences (Bryman & Bell, 2015).

3.4.2.3 Selection of Research Philosophy

The current research has been proposed to investigate the application of Industry 4.0 in supply chain management of the dairy sector for possible benefits and challenges, thus, it may vary from dairy to dairy and from stakeholder to stakeholder. Thus, an

interpretivism philosophy is better suited to this study. In this way, the current research has used interpretivism philosophy to base its beliefs about data collection and analysis.

3.4.3 Research Approach

The research approach is a plan which consists of different steps, for the collection and analysis of data and its interpretation (Bryman & Bell, 2015). Broadly, research approaches can be inductive or deductive, which are suitable in different contexts and conditions as discussed in the following sections.

3.4.3.1 Inductive Research Approach

An inductive approach is aimed at the development of a new theory. This approach works from the collection of data and its analysis by identification of particular themes from data. It provides flexibility to the researcher to move research in any direction within the scope of research. This approach is very helpful in analyzing data for new ideas and opportunities and improving understanding of even complex areas of research. It is conducted in three main steps including a collection of data, recognition of patterns, and theory development (Creswell, 2013). In this way, it moves from specific facts to more generalized findings. In an informal sense, this approach is also known as the 'bottom-up' approach. However, a degree of uncertainty lies in this approach. The main advantages of using the inductive approach are that it helps the generation of new ideas and therefore establishing new theories which helps provide rich and detailed data. This approach is more suitable in qualitative research studies which may also result in the discovery of unexpected results. Studying complex social phenomena can also be studied comprehensively using an inductive approach. However, this approach may result in biased results, and it can also be resource-intensive or time-consuming (Gray, 2014).

3.4.3.2 Deductive Research Approach

A deductive approach is aimed at the examination of an existing theory. It draws inferences from facts. Deductive research starts where inductive research ends in a way that tests the hypothesis derived from inductive research (Creswell, 2011). This approach works from general to specific findings and is also known as the top-down approach since conclusions are logically drawn from facts. This approach is more suitable for quantitative studies, and it also allows to control extraneous variables. Moreover, the research protocols for this research are also structured and clear. However, this approach requires greater prior knowledge and experience, but it also limits the exploration for new ideas and thoughts. The results of deductive research can also be affected by measurement errors and biased research assumptions while the important outliers can also be ignored under this research approach (Bryman, 2016).

3.4.3.3 Selection of Research Approach for Study

It has been observed that not all research studies fall into either deductive or inductive approaches since there can be theory building and theory testing to be done in the same study. Thus, in such a situation both approaches are combined to conduct the study. Looking at both categories, this research has been proposed to be based on an inductive research approach since it is one of the pioneer research projects in the field of industry 4.0 and the supply chain management of the dairy sector, thus, it will help to deeply investigate the main areas of focus under the broad research problem area. Inductive research for this study will also serve to examine the research problem in a detailed and flexible way (Creswell, 2014).

3.4.4 Research Methods

Research methods are the means through which research questions can be answered in the best manner. Broadly, the research methods can be observational or experimental. In

observational designs, the study is conducted without direct manipulation of variables and the analysis is conducted by collecting the data. On the other hand, experimental research methods include direct manipulation of collected observations. The observation studies can be case study research, cross-sectional, and longitudinal (Gray, 2014).

3.4.4.1 Case Study

A case study research design includes researching a specific case which can be either a person, an organization, or any other entity in the real world to get a comprehensive understanding of it. Under this type of research, either complete aspects of a particular research phenomenon are investigated, or certain specific aspects are focused. By investigating a single case study, the findings can be generalized to a larger group of the population. However, critics hold that the results of case study research are often subjective and hence cannot be generalized (Bryman & Bell, 2015).

3.4.4.2 Cross-Sectional Research

Cross-sectional research is a type of study that is observational in nature. In this type of study, the exposure of the respondents to the study and the outcome are measured at the same time. The participants of the research are selected based on certain inclusion and exclusion criteria. After the selection of respondents, their exposure and outcomes follow at the same time. Cross-sectional research can be conducted quickly and is also relatively inexpensive. The outcome of cross-sectional research can be used for cohort study. However, being a one-time measurement of respondents' exposure and the outcome, the causal relationship may not be effectively measured using cross-sectional research designs (Bryman, 2016).

3.4.4.3 Longitudinal

In a longitudinal research design, the participants of the study are questioned more than one time in contrast to cross-sectional where information is collected only once.

Longitudinal research designs are used to measure the changes in variables over time. These studies are preferred over cross-sectional designs when the changes in variables are to be measured over time or in response to the happening of certain phenomena. The most important feature of longitudinal research designs is that they help to measure the same factors that affect another variable while the inferences about the causal relationship are made perfectly. In this way, they give strong reasons to believe the changes in one variable are caused by another variable (Saunders et al., 2019).

3.4.4.4 Experimental

An experimental research design is a type of scientific study that is undertaken with two types of variables where the first type of variable is known as consonant which is used to evaluate the changes in other variables. These research designs are mainly used for quantitative research. An experimental research design is used to evaluate the cause-and-effect relationship or the importance of cause and effect. These experimental research designs can be of three main types pre-experimental, truly experimental, and quasi-experimental research design. In pre-experimental research designs, a group of variables is often kept under observation to evaluate the relationship between cause and effect (Bryman & Bell, 2015). This is being done to understand whether further investigation is needed or not. In true experimental research designs the investigation is made to evaluate the hypotheses for their possible acceptance or rejection. For this type of study, three main conditions should be satisfied. In this regard, the first condition or requirement is that there should be a control variable that is not subject to any changes, there needs to be a variable that can be affected by the researcher while the distribution should be random. Finally, the quasi-experimental research designs are similar to true experimental, but the difference is that the population of the study is not randomly distributed (Saunders et al., 2019).

3.4.4.5 Selected Research Method for Study

The current study has been based on evaluating the role of industry 4.0 technologies in the supply chain of dairy farms using qualitative research type. Thus, experimental research methods are not applicable. Secondly, the research has also been targeted at various dairy farms in India and Saudi Arabia, thus, the case study research design is also not useful here. It implies the application of cross-sectional research design since the exposure of respondents and the evaluation of outcomes have been made at the same time. The cross-sectional research designs are quite common in research of social sciences, and they are helpful to quickly investigate the research problem.

This section has discussed in detail the research design of this study. In this regard, different types of research designs have been discussed and the selected research designs have been mentioned with supporting justification. In this regard, first of all, the type of research study has been discussed where qualitative research study has been selected. The approach to conduct this research has been inductive, and the selected research philosophy is interpretivism while the research has used cross-sectional research methods. Quantitative research design is based purely on a deductive research approach while a qualitative design can be both deductive and inductive, yet it is closer to an inductive approach (Creswell & Poth, 2017). Thus, the inductive research design has been used in the current study. Furthermore, the research is based on an interpretive research philosophy and inductive research design, thus, a qualitative research design is more suitable in this situation. It has helped to investigate the research problem in a flexible and detailed manner. Additionally, the respondents' exposure and outcome have been measured at the same time, thus, the cross-sectional research design fits within this research.

3.4.5 Summary Research Design

This section has discussed in detail the research design of this study. In this regard, different types of research designs have been discussed and the selected research designs have been mentioned with supporting justification. In this regard, first of all, the type of research study has been discussed where qualitative research study has been selected. The approach to conduct this research has been inductive, and the selected research philosophy is interpretivism while the research has used cross-sectional research methods. Quantitative research design is based purely on a deductive research approach while a qualitative design can be both deductive and inductive, yet it is closer to an inductive approach (Creswell & Poth, 2017). Thus, the inductive research design has been used in the current study. Furthermore, the research is based on an interpretive research philosophy and inductive research design, thus, a qualitative research design is more suitable in this situation. It has helped to investigate the research problem in a flexible and detailed manner. Additionally, the respondents' exposure and outcome have been measured at the same time, thus, the cross-sectional research design fits within this research.

3.5 Population and Sample

Population means overall observations that can serve to provide data to study the research problem. It is also known as the target population that shares the common characteristics. The population of any research can be quite large or unlimited, may be geographically dispersed, or may be difficult to contact so it may not be feasible to investigate all units of the population for data collection purposes. In such a situation, the total population can be divided into different segments, and a representative part of the entire population is selected for data collection. The findings of the research are then generalized to the overall population (Saunders et al., 2012). The population of study is defined keeping in view the research objectives. The part of the population that is selected

to gather data is known as the sample of study. It serves as the subset of the population that is studied to understand the characteristics of the overall population (Saunders et al., 2019).

For this research, the population consists of all the workers working at dairy farms and processing plants in India and Saudi Arabia. Thus, it was not feasible to collect data from all proprietors working at dairy farms and plants in India and Saudi Arabia. In such a situation, a representative part has been selected from the entire population to collect data for this study. This representative part is known as a sample. The inclusion criteria for selecting the sample were first of all based on the size of dairy farms and processing plants which need to be larger dairy companies since the small dairy farms and plants potentially lack the opportunity to implement industry 4.0 technologies due to a lack of resources and scale. Secondly, the study has also included only those farms and plants where the participants were willing to provide information for the study.

3.6 Participant Selection

3.6.1 Sample Size and Sampling Technique

As discussed in the above section, this research will be focused on selecting a representative part of the population known as a sample to collect data. The size of the sample implies the number of respondents to be included for data collection. In large-scale research, more realistic costs and time frames are available and hence the characteristics of the population are studied more comprehensively.

In this regard, this study has proposed to select a sample size of 50 respondents from different dairy companies from both countries. The inclusion criteria for selecting any dairy farm and processing plant for data collection is that the dairy companies with substantial size have been selected. It is because larger dairy companies have the potential to implement industrial technologies.

The selection of a sample from a large group of the population is called sampling. The sample selection for any study must be representative of the overall population so that representative results can be obtained. There are several techniques available to select a sample from a population which are broadly categorized into two main types of probability sampling and non-probability sampling.

3.6.1.1 Probability Sampling

Probability sampling is a technique that provides equal opportunity for all units of population to be selected. The main feature of probability sampling is that every unit of the population should have equal and known opportunities for being selected. A probability sampling technique contains various other sampling techniques that mainly include simple random sampling, stratified random sampling, cluster sampling, and systematic sampling techniques. In this regard, simple random sampling involves the selection of a sample from a large population without any bias. The overall population is assessed and arranged and then samples are drawn from the population in a way that each unit of population contains equal chances of selection. This is the most basic and straightforward form of sampling. The next category is stratified random sampling. In this method, the overall population is divided into different groups known as strata (Schwab, 2013). These groups are working based on some common characteristics. After forming the strata, sample selection is made from every group using a simple random sampling technique. The main purpose of this type of sampling technique is that a representative part of each heterogeneous group is made from the population (Creswell, 2014). Additionally, there is the cluster sampling technique which is another type of probability sampling and is closely related to the stratified sampling technique. In a cluster sampling the population may be dispersed over various geographies and groups are formed in different geographies. For data collection, the sample is selected from each cluster using a simple random sampling technique. The

main difference between cluster sampling and stratified sampling is that in cluster sampling the groups of clusters are also selected using a random sampling technique while in stratified sampling the strata are selected to make a representation of all units of population (Creswell, 2011). The next type is systematic sampling technique. In this sampling technique, a starting point is selected and then every nth unit is selected based on decided protocols. In this way, probability sampling helps to select quite a representative sample of the overall population (Saunders et al., 2012).

3.6.1.2 Non-Probability Sampling

Non-probability sampling is a technique where sample selection is based on some other conditions rather than providing equal opportunity for selection to every unit of the population (Creswell & Poth, 2017). Thus, it does not offer random ways for sample selection. In this way, it does not focus on all units of the population. Researchers argue that sometimes, probability sampling is not feasible, and the selection of non-probability sampling provides more helpful results. The sampling under this technique is often done based on subjective judgment or sheer convenience of participants or researchers. It helps in quickly drawing samples without much cost. Like probability sampling, the non-probability sampling technique also contains several sub-categories which mainly include convenience sampling, quota sampling, purposive sampling, and quota sampling technique (Creswell, 2014). In this regard, convenience sampling is a technique where population units are selected based on the convenience of the researcher and of respondents. This is one of the most common techniques of non-probability sampling techniques used in social sciences. Instead of assigning equal chances of selection to all units of the population, the researcher moves to collect data based on his/her convenience in approaching respondents and the respondents' willingness to respond (Bryman & Bell, 2015). Due to this, it is also known as availability sampling, opportunity sampling, grab sampling, and accidental

sampling. This technique uses lower rules to collect data while the data collection process is also time and cost-efficient. The next technique is quota sampling where the selection of the sample is based on a non-randomized stratified version of sampling. Under this technique, the population is divided into different groups known as quotas. However, the selection of each quota is made using non-randomized ways based on certain proportions. After quotas are selected, the sample is drawn from each quota (Creswell, 2014). The other technique of non-probability sampling is snowball sampling where a selection of the sample is made in a way that every selected respondent refers to the next person who can provide the required information. This technique is normally used when the target population of the study may contain rare characteristics and is difficult to find. Another technique of non-random sampling is purposive sampling in which the selection of the sample is made based on certain key characteristics of the respondents (Bryman & Bell, 2015). This type of sampling technique is used mainly in qualitative research where a deeper understanding of the research phenomenon is to be made. All these are types of non-probability sampling where sample selection is made without granting equal chances of selection to each unit of the population while each type of sampling is suitable for different types of research.

3.6.1.3 Selected Sampling Technique of this Research

As the total population for this research is numerous and it is not feasible to list down all the units of the population, thus, probability sampling is not useful in this case, rather non-probability sampling is proposed to be used for this research. The sub-category of non-probability sampling which is preferred to be used for this research is convenience sampling since those units of the population have been selected which have been conveniently approached and were willing to respond to the study.

3.7 Instrumentation

Research instruments are a tool used to collect and measure data for research purposes. Different types of research instruments can be used in research depending on the objectives of the research. They may consist of interviews, questionnaires, simple tests, or other checklists. A good research instrument helps collect the research data in a way that is relevant to the research questions.

The current research is qualitative in nature where data collection has been done using different interview questions. Broadly, interview questions can be of different types including structured interviews or unstructured interviews. In this regard, structured interviews contain already defined questions that must be asked of respondents. On the other hand, unstructured interviews are those where a defined set of questions is not listed rather the questions can be asked spontaneously in any direction within the scope of the study. For existing research, structured interview questions have been asked so that the defined research objectives can be accomplished in a better way. In this regard, a total of 10 relevant major questions have been asked from respondents and a list of such interview questions has been provided in the appendix section.

3.8 Data Collection Procedures

3.8.1 Methods of Data Collection

Methods of data collection can be either primary or secondary. Primary data collection is a method where data collection is made from first-hand sources while secondary data collection includes the second-hand collection of data. Primary data collection is considered to be a very efficient, reliable, and effective data collection source where the data collection can meet the demands of research more authentically. However, this source of data collection can be very time-consuming and also may incur higher costs

if the respondents are hard to contact or the sources of data collection are dispersed across geographies (Creswell, 2013).

Comparatively, secondary data collection is considered a very quick and cost-efficient way of data collection. Secondary data collection involves collecting data from second-hand sources where data collection is already made and usually sorted based on prior needs. The researcher may consult these secondary sources to acquire data meeting the needs of his research. However, secondary data may not fully meet the needs of research and can be unreliable in some cases. This type of data collection is made when it is difficult to make primary data collection or to avoid the constraints of time and costs.

3.8.2 Selected Methods of Data Collection for Research

This research is qualitative in nature using an inductive research approach that invites to research the problem area in detail. For this purpose, the common methods used for data collection include surveys, observations, and interviews. This study will use a primary data collection methodology where the data collection will be made mainly through interviews. In this regard, a sample size of 50 respondents will be selected from different dairy companies and will be interviewed using open-ended questions. The technique to select sample respondents has been snowball sampling as discussed earlier where each respondent provided a reference to contact the next respondents to obtain relevant information for study purposes.

3.9 Data Analysis

There are various approaches available to analyze qualitative data which may include: content analysis, thematic analysis, textual analysis, and discourse analysis. In this regard, a content analysis is used to extract common words, ideas, and phrases from within the data. With the help of content analysis, the researchers can evaluate different words or themes. Based on it, inferences can be made to the overall research. The data to conduct

content analysis can be collected through open-ended questions, interviews, observations, notes, and similar other forms of text. In this way, content analysis is the systematic and objective analysis of data to identify its characteristics (Creswell, 2011). This analysis is used to evaluate the attitude of people towards certain research phenomena or the patterns highlighted within communication. Content analysis can be conceptual or relational based on the research requirements. It is also known as textual analysis. This analysis is used to evaluate the structure, content, and design of texts within the data. It helps to evaluate any form of text including pictures, videos, and audio (Creswell, 2014).

Thematic analysis, on the other hand, identifies the common patterns of themes within the data in the qualitative data. It is a flexible technique that evaluates the pattern or theme of qualitative data. Thematic analysis is very useful for larger datasets. With this, inductive development codes are made possible. From these codes, first-order themes and second-order themes are often extracted. However, the greater flexibility provided by thematic analysis often makes it hard for novice researchers to understand which data aspects need to be focused on more (Bryman & Bell, 2015).

Finally, discourse analysis is used to evaluate how the language is used within specific contexts in data so that social meanings can be created. It can also be defined as listening to the narrative of people related to a particular situation. It is both a qualitative as well as interpretive way of analyzing the data. However, it is very important to keep in mind the actual context of the study and the respondents while evaluating the qualitative data using discourse analysis. With time, discourse analysis has become very popular within the disciplines of social and management sciences (Saunders et al., 2012).

3.9.1 Selected Data Analysis Technique for Research

After the collection of data, it has been analyzed using the appropriate data analysis methods. In this regard, the research is qualitative in nature and the data collection has been

collected using interviews, thus, the appropriate methodology to analyze the data for this research has been 'thematic analysis'. For this, the interviews of respondents were organized in a way that the appropriate themes were extracted from the data, and discussion was made accordingly. In this regard, to conduct thematic analysis, first of all, the collected data was evaluated and appropriate codes were identified which in turn were arranged to extract the relevant themes from within the data. Thus, themes in different orders i.e. first order and second order have been extracted. The overall analysis has helped to evaluate the results of this study in quite a greater detail.

3.10 Research Design Limitations

This research has selected the most suitable research design to achieve the aim and objectives of the study. However, there have been certain limitations faced while implementing the selected research design. These limitations have been mainly discussed as under:

First of all, the study has focused only on large dairy companies while small companies were excluded since they lack the potential to implement the latest fourth-generation technologies. However, the exclusion of smaller farms and process plants may limit the generalizability of results to only large dairy farms and processing plants.

The study has included primary data collection using qualitative methodology where the results have been obtained flexibly. These results, though, have been supported using relevant discussion collected from past research, yet the derived results from this study are mainly based on primary data collection. Moreover, the analysis of data using thematic analysis, though, has provided a rich understanding of the interviews conducted, however, the measurability of research results has not been possible.

3.11 Research Ethics

Research ethics includes ethical conduct while planning conducting, and finally reporting the research results. In this way, ethics are the pillar of good research, thus, they must be followed while conducting any research study. Ethical guidelines help observe that the researchers have shown responsible conduct while undertaking their study. Ethical principles are numerous depending upon the type of research study being undertaken. They mainly include honesty, objectivity, carefulness, openness, respect for the protection of intellectual property, responsible mentoring, responsible publication, social responsibility, non-discrimination, legality, competence, protection of human subjects, animal care, and contribution of research to resolve practical real-world problems (Bryman & Bell, 2015).

There are various reasons why ethical guidelines must be followed in every research. First of all, adhering to ethics helps to promote the aim of the study. For instance, avoidance of misrepresentation or falsification helps in minimizing the research error. Secondly, ethical values in research help to promote collaboration and coordination which is critical in conducting valid research. Different ethical principles including patent policies, copyrights, and other data protection policies are quite helpful for acknowledging the work of others and thus, enhance the cooperation among the concerned stakeholders. Thirdly, the ethical guidelines are also important because they make the researchers accountable to the public. In this regard, the ethical norms require ensuring the protection of animals and people and avoiding misconduct and conflict of interest. Fourthly, ethical research is also important to secure public interest and cooperation. People would like to fund the research which is helpful to provide them with authentic, and valid results. Additionally, adhering to ethical guidelines is also important to ensure the fulfillment of other moral and social norms like social responsibility, protection of human rights, and public health and safety (Creswell, 2014).

For current research, the applicable ethical principles included the anonymity of study respondents and research to bridge the gap in the literature and provide practical implications for the dairy sector. To ensure the anonymity of research respondents, no personal information of respondents or their farms has been obtained or disclosed. Secondly, the results of the study have also provided important practical contributions for dairy farms in the era of dynamic technologically advanced supply chains. The overall findings have been drawn up adhering to relevant principles of integrity and authenticity. Thus, the ethical principles have been followed for this research.

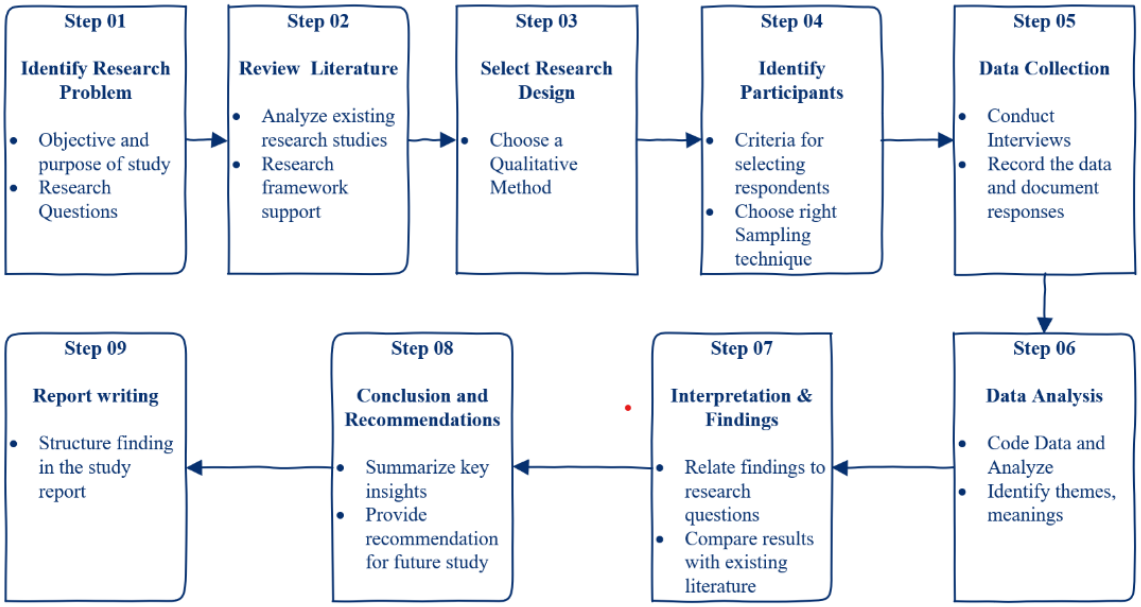

Figure 3.1
Flow Chart Illustrating the Key Steps and Methodologies in the Research Process

3.12 Conclusion

This chapter has provided rich details of different available methodologies to conduct research and the selection of the most appropriate methodology for this study. In this regard, the chapter has provided an overview of the research problem to be investigated

and the operationalization of key terms. The study has discussed in detail the research designs. The selected research design has been cross-sectional with an inductive approach and qualitative methods to be conducted using interpretivism philosophy. Moving forward, the population of the study consisted of all dairy companies in Republic of India and Kingdom of Saudi Arabia, however, due to the lack of feasibility to collect data from all dairy companies, a representative sample of 20 managers from different dairy companies were selected using a snowball sampling technique with certain inclusion and exclusion criteria. The participants were approached based on their willingness to provide a response and their knowledge about Industry 4.0 technologies. The respondents were interviewed using semi-structured interview questions to get their responses and were further analyzed using the thematic analysis technique. The ethics of research and limitations of the study have also been discussed. The next chapter contains detailed results obtained through thematic analysis of collected data.

CHAPTER IV:

RESULTS

4.1 Introduction

The dissertation has been aimed at analyzing the impact of Industry 4.0 in the supply chain management of the dairy sector. For this purpose, 19 interviews have been conducted within the dairy sector of Saudi Arabia and India which helped to examine the key research objectives and research questions of this study. The chapter has provided a detailed qualitative analysis of the interviews using coding and thematic analysis. For this purpose, a parallel comparison of both the Saudi Arabia and Indian dairy companies has been made in the results section. The overall analysis has been presented as under:

4.2 Overview of Participants' Information

The study has been focused on analyzing and comparing the implementation of Industry 4.0 technologies in the supply chain management of the dairy sector. For this purpose, the large dairy industries have been approached to collect data. Large dairy industries have been selected for this research because they are more inclined to implement Industry 4.0 and are eager to make improvements in the overall results. Moreover, they have larger supply chains where the real benefits of Industry 4.0 can be achieved. The following table provide information about the selected dairies for this study:

Table 4.1
Interview Respondents

Respondents' Summary	**KSA**	**India**
IT Manager	3	3
Operations Manager	0	1
Engineering Manager	1	0
Project Manager	0	1
Supply Chain Manager	1	1

Automation Manager	3	3
Farm Manager	1	1
Total number of respondents	**9**	**10**

Table 4.1 provides the details of the respondents of this study.

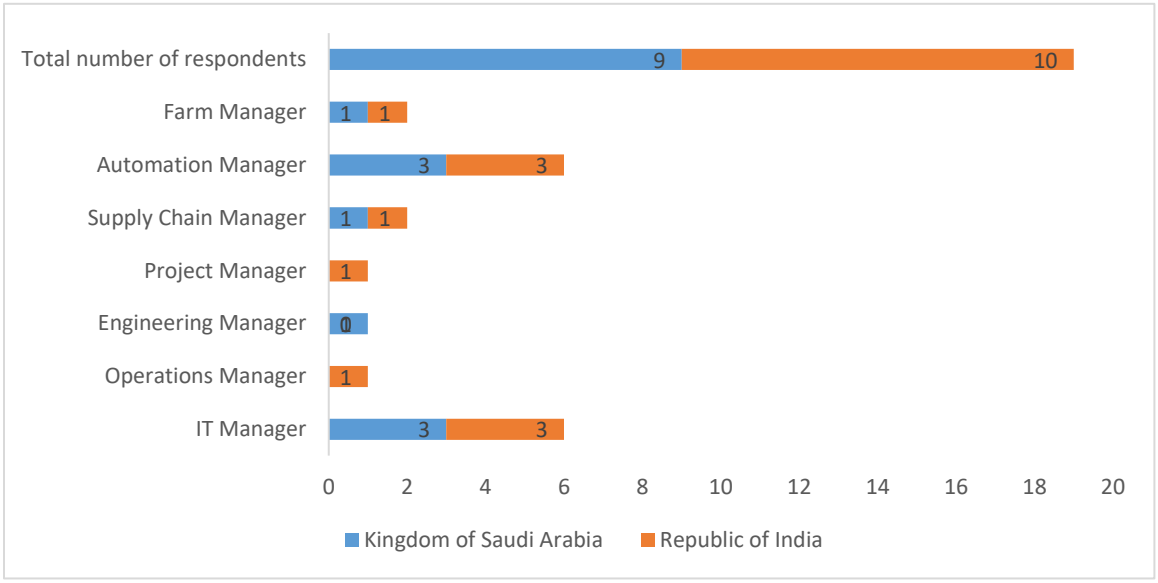

Figure 4.1
Visual Summary of Respondents

After the initial survey conducted with 50 targeted respondents, it has been selected a total of 19 respondents, out of that 9 respondents are from KSA, and 10 respondents are from India have been interviewed. In this regard, the sample respondents largely consist of IT Managers and Automation Managers, since the questions are related to the adoption of I4.0 technologies at farms, process plants, and supply chain. Moreover, a few farm, supply chain, Engineering, Projects and Operations managers were also selected to be interviewed to collect information about different operations of the business. There are a total of 10 main questions selected for the main interview. The justification for the selection of a greater number of IT Managers and Automation Managers for study purposes is mainly because the interview questions are related to the application of the latest technologies that

are more relevant to IT and Automation personnel. The following section provides detail of different themes extracted from the responses of the interviews.

Table 4.2
Participants' Coding Table

Participants Coding Table						
Sl. No.	Code	Participant Designation	Experience (years)	Company	Company size	Country
1	KSA1	IT Manager	14	Company 01	Large	Kingdom of Saudi Arabia
2	KSA2	IT Manager	12	Company 02	Large	Kingdom of Saudi Arabia
3	KSA3	IT Manager	16	Company 03	Large	Kingdom of Saudi Arabia
4	KSA4	Automation Manager	10	Company 01	Large	Kingdom of Saudi Arabia
5	KSA5	Automation Manager	12	Company 04	Large	Kingdom of Saudi Arabia
6	KSA6	Automation Manager	15	Company 05	Large	Kingdom of Saudi Arabia
7	KSA7	Engineering Manager	22	Company 02	Large	Kingdom of Saudi Arabia
8	KSA8	Supply Chain Manager	30	Company 01	Large	Kingdom of Saudi Arabia
9	KSA9	Farming Manager	27	Company 01	Large	Kingdom of Saudi Arabia

10	I1	IT Manager	13	Company 01	Large	Republic of India
11	I2	IT Manager	19	Company 02	Large	Republic of India
12	I3	IT Manager	11	Company 03	Large	Republic of India
13	I4	Automation Manager	14	Company 01	Large	Republic of India
14	I5	Automation Manager	17	Company 04	Large	Republic of India
15	I6	Automation Manager	12	Company 05	Large	Republic of India
16	I7	Operations Manager	21	Company 06	Medium	Republic of India
17	I8	Project Manager	20	Company 07	Large	Republic of India
18	I9	Supply Chain Manager	24	Company 07	Medium	Republic of India
19	I10	Farming Manager	26	Company 01	Large	Republic of India

4.3 Analysis of Interviews

The study used coding and thematic analysis for the analysis of collected qualitative information. These themes and codes have been generated using the pattern and structures of words. The study participants were contacted personally for the information and some

through references, but their voluntary willingness was taken to collect data. The interview questions were sent to the participants before the start of the interviews so that they could be well prepared for the interview questions. The interviews were conducted in formal settings and the anonymity of study participants was assured. After conducting the interviews and analyzing them, the following major themes with sub-themes emerged which have been analyzed for the achievement of research objectives:

Table 4.3
Research Themes and Subthemes

Sl. No.	Main Theme	Subthemes
1	Industry 4.0 Technologies in the Supply Chain of the Dairy Sector	1. Big Data Analytics 2. Internet of Things (IoT) & RFID 3. Robotics 4. Artificial Intelligence and Machine Learning 5. Cloud Computing 6. Augmented Reality, Virtual Reality, Simulation, and Digital Twins 7. Cyber Physical Systems and Cyber Security 8. Additive Manufacturing (3D Printing)
2	Benefits of Implementing Industry 4.0 in the Supply Chain of the Dairy Sector	1. Efficiency Enhancement 2. Improved Decision Making 3. Automation 4. Logistics Optimization 5. Increased Visibility, Traceability, and Sustainability
3	Challenges of Implementing Industry 4.0 in the Supply Chain of Dairy Sector	1. Lack of Skilled Human Resources 2. Incompatible Infrastructure 3. Lack of Resources 4. Data Security and Privacy Concerns
4	Resilience brought by Industry 4.0	1. Integrative Environment 2. Smooth Information Sharing 3. Timely Response to Disruptions 4. Real-Time Monitoring

Table 4.3 summarizes the main information about the major and subthemes of the study. The interviewees were asked to respond concerning their dairy plant or farm and

their experience of Industry 4.0 technologies if it is implemented within their supply chain operations. In this regard, the response of study participants led to the creating of the following major themes:

- Industry 4.0 Technologies in the Supply Chain of Dairy Sector
- Benefits of Implementing Industry 4.0 in the Supply Chain of the Dairy Sector
- Challenges of Implementing Industry 4.0 in the Supply Chain of the Dairy Sector
- Resilience brought by Industry 4.0

Details of these themes and their related sub-themes have been provided as under:

4.3.1 Theme 1: Industry 4.0 Technologies in the Supply Chain of the Dairy Sector

Theme 1 is related to the application of different types of I4.0 technologies in the dairy sector in both the Kingdom of Saudi Arabia (KSA) and India. In this regard, different questions were asked related to different I4.0 technologies in the dairy sector. A list of such technologies was asked as the relevant areas where they are being used in dairy farms, processing plants, and in the supply chain. The following table summarizes the key findings with evidence of support cases. The support cases consist of the respondents with unique IDs assigned to them from 1 to 9 for KSA respondents and 1 to 10 for India respondents separately.

Table 4.4
Theme 1: Subthemes and Related Cases

Sl. No.	Sub Themes	Related cases from Saudi Arabia	Related cases from India	Total no. of cases supported
1	Big Data Analytics	KSA1, KSA2, KSA3, KSA4, KSA5	I1, I2, I4, I6, I7, I9, I10	12
2	Internet of Things (IoT) & RFID	KSA1, KSA2, KSA3, KSA4, KSA5, KSA6, KSA7, KSA8, KSA9	I1, I2, I3, I4, I5, I6, I7, I8, I9, I10	19

3	Robotics	KSA2, KSA3, KSA4, KSA5, KSA6, KSA7, KSA9	I1, I2, I4, I5	11
4	Artificial Intelligence and Machine Learning	KSA1, KSA2, KSA4, KSA5, KSA8,	I1, I2, I3, I4, I5	10
5	Cloud Computing	KSA1, KSA2, KSA5, KSA8, KSA9	I1, I2, I3, I4, I5, I6	11
6	Augmented Reality, Virtual Reality, Simulation, and Digital Twins	KSA1, KSA3, KSA4, KSA6	I1, I2, I5, I7, I8, I10	10
7	Cyber Physical Systems and Cyber Security	KSA1, KSA2, KSA4, KSA6	I2, I5, I7	7
8	Additive Manufacturing (3D Printing)	KSA1, KSA3, KSA5, KSA7	I2, I5, I9	7

Here, I = India, KSA = Kingdom of Saudi Arabia

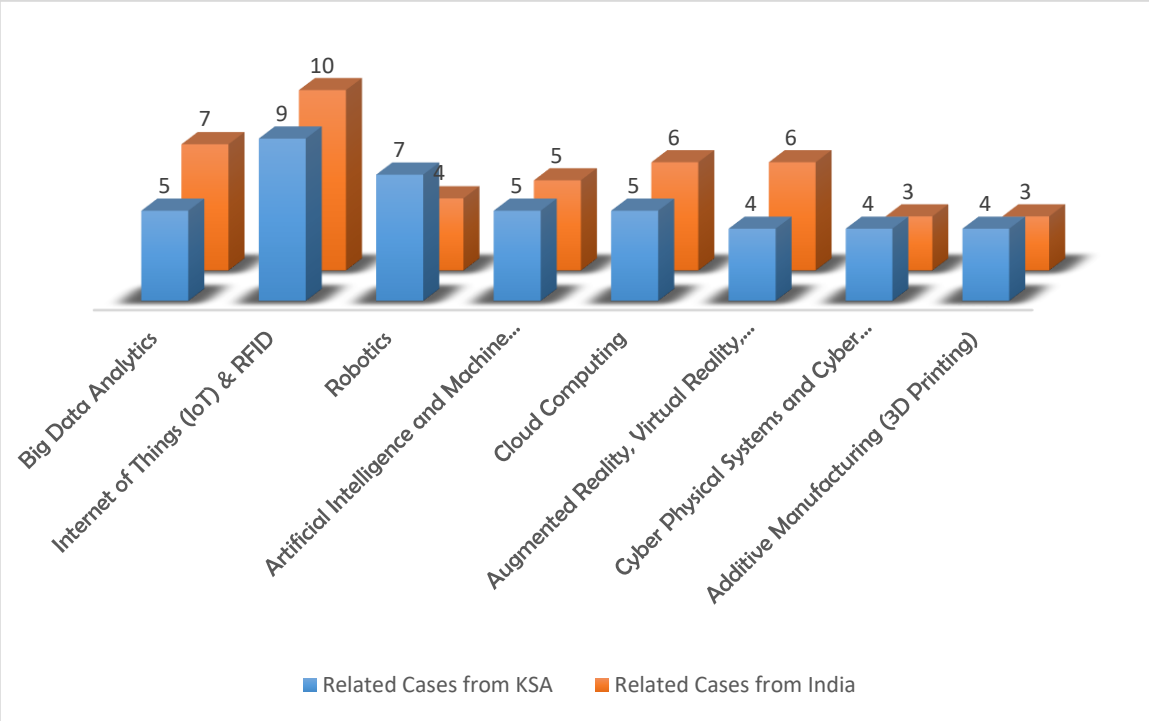

Figure 4.2
A Comparative Analysis of Technology Response, Illustrating the Adoption of Industry 4.0 in KSA and India

Table 4.4 summarizes the results for Theme 1, where the table provides details for different subthemes in the form of a list of I4.0 technologies being adopted by various stakeholders in supply chain of dairy sector in India and KSA. For instance, the first row of the table provides that Big Data Analysis technology has been adopted by Seven Indian dairy players and six KSA players for different applications within supply chain. The overall information extracted from interviews has revealed that the application of I4.0 technologies in dairy supply chain of both India and KSA is almost at similar maturity level. However, the KSA dairy sector found little more robust technologies than Indian dairy sector. The dairy companies that have richer applications of Industry 4.0 technologies include those that have more supply chain channels. Additionally, the companies with larger scales have greater implementation of industry 4.0 technologies.

A further categorization has shown that the KSA dairy sector has been in greater need of the implementation of the latest technologies as part of the government initiatives and supply chain requirements. In this regard, the respondents have provided the application of I4.0 is at a lower level in the dairy farms of the country. The large companies have implemented few of these technologies or are in the planning phase to extend such adoption. The respondents have provided that they use visibility and traceability technologies within the entire supply chain to effectively examine the delivery of products from the farm to the market. The commonly used traceability technologies include Enterprise Resource Planning (ERP) while broadly they have covered with barcode systems, RFIDs, and GPS systems i.e. Geographical Positioning Systems. In transportation trucks, the companies use sensor trucks to maintain temperature while barcode readers and oracle systems are also used in distribution departments. Furthermore, the processing plants studied in the dairy sector were reported to have greater application of I4.0 technologies. In this regard, they have integrated product lifecycles where the processes are carried out

in combination with digital tools and human intervention while for repetitive tasks, they have advanced technological implementation. These tasks mainly include those on the shop floor while the processes are carried out using pre-programmed software that governs the overall tasks. Process automation has become a generic phenomenon at these processing plants, and they help them become 'intelligent factories or smart factories' working using new industrial technologies.

On the other hand, the Indian dairy farms as well as processing plants and logistics companies have been reported to have greater implementation of Big Data Analytics due to the robustness of IT industry of the country and better data management. It has been reported that Indian dairy companies have been working to transform their factories into smart factories with smart life cycles. The main technologies that are being implemented in the supply chain operations of both Indian and KSA dairy sectors as provided by respondents of this study include the following:

4.3.1.1 Big Data Analytics

The application of big data technologies is made to larger sets of data that are not possible to be analyzed using traditional methods. The studied Indian dairy sector uses big data technologies for farm management, milk production, real-time monitoring, supply chain sustainability, better decision-making, and evaluating animal health. Some of the respondents have provided that they use PAT (Prediction and Analysis Tool) which helps predict individual and group cow production. It is helpful for the optimization of overall processes. Furthermore, in dairy processing plants, the use of big data is being made to improve processes, make continuous improvements and add to yield. Big Data Analytics, on the other hand, has been frequently reported to remove inefficiencies, reduce costs, and thus, add to overall profitability. In this regard, 'Apache' has been commonly used big data tool at some processing plants.

On the other hand, in the KSA context, though, there is greater importance on the implementation of the latest I4.0 technologies in line with Vision 2030 to diversify the economic growth of the country, however, the application of big data is limited in the dairy sector due to the data handling and data security that limits the implementation of Big Data Analytics. Thus, while responding to the question of listing down different I4.0 technologies being implemented in dairy sector, six of the Saudi respondents included Big Data Analytics in the list with limited applications. Talking about industrial plants and warehousing, the application of big data is quite high. They have reported to automate their processes while quickly identifying the loopholes in the system. Additionally, they have also reported using big data to automate their processes as per the demands of customers to manage effective planning so that the required output can be produced. Thus, their application of big data is made for both operational as well as marketing points of view.

Some of the respondents in both countries have provided that they use Blockchain for the monitoring of their products from the farm to the point of sale. For this purpose, they have reported using crowdfunding functionality and smart contacts to offer their dairy products fresh and healthy at reasonable rates. Blockchain technologies also served to help them comply with regulatory requirements. Blockchain technologies have also been reported to promote openness that leads to building confidence across the supply chain. This has been possible since every activity and transaction is recorded at every step which is helpful in easy traceability while also promoting accountability. Moreover, the intermediaries are removed, and the transactions are carried out only between legitimate stakeholders of the overall supply chain. As one of the respondents in India replied:

"*We have found Blockchain technologies quite helpful since they enable us to track the overall product journey. In this way, we can rapidly identify the contaminated products*

and recall them. This has resulted in the supply of quality products with higher nutritional value to customers."

Another respondent at a processing plant has reported that:

"We use Blockchain technologies for smart contracts. With this, we are able to for a seamless transaction in a way that the product procurement, its management, shipment, and clearance is done quite efficiently to customers. In this way, the record keeping of the overall system is effectively made which helps maintain a better audit of the overall processes".

On the other hand, the KSA respondent replied that:

"We are not using Blockchain technologies to the extent it should be used. In this way, we are unable to enjoy the first-mover advantages of the application of these technologies. These technologies are being used to a limited extent in particular niches. These need to be implemented in different areas of life to avail greater opportunities in the future".

4.3.1.2 Internet of Things (IoT) & RFID

IoT is being increasingly used for the collection and dissemination of data across various stakeholders of dairy sector. Such information may include the temperature and health information of animals. Based on this information, they decide about the dietary requirement of cows and their feeding mechanism. IoT has been reported to be increasingly used in both KSA and India for different purposes including dietary plans and feeding mechanisms at farms and for inventory management, maintenance applications, traceability and quality assurance at processing plants. Moreover, the respondents have also reported that they can improve the overall logistics of their business operations. Though, Indian dairy companies also need to aggressively implement IoT in their various supply chain operations, however, Saudi Arabia is a country facing the issues of water

scarcity and extreme weather, thus, implementation of IoT solutions is imperative in its dairy farms and across all segments. In this context, one of the Indian respondent's statement was:

"We are successfully using IoT technology in our different applications in operations where the key areas of focus include cow behavior, milking pattern, and health identification. Moreover, we also use IoT to assess the demand and production levels to accurately forecast inventory levels and for predictive maintenance".

On the other hand, one of the Saudi respondents also provided that:

"IoT technology in the different applications has been assisting us in resource efficiency, improvement in productivity, sustainability, traceability and efficiency with its larger application in predictive maintenance system. With these motives, the application of IoT technology in dairy sector of the kingdom has been rising".

The use of IoT has been largely reported to help in predictive maintenance systems. Respondents have provided that it has helped to improve reduce machinery downtime at processing plants which in-turn has reduced maintenance costs. This has also helped to improve assets lifetime. Respondents have also reported use of Blockchain technologies along with IoT for efficient and reliable supply chain infrastructure. These are often used in combination with IoT to enhance and keep the nutritional values and quality of dairy products and also to identify the contamination and adulteration of products. From the interview information obtained, it has been observed that Indian dairy farms are increasingly using Blockchain technologies, mainly at processing plants and logistics centers for their different operations while its application at KSA dairy sector has also been rising.

RFIDs (Radio Frequency Identification) are being largely used in both India and Saudi Arabia for record keeping, animal monitoring, herd management, mating

management, and improvement in quality and quantity of milk, thus, ensuring the removal of obstacles from milk production and distribution. This has been reported to be the key enabler for the transformation of the dairy supply chain. It is also used to enhance inventory management by collecting precise data from suppliers and from warehouses. The RFIDs are being increasingly used in both Indian and KSA farms and plants. They are being used to strengthen the dairy supply chain.

One of the respondents in the Indian dairy industry has argued that *"Modern dairy farms cannot work without RFIDs. They have become the need of the hour. We have been using RFIDs for quite a long time and we are still introducing new technologies for further improvement".*

On the other hand, Saudi dairy farms also have implemented RFIDs in many applications within its operations including cow's temperature monitoring, milking, and herd management. Thus, maintaining a required temperature for better health of the animals is quite important for better dairy performance. These have become the basic requirement for dairy farms across the globe and their application is mandated in this technologically advanced world.

One of the Saudi respondents stated that:

"RFID is a key element to support traceability from farm to market. We use RFIDs in the processing plants during the thermal batch processing for some of the products. We have a traceability software to trace the product and we keep the processing information data for minimum one year."

4.3.1.3 Robotics

The use of robotics has been increased in the dairy sector specially in packing and palletizing lines in processing plants. Robotics are used in different segments of the dairy supply chain mainly in warehousing, bottling, and packaging. They have helped enhance

the efficiency and hygiene of dairy products. However, it has been examined that robotics has been an expensive technology for which an abundance of financial resources is needed. The application of robots in the Indian industry is lesser and for a variety of functions within the overall supply chain operations. On the other hand, in the KSA dairy industry, it has been reported that the use of robotics is being made but to a limited extent in the processing plants and mainly for packaging operations. In this regard, the Indian respondents have provided that robotics have helped to enhance inventory management and distribution speed. However, they are considered one of the most expensive technologies requiring larger capital while greater human skills are also needed to maintain it. One of the respondents has comprehensively discussed using robotics in the supply chain of a dairy plant in the following words:

"The use of robots has been quite cost-intensive; however, it is helpful to reduce labor costs and improve production capacity. For supply chain operations, the use of robots has not been greatly focused yet".

Saudi dairy farm managers have also reported that the use of robotics milking as well as feeding at only planning phase and its practical implementation is yet to be done. However, they are useful to proliferate. Robotic feeders at dairy farms are helpful in nutrition optimization and customizing feed mixing to the dietary requirements of different animals. With this greater animal nourishment is possible. However, respondents have provided that the use of robotics in the dairy industry is at initial phase compared to other industries mainly due to the variable nature of the industry. The areas where the application of robotics is more helpful include palletizing and packaging i.e. at the end of production lines. During the interviews, respondents provided certain limitations of robots as they are often programmed for limited functions. Moreover, they need very high-level and

sophisticated AI. They do not function properly in case of emergency or if there is any variation in routine tasks.

4.3.1.4 Artificial Intelligence and Machine Learning

AI technologies are very helpful for the quick transition of food processing and dairy farming, which leads to sustainable supply chain operations. The application of AI technologies has been made at both KSA and Indian dairy sector with few limited applications. The selected respondents provided that the main areas for extensively using AI technologies are decision-making and real-time monitoring. The demand prediction of dairy products is highly important since the industry has short-lived products; thus, inaccurate forecasting may create heavy losses.

In the words of one of the Indian respondents, *"AI-based technologies have been of greater benefits, and they help a large dairy plant to successfully operate. The key areas in which we use AI-based application on our farm include disease detection in animals, AI-driven nutritional diet for animals for better quality milk, inventory forecasting, route management, and needs forecasting".*

Respondents in India have also provided that they are in a process to implement AI-powered milk scanning technologies for better quality controls. This technology assists in the evaluation of the composition of different factors like protein, fat, and somatic cell count. With this, they can maintain high standards and meet high-quality milk products. The predictive capability of AI has been revolutionizing the supply chain with the minimization of waste and overproduction. The creation of monitoring variables for humidity and temperature for in-transit products is possible with AI and these technologies are further linked with IoT to set new logistics and distribution standards.

The KSA respondents have also provided that they are also proposed to implement some of the AI-based applications for different operations. In this regard, the use of AI will

be focused on disease detection, checking for milk quality, forecasting, inventory management, and plant process control. Furthermore, they are planning to make even more extensive use of AI technologies to streamline their plant operations.

Cloud Computing

The application of cloud technologies in the dairy supply chain has been reported to be quite effective in a way that it increased efficiency and flexibility and reduces costs. The processing plants store their data at a centralized location that can be accessed by authorized persons anywhere in the supply chain. In this way, it provides an opportunity to stakeholders to collaborate in real time environment and share their data and information accordingly. Respondents of study have provided that the cloud computing has helped them automate different processes in supply chain from order tracking to warehouse optimization. Thus, a secure flow of information is possible that is helpful to reduce risks to food safety. Similar information has been reported by both the respondents of KSA and India.

One of the respondents from KSA reported that:

"We have used the Cloud Computing platform to our Manufacturing Execution System (MES) for our dairy plants which is supporting to have reduced cost of infrastructure and easy access for the stakeholders and the real time data dashboards in our head office."

Another respondent from KSA commented that:

"Our Enterprise Resource Planning (ERP) systems are moved to Hybrid Cloud recently which helps reduce the maintenance and the infrastructure requirements."

Respondents from India and KSA commented that most of the brownfield projects are considering cloud-based applications.

Augmented Reality, Virtual Reality, Simulation, and Digital Twins

The application of AR, VR, Simulation, and Digital Twins is quite low rather negligible at dairy industry in both KSA and India as reported by respondents of study. But new greenfield and brownfield projects are considering this technology for the new projects. The processes where they are used are mainly at processing plants for Processing and CIP (Clean-in Place) where the plant and machinery are used for processing the milk and further cleaned without disassembling it. It has provided the virtual visualization of the plant operations as well as process flow. It helps reduce downtime and ensure proper hygiene. Respondents have provided that the use of VR, AR, Simulations, and Digital Twins is quite helpful, however, the industry is not much developed yet while it also lacks resources which hinder application of these technologies. However, those who implemented it in other industry reported better results in the form of plant performance and enhanced efficiency. A comparison of the two countries has revealed that KSA dairy supply chain has more focus on these technologies as the government has been incentivizing the dairy industry under its Vision 2030. On the other hand, India despite being the agrarian economy is struggling to implement latest technologies greatly due to financial constraints.

One of the respondents from KSA explained that:

"We use Simulation option of the plant control system for the process improvements which helped us to save the time as well as the cost of trials."

Cyber-Physical System and Cyber Security

The adoption of cyber-physical systems is critical for the security of dairy supply chain. Respondents have though, provided that there is less focus on protecting the cyber space in the dairy supply chain which makes dairy data more vulnerable to security challenges. This is also because of more small and medium size (SMEs) industries in dairy

supply chain which usually have lower financial resources to direct towards cyber security. However, the higher application of different IoT technologies and interconnectivity of devices increase the risk of cyber-attacks. They have further predicted that due to lack of security focus, there can be more problems in future for the protection of systems in the coming years. In this regard, the most common types of cyber challenges may result in the form of deliberate damage of the infrastructure of Operational Technology (OT) and Information Technology (IT) systems of the dairy plants.

The National Cybersecurity Authority (NCA) in KSA has issued guidelines for the cyber security as part of the digitalization of the industries which is aligned to the Vision 2030 Program. The guidelines include the cyber security of IT and OT requirements of all the manufacturing companies. Bigger dairy companies are starting to make cyber security systems of its Operational Technology and Information Technology systems. One of the respondents from KSA has confirmed the implementation of cyber security systems in their facility. He has explained that:

"We have implemented Cyber security systems in our two processing plants which is Dragos Cyber Security platform software for the operational technology (OT) systems, and we have implemented Phosphorus Cyber Security solutions for our IoT systems. These cyber security solutions are aligned to NCA regulations."

Additive Manufacturing (3D Printing)

Additive Manufacturing technology has been reported by the respondents as being used in different functions of their supply chain. The main advantages of this technology are reduction in extra processes which reduces costs and improves efficiency. Thus, quicker decision making is possible. The respondents from Indian dairy industry reported that they use quick response codes enabled by block chain technologies, thus, helping them to improve and speed up their processes. However, the application of this technique is used

for packaging development and spare parts optimization projects in KSA dairy industry. One of the respondents from KSA indicated that:

"We have 3D printing facility available in our packaging innovation lab. We are in a discussion with the 3D printing equipment supplier to develop in-house spare parts within facility."

Theme 1: Conclusion

The complete results obtained through interviews have shown that big companies in India and KSA dairy sector have majority of the I4.0 technologies are in place even if some of the applications are in the initial phase. But majorly, Indian dairy sector is more focused in big data analysis applications compared to Saudi dairy sector. The possible reasons that can be cited for this difference mainly include India with higher proliferation of the latest information technologies while India is also categorized as a more agricultural economy while Saudi economy is mainly an energy economy where the greater application of the latest technologies is made to energy companies. However, the respondents in both countries have discussed that they are planning to strengthen their adoption of the latest technologies to enhance the efficiency of processing plants, farms and entire supply chain to make them more sustainable.

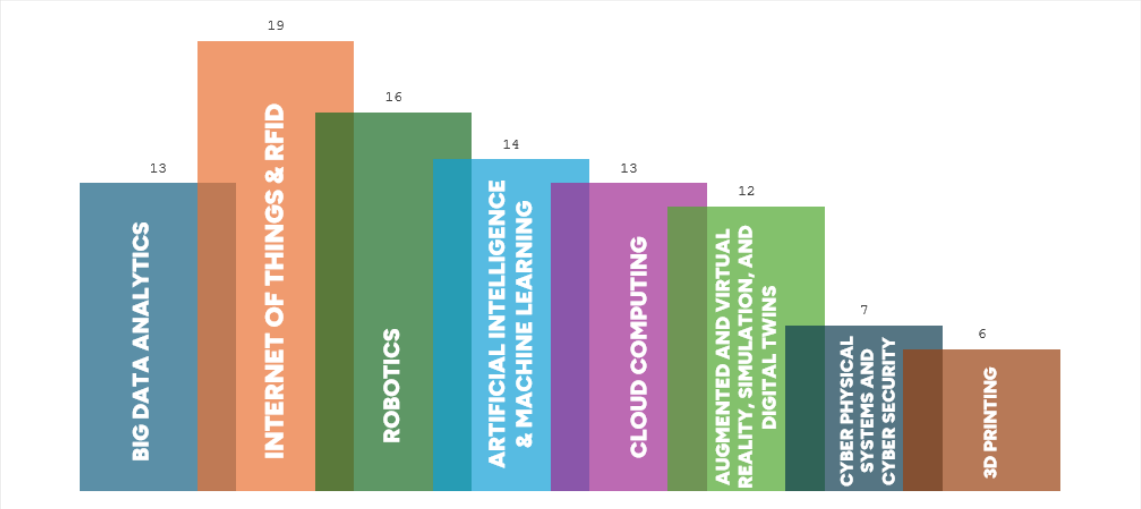

Figure 4.3
A Graphical Representation of Technology Response, Illustrating the Adoption of Industry 4.0 In KSA and India

4.3.2 Theme 2: Benefits of Implementing Industry 4.0 in the Supply Chain of the Dairy Sector

The second theme categorizes various benefits or advantages reported by respondents with the application of I4.0 technologies. These have been responded to different questions asked about the advantages of implementing these technologies. These questions were related to the main KPIs achieved using I4.0, their environmental impact, improvement in sustainability operations of the business, and the achievement of UN goals of sustainability. In this regard, it has been largely observed from the results obtained through interviews that both countries have limited application of I4.0 technologies in its entire supply chain as due to the lack of integration of all technologies from farm to shelf, thus, it has achieved lower benefits compared to other major industries that have the higher application of these technologies, and resultant benefits. Table 4 provides a summary of the benefits reported by different respondents:

Table 4.5
Theme 2: Subthemes for Benefits Received by Adoption of I4.0

Serial No.	Sub-themes	Related Cases from Kingdom of Saudi Arabia	Related Cases from India	No. of Cases Supported
1	Efficiency Enhancement	KSA1, KSA2, KSA3, KSA4, KSA5, KSA6, KSA7, KSA8, KSA9	I1, I2, I3, I5, I7, I8, I9, I10	17
2	Improved Decision Making	KSA1, KSA2, KSA3, KSA5, KSA7, KSA9	I1, I2, I3, I5, I10	11
3	Automation	KSA1, KSA2, KSA3, KSA4, KSA7, KSA9	I1, I2, I3, I5, I6, I10	12
4	Logistics Optimization	KSA2, KSA3, KSA5, KSA6, KSA8, KSA9	I1, I2, I3, I5, I8, I10	12
5	Increased Visibility, Traceability, and Sustainability	KSA1, KSA2, KSA3, KSA4 KSA5, KSA6, KSA7, KSA8, KSA9	I1, I2, I3, I4, I7, I9, I10	16

Here, I = India, KSA= Kingdom of Saudi Arabia

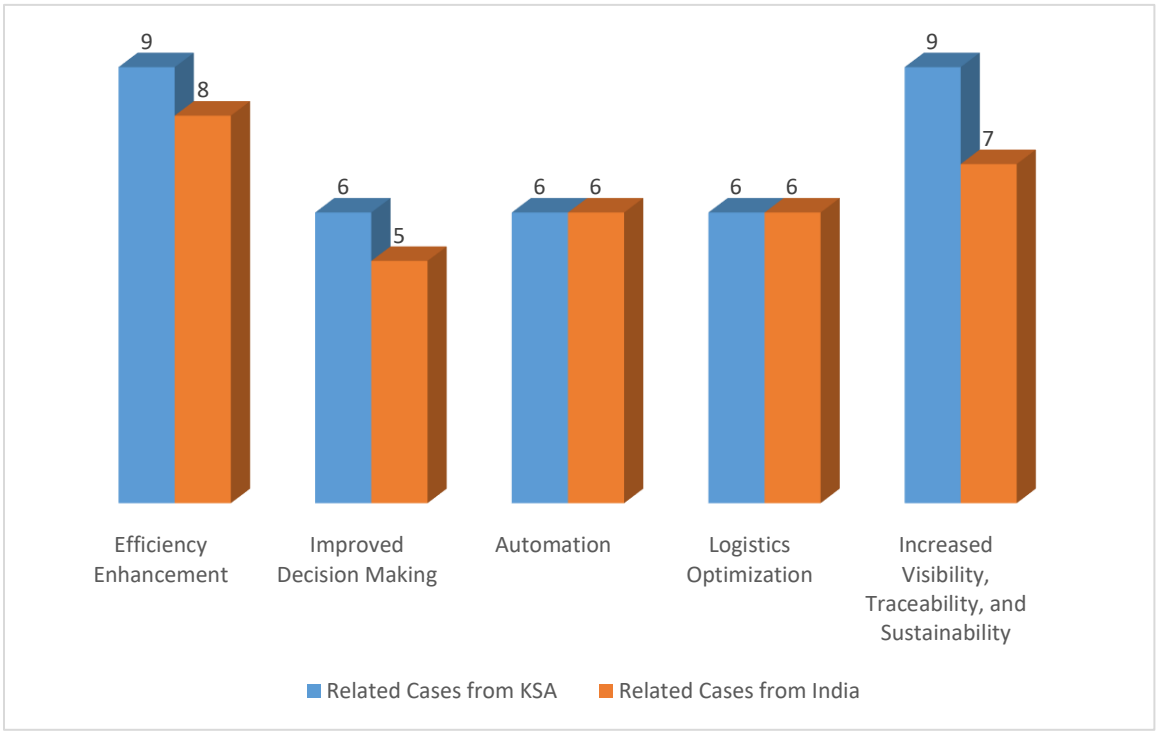

Figure 4.4
A Comparative Analysis of the Benefits of Industry 4.0 Technologies in KSA and India

Efficiency Enhancement

The implementation of I4.0 technologies in the supply chain helps in more efficient resource allocation and also efficient supply chain operations. When asked about respondents' benefits of Industry 4.0 technologies in supply chain operations, efficiency enhancement was reported by almost all respondents of the study. However, the mere adoption of technologies is not sufficient rather understanding of complementarities of different technologies and integrating them to achieve synergies is quite important to achieve enhanced efficiency in the operations of the supply chain.

In this regard, the Indian respondents have largely provided that the application of Industry 4.0 helps in the optimization of various supply chain operations and traceability performs the key role. Furthermore, simulation and quantitative modeling are among the key techniques that help to achieve efficiency. Supportive technologies are also found helpful in efficiency improvement. In this regard, the use of RFID tracking systems and prototypes leads to economic efficiency. With the help of real-time data, they enable stakeholders to make decisions promptly. The use of Blockchain and traceability technologies also makes the transportation of dairy products from farm to fork in a more transparent manner. This in turn, helps raise the confidence of consumers when they are provided with accurate real-time information. Furthermore, the respondents have also provided that it does not matter whether the I4.0 technologies are adopted as stand-alone or in combination with each other. However, when adopted as a combined, they provide better synergies, and efficiency attainment is enhanced.

Though the implementation of these technologies is limited, however those who have adopted reported greater efficiency achievement. In this regard, the Saudi respondents have provided that the different technologies adopted are helpful for them to conduct their operations quite efficiently. The use of automated milking with RFID traceability as well

as the feeding process has helped to reduce costs and improve efficiency to a greater extent. Furthermore, they added that the time saved through automated milking and feeding is helpful to pay greater attention to animal health. They have further provided that they are improving their farming experience through new technologies. In this regard, some farms are implementing vertical farming and other greenhouse facilities using IoT. With this, they are prioritizing health, safety, and sustainability. All this is in line with the Kingdom's broader objectives of enhanced sustainability. Thus, the adoption of I4.0 has been widely reported to achieve greater efficiency. In parallel, one of the Saudi respondents witnessed that processing plants are achieved higher efficiency and yield by implementing more automated lines and robotics packaging systems throughout its processing lines. Plant predictive maintenance has been improved with IoT sensors and AI-based softwares installed in its machines.

Improved Decision Making

With the contribution of different I4.0 technologies, the overall decision-making of business is improved to a greater extent. Respondents provided that the use of Big Data Analytics and AI technologies has been quite helpful for them to achieve a competitive advantage by making the right decisions at the right time. It leads to readily implementing the changing market dynamics and managing the environmental uncertainties, thus, making their supply chains more sustainable. This is in line with Ag et al., (2020) and Rasouli, (2019), who have also provided that by establishing supply chain resilience through better decision-making, businesses can better manage their external environment and unexpected disruptions. Businesses all over the world have faced various challenges and disruptions, especially during COVID-19. These disruptions mainly included complexity, vulnerability, risks, and uncertainty. Respondents have provided that I4.0

technologies even helped to improve their decision-making during pandemic disruptions through Big Data Analytics and other traceability technologies.

Talking about improved decision-making, one of the respondents at Indian dairy companies reported that:

"The use of AI and Big Data Analytics helps in automating the overall decision-making process. These systems assist in quick decision-making in complex situations. Furthermore, they help in creating different scenarios which led to making more informed choices."

Automation

Automation includes automating the manual work to improve efficiency and streamline the workflows. In this regard, automation has been reported to be one of the most important benefits provided by the I4.0 technologies. This is the basic purpose of these technologies. Indian respondents have largely reported automation to be increasingly achieved in their operations as well as across the entire supply chain. Automation has largely been reported to be an important contribution of I4.0 technologies at Indian dairy companies. In this regard, not only the production processes like cow milking and their feed mixing are automated but the delivery of dairy items across the supply chain including the processing and packaging are also automated. Additionally, the latest technologies have also been found to automate various other processes. The respondents have also provided that they have been engaged in precision livestock farming for many years where different sensors are used to automatically detect the behavior of animals. Furthermore, they also reported that attaching RFID with cows has been quite comfortable since cows can work with heavy sensors and relevant batteries. I4.0 has made the digital supply chain using different smart technologies including Blockchain, AI, and IoT. A digital supply chain has been found to work better than a manual supply chain.

However, the respondents at Saudi dairy industry have reported that they have RFIDs installed in cows and it is using for all the cow information including health, feed and milking as well. They are formulating further proposals for using sensors with integrated solutions. The data exchange throughout the supply chain has been very limited, making it difficult to achieve yet the operations across the supply chain are a little automated using technologies like AI, IoT, and Blockchain. The respondents at dairy companies of KSA have reported that they aim to enhance the automation of their processes to achieve enhanced efficiency and save time and costs and this all is possible with higher proliferation of latest technologies. All this is helpful in machine automation and reduction of costs.

One of the KSA respondents stated that:

"Our greenfield projects are looking with fully automated processing plants up to the truck loading. One of the latest processing plant which we have commissioned in 2017 is fully automated production lines with minimum human intervention. We have added multiple robotics, scanners, 2D and 3D barcodes for this project."

Logistics Management

Logistics management is one of the most important contributions of using I4.0 technologies. A combination of all these technologies helps companies manage their logistics operations, supplier relations, transportation, route management, and inventory management quite effectively. The use of big data analytics has been quite useful in accurately predicting the demand which leads to logistics improvement.

Respondents in Indian dairy sector have provided that the latest technologies provide with making different spans of perishable products that lead to better inventory management. It leads to distribution optimization and uncertainty reduction. The techniques mainly used for distribution optimization include AI, IoT, and mathematical

modeling. In this regard, the respondents have also provided that they use different software for supplier relationship management where Food LogiQ is one of the most commonly used software referred by various respondents. With this software, they can create a community of suppliers to directly and immediately discuss the problems with suppliers and achieve a full-scale traceability of the entire supply chain. The main features of this application included consolidation of huge data, identification of system problems, receiving of quality complaints, creation of a dashboard for new suppliers needed, and various others. Dairy companies are aimed at making their operations more sustainable. Using sensor-based welfare and health management systems, the sustainability of the dairy farms has been greatly enhanced. The help of increased collaboration offered by I4.0 technologies brings greater value to the business. One of the respondents in India provided that:

"We use IoT, Simulation, Genetic Algorithm, and Blockchain technologies in our supply chain operations which help us with cost optimization, safety and quality management, and route planning. Moreover, for the management of inventories, we use genetic algorithms, and smartphone applications which all are helpful for better inventory management and dealing with inventory issues".

Saudi respondents have also provided similar results where they have reported that the application of I4.0 technologies maturity at their supply chain has not reached optimal level rather it has been at mid-level. However, they are better managing their logistics based on these technologies since they provide readily and accurate information. Such information is used while making future projections and taking steps to further improvement of supply chain operations.

Increased Visibility, Traceability, and Sustainability

The application of the latest technologies has been helpful in the achievement of greater visibility. It is because traceability technologies lead to making overall logistics operations and products visible at each step of distribution which greatly adds to quality of products. The respondents have provided that the increased visibility helps improve overall accountability and better manage its inventories. In this regard, the use of Blockchain technologies plays an important role in increasing visibility. This has also been found in different other studies. For instance, the use of Blockchain technologies helps to improve the transparency in the overall supply chain process which helps in tracing the inventory across the supply chain (Galvez et al., 2018; Chang et al., 2021). The other I4.0 technology also contributes to increased visibility. With this, the ability to see around the corners is enhanced which leads to the creation of a competitive advantage. The use of RFID tags and sensors makes goods visible across the supply chain which enhances transparency and visibility.

Manufacturing Execution Systems (MES) integration from the processing plants to the distribution channels makes the visibility of the process and products from raw materials to finish foods throughout the supply chain. One of the KSA respondents detailed that:

"We have MES which is integrated between the process control systems of the manufacturing plants and the ERP software (SAP-System Application and Product in data processing). This is helping us to manage the order processing from sales to manufacturing with the proper inventory management, traceability, and quality control."

Respondents have greatly emphasized the attainment of visibility through the implementation of new technologies. The real-time tracking and monitoring of supply chain operations are quite helpful in enhancing visibility. In this regard, RFID, IoT, and

some other technologies have been most widely reported to provide accurate information about the location and condition of inventories in the supply chain. Additionally, the installation of sensors at different points in the supply chain is helpful to better monitor the inventories. All these technologies not only store, process, and exchange information but the detection of inventory movement, temperature, and activity related to it can be well reported. Majority of the respondents have provided that they largely use wireless sensor networks which assist in maintaining the quality and safety of the products during transportation.

I4.0 adoption in the dairy companies improved the sustainability goals by reducing the wastage of energy, resources, and products. The improvement with the efficiency operations of the facilities brought more outputs with the reduction of all types of waste which ultimately reduced the carbon emissions to the environment.

Theme 2: Conclusion

The overall results have shown that the real benefits of I4.0 technologies in the dairy industry are quite impressive and they serve to achieve the potential of the dairy sector, streamline its supply chain, waste reduction, and environmental preservation, and increase efficiency, productivity, and profitability of dairy companies. These benefits suggest to take immediate initiatives for the implementation of these technologies. However, a comparison between process plants and dairy farms in both country has shown that process plants are having higher adoption of these technologies. Comparatively, supply chains of both countries are generally lacking in achieving the required benefits mainly because their speed of adoption of I4.0 is low. Moreover, they are also implementing very few of these technologies. However, a comparison of the two countries puts KSA at the leading end in terms of technology adoption and realization of benefits due to the government's support to digitalization. The participants of the study from both India and

KSA have indicated the plan to adopt to make enhanced use of these technologies and enjoy greater benefits across their supply chains in the future.

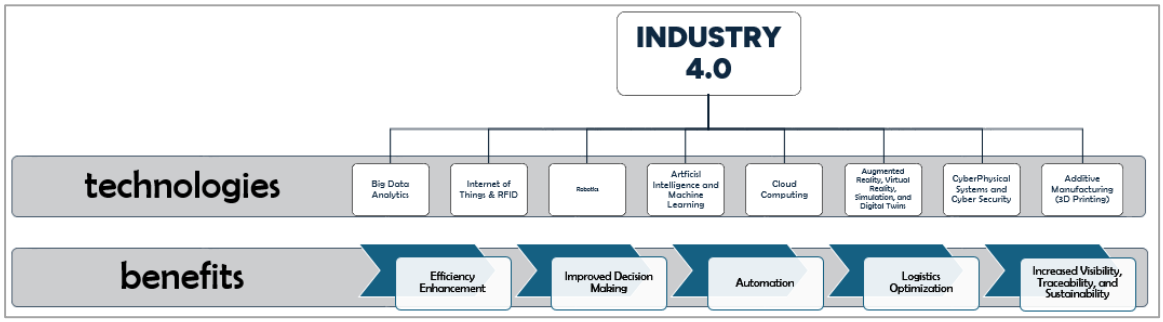

Figure 4.5
A Visual Summary of the Core Technologies of I4.0 and their Benefits

4.3.3 Theme 3: Challenges of Implementing Industry 4.0 in the Supply Chain of the Dairy Industry

The respondents were asked different questions about the challenges of implementation of I4.0 in their respective supply chains. To answer these questions, the respondents in both countries have provided different responses and the current section has organized the responses into different categories. For both India and KSA, the challenges are almost similar, however, India has been facing more challenges than KSA dairy farms since the implementation of technologies in the Indian dairy farms is at a lower level, however, processing plants of country have an accelerated application of I4.0 technologies. The overall value chain of the farms may not be structured keeping in mind the latest trends. In this regard, the respondents provided that controlling food supply chain losses is challenging. This is because the preferences of customers are rapidly changing while the regulations are also conflicting and overlapping. Moreover, lacking a record system also restricts the response system. The respondents have also reported that the lack of consistent demand for dairy products has been one of the biggest hurdles that restrict the

implementation and achievement of required results of I4.0 technologies. It implies that the market for demand needs to be stabilized to achieve the full advantages of the implementation of Industry 4.0.

The responses provided by the respondents have been organized into the following table:

Table 4.6
Theme 3: Subthemes and Related Support Cases

Serial No.	Sub Themes	Related Cases from kingdom of Saudi Arabia	Related Cases from India	No. of Cases Supported
1	Lack of Skilled Human Resources	KSA1, KSA2, KSA4, KSA5, KSA6, KSA8, KSA9	I1, I2, I3, I4, I5, I6, I9, I10	15
2	Incompatible Infrastructure	KSA1, KSA2, KSA3, KSA4, KSA5, KSA6, KSA8, KSA9	I2, I4, I5, I7, I8, I9, I10	15
3	Lack of Resources (technology developers, integrators, proof of concept, costs)	KSA1, KSA2, KSA4, KSA5, KSA6, KSA7, KSA9	I1, I2, I3, I4, I5, I7, I9, I10	15
4	Lack of Technological Integration between stakeholders	KSA1, KSA2, KSA3, KSA4, KSA5, KSA6, KSA8	I1, I2, I3, I4, I6, I7, I9, I10	15
5	Data Security and Privacy concerns	KSA1, KSA4, KSA5, KSA6, KSA7	I1, I2, I5, I6, I7, I8, I9	12

Here, I = India, KSA = Kingdom of Saudi Arabia

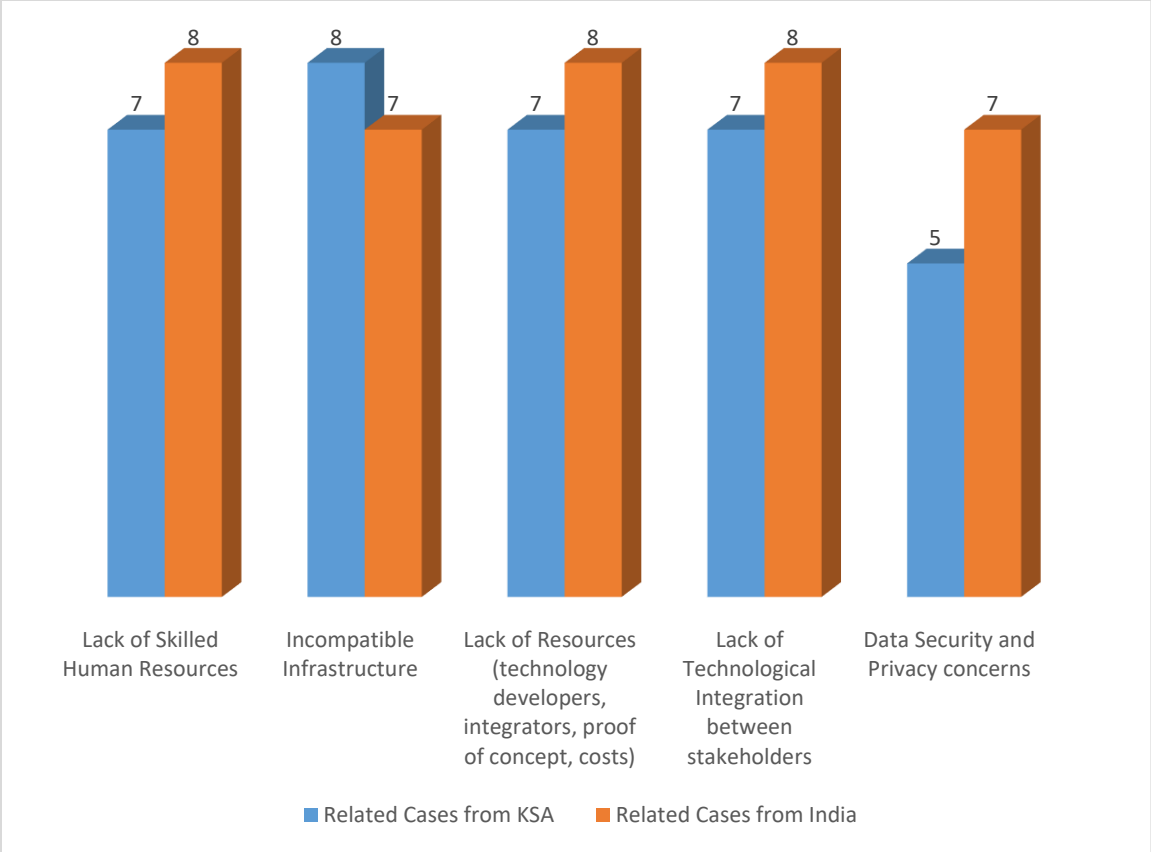

Figure 4.6
Comparative Analysis of Industry 4.0 Adoption Challenges in KSA and India

Lack of Skilled Personnel/ Human Resources

I4.0 are quite complex and technologies that require highly specialized and trained staff to not only implement them but to work with them. However, all this requires greater time and effort to have specialized staff at each dairy company for this purpose. Thus, almost all of the respondents have highlighted it to be among the top hurdles for the implementation of the latest technologies. In this regard, the Saudi respondents have provided that they generally lack the required skills, manpower, competencies, and knowledge for the implementation of I4.0 which restricts them from enjoying the concept of smart factories. Moreover, they also reported a lack of data recording and preparation of

a centralized data system within their business hinders making use of the latest technologies.

On the other hand, the same limitation has also been reported by the Indian respondents who explained that the lack of skills and competencies to implement and use the latest technologies, especially in small companies is the main hindrance to the implementation of the latest technologies. The small companies are at a higher risk of finding insufficient skills and capabilities of employees. In this regard, one of the Saudi respondents has provided that:

"The employees need greater skills transformation for effective implementation and usage of new technologies. However, currently, the job market has a significant shortage of skilled employees in all sectors, and the dairy industry is no exception. To overcome this challenge, huge efforts are needed that may take a longer time. However, to enjoy the real benefits of Industry 4.0, these challenges need to be addressed.".

Incompatible Infrastructure

New technologies are required to be effectively integrated within the existing systems. However, it is often difficult to integrate the latest technologies with the traditional systems, thus, hindering the implementation of new technologies. These results indicate that dairy business are restricted from implementing the needed benefits of I4.0 technologies due to compatibility issues.

Saudi respondents from the farm have reported that lack of immaturity has been the main reason for poor or low implementation of I4.0 technologies which restricts even the large farms from using the latest technologies (Kumar et al., 2024). In this regard, they included various factors to form the infrastructure of the business. They mainly include regulatory challenges, technical, cultural, organizational, lack of awareness, and lack of

data integration as the key hindrances to the adoption of the latest technologies. Regarding cultural barriers, one of the respondents provided that:

"The top management at our company needed to have more proven technologies with enough technical support to adopt the technologies to the business."

Another respondent has elaborated that:

"We are increasingly faced with compatibility issues since our existing system requires major investment in infrastructure and also greater spend for employee training for the new system which has slowed down our transformation to the latest technologies".

The implementation of I4.0 technologies at Indian companies is also at quite an infancy stage where the integration of new technologies into existing systems has been facing difficulties as reported by different respondents. The study participants from the Indian dairy industry have provided that one of the main challenges of technology adoption is that most of the dairy companies are located in rural areas where the location of dairy companies impedes the spread of technologies which restricts the application of new technologies.

Lack of Resources (technology developers, integrators, proof of concept, costs)

Lack of resources has been an important challenge for dairy companies operating both in India and KSA to implement the latest technologies. In this regard, the respondents have provided that the adoption of I4.0 technologies may not provide the required benefits in the short term due to higher costs which results in lower benefits received, thus, restricting the adoption of the latest technologies. They have further provided that dairy sector itself is capital intensive where the companies already facing budget constraints find it quite challenging rather impossible to implement new technologies. One of the respondents explained that there is a lack of financial resources especially among small companies while a lack of understanding or awareness of the real benefits of I4.0

technologies contributes significantly to the slower adoption of these technologies and strengthens the business. For this government support and assistance are increasingly needed. However, developing countries like India face further limitations in financial support from the government while countries like KSA may get higher financial assistance from the government to modernize their dairy farms to supply chain under Vision 2030 of the government.

The farm manager in KSA also highlighted the support provided by the government for the implementation of the latest technologies in enhancing productivity and sustainability. In this regard, the government offers different training and skills enhancement facilities to equip livestock farmers with the latest technology implementation techniques and embrace the technological revolution effectively. Furthermore, the government has also been offering partnerships in different segments of technology adoption which is quite helpful to adopt the new technology paradigm. Such facilities, some of the respondents provided that they have been making efforts to avail the opportunities, however, these facilities need to be expanded since they are insufficient for mass-scale milking in the country.

It was reported by the Indian respondents that higher initial costs are needed to implement I4.0 which needs greater financial planning. Though, companies are increasingly pursuing external funding opportunities while they are also working in partnership with each other to overcome their resource deficiency, however, the problem is still proliferating. Saudi respondents have reported that the limited financial resources do not allow the dairy companies especially the small-scale businesses to adopt these technologies. The implementation of new technologies involves very high costs, thus, small companies are restricted from adopting new technologies one hand, and on the other hand, the large companies with abundant resources can adopt these technologies, creating

a greater divide between small and large companies and thereby provide a competitive advantage to large companies.

There are limited equipment designers and suppliers to enhance advanced technologies in the new design of the dairy equipment with the reasonable timeframe. Upgrading of the existing installed equipment with the new technologies is more complicated, since the interest of upgrading older systems by designers and suppliers are limited. The companies need to have proven technologies to be installed in their facilities which make more lead time for the suppliers to trial and develop the technologies at the satisfactory level.

Lack of Technological Integration between Suppliers

One of the most important challenges cited most of the respondents has been lack of integration of software technologies between different suppliers in the overall supply chain. In this regard, respondents have largely reported that they have been facing the problem of different software being used by different stakeholders in the supply chain which makes it difficult to harmonize the overall supply chain. For instance, the respondents have provided that those at farms, factories are using different technological software from those who are in transportation or logistics. These are different for processing units and also at distribution centers. Thus, tracking or traceability is possible but lack of harmonization between different stakeholders has been challenging. Moreover, such an issue will take time and has not seemed to be resolved in near future. The similar problem has been reported in both Indian and Saudi dairy supply chain. One of the respondents in Indian dairy sector has reported that:

"Lack of integration of software technologies in the entire supply chain has been observed as one of the key challenges for implementation of I4.0 technologies. It creates

problems for employees for lack of adjustment of in the supply chain. It is a big hurdle in bringing consistency in the supply chain operations".

Similarly, respondent in KSA dairy sector has reported:

"Out of all the challenges we face for the implementation of I4.0 to improve our processes, lack of integration of these technologies in the overall supply chain restrict to achieve the full potential".

Another KSA respondent commented that:

"We have implemented our new greenfield project with end-to-end integration of software platform from processing, packing, shipping, and sales systems. We faced a lot of challenges in this integration with different software companies."

Data Security and Privacy Concerns

The use of I4.0 helps attain various advantages as discussed under theme 2. However, industries adopting these technologies are under greater threat of cyber security. The cyber vulnerabilities expose the critical infrastructure of businesses to cyber criminals, thus, reducing the competitiveness of businesses. I4.0 is based on increased connectivity of different devices that offer a lucrative opportunity for cyber criminals to target the weak points in the infrastructure. Thus, they can interrupt the smooth functioning of farms, and the animals at farms need to be trained again after the interruption which may cause serious losses of productivity, time, and costs. Thus, the study respondents have provided that they face limitations of regulatory approval while implementing all types of technologies because of the concerns of cyber security. The higher extent of interoperability and openness of supply chain operations often create privacy and data security issues which make implementation of the concerned technologies difficult.

Some of the respondents have provided that there is a risk of important data being compromised since the data analytics and increased level of connected devices may create

privacy and data security concerns. The elimination of handling of cyber-attacks at this stage when the implementation of these technologies is at the infancy level and the companies are facing the limitation of unskilled manpower, handling of cyber-attacks is difficult. Moreover, resuming the system after the criminal attack is over is also quite challenging. Both KSA and Indian respondents have provided similar responses to questions on cyber security. Moreover, the Indian respondents have also provided that it is quite difficult to implement advanced technologies in different segments of industry of a developing country, however, because of IT advancements in the country, the pace of adoption is high while this is not the case with other developing countries that are facing greater financial constraints, skills shortage, and lack of infrastructure.

One of the KSA respondent recommended that:

"We are following the National Cybersecurity Authority (NCA) guidelines and there are difficulties to find the right solutions within Operational Technology (OT) networks, since all of the solutions are not compatible with the existing installation."

Theme 3: Conclusion

The wider discussion on challenges of I4.0 adoption in the dairy sector supply chain has indicated that various hurdles restrict the adoption of technologies or to achieve their full potential. These challenges mainly include a lack of awareness, technical expertise, resistance to change, lack of resources, data security and privacy challenges, and others. Though governments of both countries are trying to reduce such challenges yet there is much to do to reach the required level of implementation. Furthermore, a comparison of both countries has indicated similar challenges, but the KSA government's support for digitalization will give a leading edge to the country, on the other hand, India being an Information Technology (IT) hub, will also support the implementation of new technologies in its various sectors. Respondents have also stressed that it is not only the

I4.0 technologies that help achieve the resilient supply chain but there must be relevant capabilities to efficiently use the resources. In this way, there should be dynamic capabilities to achieve the required results of resilience and here the lack of expertise and awareness plays the most negative roles.

Figure 4.7
A Graphical Representation of Technology Response, Highlighting the Challenges of Industry 4.0 Adoption in KSA and India

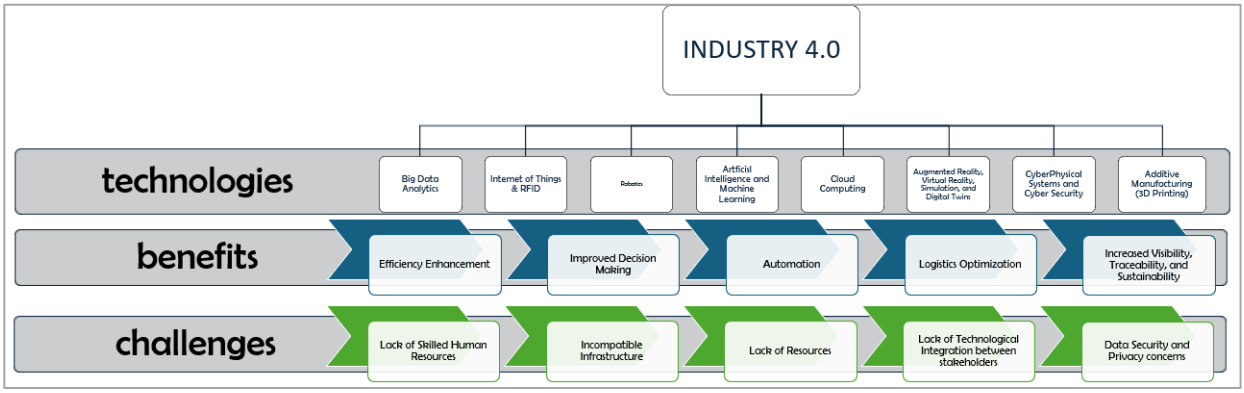

Figure 4.8
A Visual Summary of the Core Technologies of I4.0, their Benefits, and the Challenges Across Key Sectors

4.3.4 Theme 4: Resilient Dairy Supply Chain through Industry 4.0

Supply chain resilience, for this research, includes recovering from disruptions, and absorbing the shocks and risks in responding to bouncing back in a better way that leads to growth (Ambulker et al., 2015). It is a reactive measure that helps in quickly recovering from disruptions and carrying out the operations in an efficient manner (Ali et al., 2017). In this way, it helps enhance customers' satisfaction, experiences, and values through fast and time delivery and ensuring continuity of operations even during uncertain environments (Gu et al., 2023).

The study has used different questions to understand the level of resilience have achieved by the business due to the application of I4.0 technologies. The managers have been asked to provide their responses to evaluate whether they have achieved resilience in their supply chain operations or not the level to which they have achieved such resilience and what are the hurdles they have been facing in achieving resilience in their supply chain operations. Industry 4.0 has been quite helpful in bringing resilience to supply chain operations of any sector including the dairy sector. Respondents were asked different questions about whether Industry 4.0 has helped to achieve resilience in dairy operations or not. The results of such questions have indicated that there has been lesser agility and resilience achieved in the dairy sector since the extent to which these technologies are implemented is at a lower level.

In this regard, the supply chain of the dairy sector can be made more resilient with the help of Industry 4.0, however, the speed of implementation is low which restricts enjoying the real benefits of Industry 4.0 and the resilience accordingly. Additionally, the Saudi dairy sector is having more integrated dairy farms with processing plants, but in India many of the farms are separated from dairy companies. The respondents have emphasized that they understand that the technologies help make supply chain operations more

resilient, but it will take time and is not possible in the short term. One of the respondents from a top dairy farm in India has reported that:

"The implementation and integration of Industry 4.0 technologies is costly, which is restricting its greater application, however, these higher costs can be offset by the efficiencies and economies received in the long run. This is because the cascading effect of digitization and continuous improvement is helpful to achieve cost efficiencies in the long run".

Respondents have provided that they are using different key performance indicators to measure the performance of their supply chain operations. In this regard, most of the respondents have provided that they measure the performance using waste reduction and delivery accuracy as the KPIs for the performance. However, some respondents have disagreed with these KPIs for performance measurement since they may not serve in periods of uncertainty. Moreover, they are the results of existing performance while future results may not be predicted based on these results.

The respondents in KSA have provided that the logistics performance is usually focused lesser than the internal business performance. However, there are certain KPIs developed and monitored throughout the supply chain. Comparatively, Indian respondents provided greater emphasis on logistics performance where the KPIs used for performance measurement include on-time delivery, lead time, shipping error, returns and allowances, customer complaints, customer satisfaction, order cycle rate, stock shortages, inventory obsolescence, inventory overages, order fill and others. Some other respondents have provided that along with these measures, they also use resource utilization and the ability of businesses to meet the demands with a particular focus on inventory spoilage, expiration, loss of value of inventory, and others based on which proactive steps can be taken for performance improvement. To a question, one of the respondents said that:

"There are various KPIs to measure the performance of I4.0 technologies in the dairy supply chain, however, not all KPIs are equally helpful in each context. To measure the performance, there is a need to first evaluate the context to implement relevant KPIs".

On the other hand, based upon the collected data it has been determined that the KSA dairy industry has been on the way to acquiring resilience in its supply chain operations using Industry 4.0 while the Indian dairy industry has been performing low and yet to achieve the required results. However, the respondents from Saudi Arabia largely hold that with the help of government support and collaboration of various stakeholders of dairy companies, the resilience of dairy business can be improved. A summary of responses collected from different respondents of the study has been organized in the following table:

Table 4.7
Theme 4: Subthemes and Related Support Cases

Serial No.	Subthemes	Related Cases from Kingdom of Saudi Arabia	Related Cases from India	No. of Cases Supported
1	Smooth Information Sharing	KSA1, KSA2, KSA3, KSA5, KSA7, KSA9	I1, I2, I3, I4, I5, I7	12
2	Real-Time Monitoring	KSA1, KSA2, KSA3, KSA4, KSA5, KSA6, KSA7, KSA9	I1, I2, I4, I5, I6, I7, I9, I10	16
3	Timely Response to Disruptions	KSA2, KSA3, KSA7, KSA8, KSA9	I1, I2, I3, I5, I7, I8, I9, I10	13
4	Integrative Environment	KSA2, KSA3, KSA7, KSA9	I1, I2, I3, I5, I7, I8, I9, I10	12

Here, I = India, KSA = Kingdom of Saudi Arabia

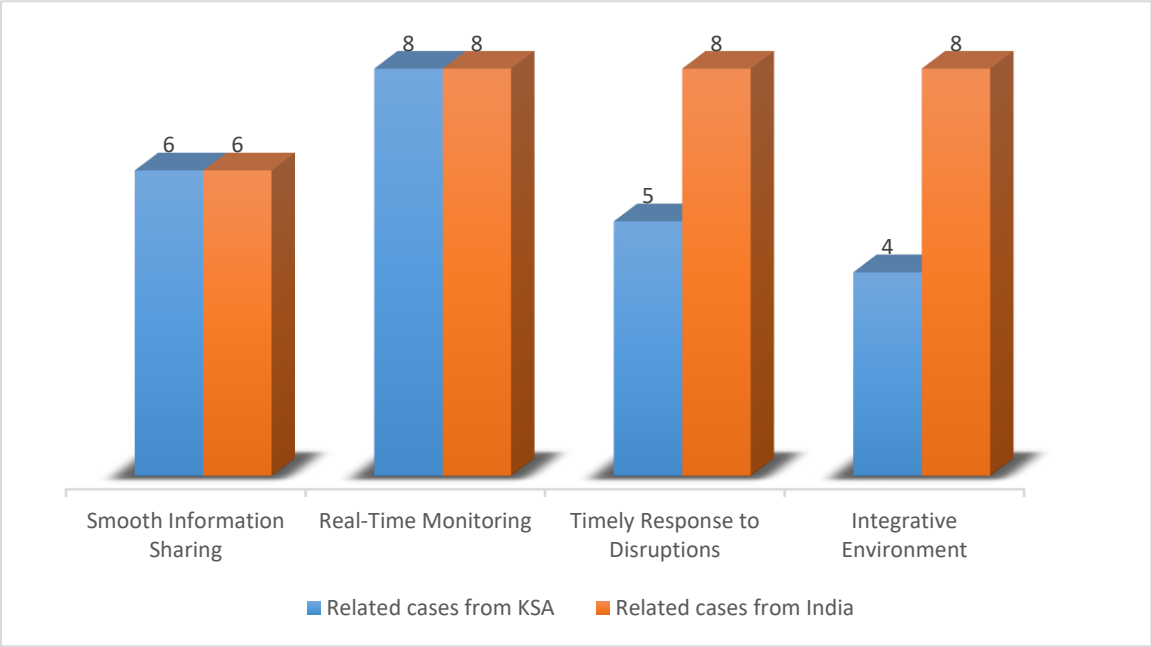

Figure 4.9
Comparative Analysis of the Resilience of Industry 4.0 Adoption in KSA and India

Smooth Information Sharing

I4.0 helps ensure smooth information sharing between different stakeholders of the supply chain which creates resilient supply chains. It has been widely reported by respondents that IoT helps to make the supply chain resilient by improving its flexibility by making rapid transformations in the form of efficient utilization of resources and smooth information sharing. With the increase in the speed of information flow, the agility of business operations also increases. At multiple tiers, information is shared which in turn helps accelerate coordination and collaboration among different supply chain partners. From the responses of various study participants, it has been well determined that the use of IoT influences the supply chains in several ways to make them more resilient through enhanced awareness, risk management, enhancing robustness, and various other ways including boosting collaboration through information exchange.

One of the Indian respondents reported that:

"We can improve the overall collaboration throughout our supply chain using the latest technologies that have served to position us to make timely decisions and improve our overall information exchange quite smoothly".

Such an advantage has been largely reported by most of the respondents where the main role is of IoT that helps build strong coordination and collaboration. The key technologies reported by many of the respondents in both countries have helped data-driven decision-making, application of sensors, artificial intelligence, and machine learning for better management. The use of AI and related IoT technologies results in improved animal health, welfare in the farms, enhances the quality of products, and productivity within the process plants which helps overcome challenges and promotes long-term resilience of dairy supply chains. The increased information sharing is also helpful in decentralized decision making which also makes the supply chain more resilient since the decisions are timely made with the best available information.

Real Time Monitoring

Respondents of the study have largely reported that they can make their supply chains more resilient due to real-time tracking and monitoring of their supply chain operations which leads them to make timely decisions and enhance coordination and collaboration with each other. It makes better visibility of inventory and improves logistics flow. Different technologies, as reported in theme one, are used for enhanced visibility or tracking in supply chain operations like IoT, AI, and others. Robotics have more common applications in large dairy sector in both India and KSA with greater proliferation in KSA companies. However, so far, their application has largely been targeted in operations like milking and fewer applications are being made for packing, warehousing, and distribution

purposes. In this way, the use of robotics helps enhance robustness, collaboration, agility, and flexibility. One of the respondents provided that:

"Robotics have greatly helped to improve our operations, bring more efficiency, quality, and enhance production levels which all contribute to resilience in our supply chain as well".

Additionally, the use of Big Data Analytics, and automation brought by these technologies help make real-time monitoring of the operations. The well-designed and well-structured procedures established by these technologies help in enhancing end-to-end transparency which makes tracking and traceability of the products in the supply chain quite easier, thus, monitoring has become much easier than traditional supply chains. This real-time monitoring also benefits the companies to match the demand and supply equations while adjustment to the new market trends has also become easier. However, all these can be further improved by implementing a combination of all relevant technologies.

Timely Response to Disruption

As reported by respondents I4.0 helps in real monitoring of the supply chain operations, and it has a direct impact on timely managing the responses to disruptions. However, the majority of the respondents have reported that it is the joint application of various I4.0 technologies that helps achieve the required results. Such a collaboration is important in timely responding to disruptions and making effective decisions. In this way, when anticipated and unanticipated disruptions are managed, companies can achieve resilience in their supply chain across all supply chain partners. One of the KSA respondents explained that:

"We can maintain resilience in our supply chain when we can collaborate with our supply chain partners and timely manage disruptions. It is further helpful in maintaining

goal congruence and synchronization of operations throughout our supply chain, since we jointly develop our strategic plans, share risks, and create our mutual interests".

The application of I4.0 helps ensure a smooth flow of information, collaboration, and coordination between supply chain partners. This creation of mutual interests is one of the main pillars for achieving resilience in supply chain operations. It helps in generating system-level response and recovery procedures whenever disruptions occur. Such response has been provided by various study participants who indicated that the selected dairy companies can achieve resilience through enhanced collaboration and coordination at the back of I4.0 technologies.

Talking about artificial intelligence, respondents have agreed that the use of AI is very helpful in bringing supply chain resilience. With this, various related factors including knowledge management, collaboration, security, information sharing, robustness, flexibility, visibility, and situation awareness, are all improved which leads to enhanced disruption management. Blockchain technology helps improve security. One of the IT personnel from India have reported that using the collaboration of AI and Blockchain technology has helped work against cyber threats. It reduces the cost of disruptions, recovery times, and also the number of affected stakeholders. A summary of the key benefits reported by respondents to enhance supply chain resilience include robustness, information sharing, collaboration, flexibility, agility, and risk management.

One of the KSA respondents stated that:

"We use I4.0 enabled simulators and sensors that help in taking timely information about any disruption in the supply chain and managing it promptly. These technologies have greatly helped us during the pandemic to timely monitor the disruptions of obtaining animal feeds, raw materials, packaging materials, and all project deliveries while the routes of the outflow of our products were also observed keenly. All this helped to timely

assess the disruptions and take corrective actions and hence, we have been able to perform stronger and avoid supply chain disruptions using the latest technologies".

Another advantage mainly reported by respondents for the achievement of resilience using I4.0 is the visibility created by the technologies across the supply chain. Various tracking technologies help make supply chains more visible, create greater transparency, and cope with the supply chain risks and disruptions. Moreover, it allows for the timely exchange of any information for possible disruptions, thus, leading to making supply chains more responsive and prepared for managing disruptions, thereby adding to resilience. In this way, a timely response through collaboration and better visibility helps make the supply chain more resilient. Thus, dairy managers have reported that the use of advanced technologies for the improvement of traceability has helped to gain consumer trust as well as their confidence that they are not faced with shortages or delays.

Integrative Environment and Cost Reduction

The results of responses obtained from study participants have provided that the enhanced food safety and preservation technologies have helped dairy companies to avoid dairy wastage which leads to not only increased profitability but also environmental protection. Respondents have also provided that the use of technologies in the dairy supply chain is helpful to benefit in three different dimensions including economic, environmental, and social. In this regard, the use of RFID helps provide real-time data which is used for better decision-making. Furthermore, the reduced energy consumption using these technologies makes lower greenhouse gas emissions which is quite important for environmental protection. Studies have also provided that it is helpful in the creation of new job opportunities for skilled employees which is helpful in the reduction of unemployment and also elimination of unlawful behavior. Using IoT the dairy processing cost is reduced. Furthermore, the application of Simulation is also helpful in the reduction

of supply chain costs. It is because the simulation programs are quite helpful in designing the best possible inventory designs which are also helpful in improving the overall supply chain operations.

In this regard, a respondent stated that:

"We can track our dairy items from farm to end point of sale, thus, a whole record of product journey is maintained using Blockchain solutions. With this, we can avoid food wastage and recall any contaminated product. However, the technologies provide higher precision which is helpful to avoid mass recalls".

The respondents in India provided that the adoption of technology is helpful in the supply chain to play important roles in milk processing, efficient collection, efficient and timely transportation, and reduction of costs and waste. Manure management using the latest technologies and converting them into biofuels has not only resulted in greater efficiency but also added to environmental sustainability and resilient supply chains.

The information collected from respondents also provided that the farms collect and maintain huge amounts of data which is very useful in making better analysis and also making future predictions. This is also helpful in the reduction of disruption risks through proactive initiatives of risk prevention. Moreover, Big Data Analytics is also helpful in enhancing collaboration, information sharing, agility, robustness, knowledge management, and risk management.

Regarding a question about the environmental impact of dairy farms, it has been reported that dairy farms are affected by extreme weather mainly due to rising temperatures, especially across KSA. Moreover, it has also been reported that dairy farms also impact the environment. For improvement to climate change dairy farms also need to fulfill their duties toward the environment for which I4.0 technologies are quite helpful. In this regard, the respondents have provided that the use of new and advanced technologies

contributes to environmental improvement by different means like reduction in feed usage due to waste avoidance, reduction in water usage due to appropriate usage, reduction in land usage due to better organization, and reduction in GHG emission through manure management and conversion to bio-fuels. All this indicates that the usage of the latest I4.0 technologies has a positive impact on the environment while they have also made the farms more environmentally protected and the farm animals avoid extreme temperatures.

Theme 4: Conclusion

The overall discussion of theme 4 has provided that various technologies implemented within the supply chain including IoT, Big Data, AI, cloud, and others are quite important and they are very important to respond to disruptions through enhanced communication, collaboration, and integration between various stakeholders which ensures smooth flow of information and provide real-time information available to concerned stakeholders that helps in managing the disruptions promptly. All this helps make supply chains more resilient and agile. Almost all of the respondents agreed about the resilience impact of I4.0 technologies, however, the required benefits or the level of resilience has not been achieved at the majority of farms due to a deficiency of skills, expertise, resources, and other hurdles.

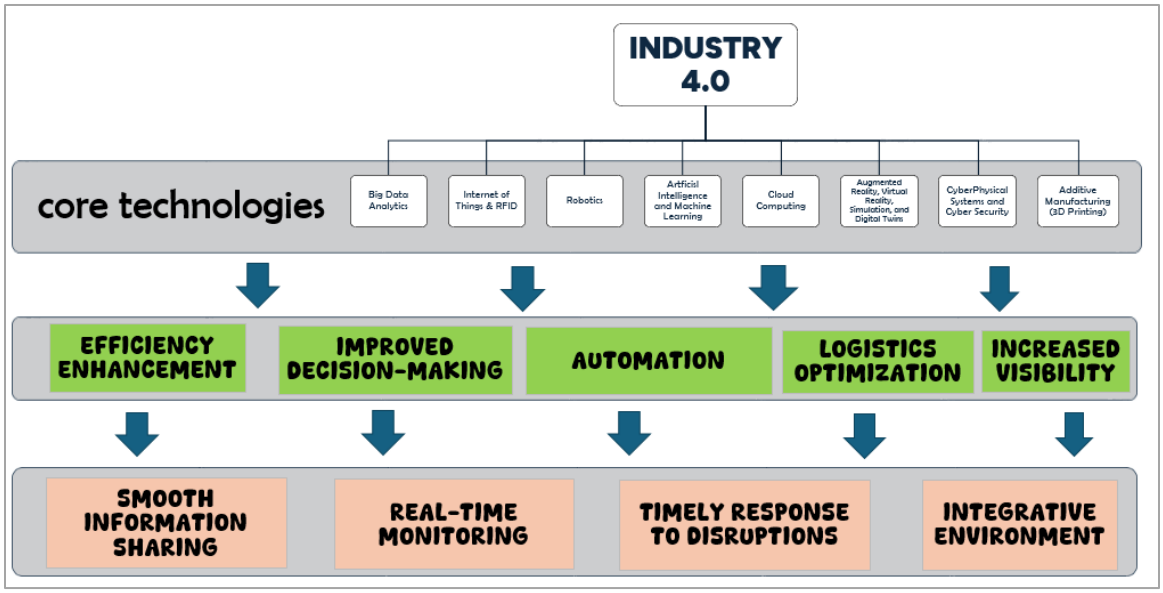

Figure 4.10
A Visual Representation of the Core Technologies of I4.0, their Benefits, and the Reflection of Resilience

4.4 Chapter Summary

This chapter has provided a rich summary of the results obtained through interviews with 19 different dairy sector operators in KSA and India which consisted of different stakeholders in the industry including those at dairy farms, processing plants, and also engaged in warehousing and logistics operations. The overall results have been divided into different themes generated based on repeated words and patterns of words. In this regard, the main themes obtained from the results of the study included: the types of I4.0 technologies being used in dairy supply chain which mainly include IoT, Blockchain Technologies, AI, Robotics, RFID, and others. The second theme is related to the benefits provided by the adoption of I4.0 technologies where the key benefits have been categorized under subthemes including efficiency enhancement, improved decision-making, automation, logistics optimization, increased visibility, traceability, and sustainability. However, the respondents have reported several challenges that restrict the implementation of I4.0 technologies and enjoy their real benefits in supply chain operations. These

challenges have been categorized under theme 3 with several subthemes including lack of skilled human resources or lack of expertise, incompatible infrastructure, lack of resources, data privacy, and security issues. Finally, the last theme talks about the resilience obtained through the implementation of I4.0 in supply chain operations. The results have discussed different measures to assess the resilience achieved while the main drivers of resilience have been categorized under sub-themes of theme 4 and they included: smooth information sharing, real-time monitoring, timely response to disruptions, and increased sustainability obtained through positively impacting the environment. Based on these results, the next chapter provides a detailed discussion and achievement of the research objectives of this study.

The application of I4.0 in dairy supply chain analyzed using SIRI framework in the form of horizontal integration processes with the help of interview results of selected stakeholders in dairy industry. In this regard, it has been found that an application of I4.0 helps in achieving seamless collaborative system across entire supply chain. In this research, the application of I4.0 in negligible at dairy farms, however, it is being applied at processing plants and logistics operations to some degree. However, there are many obstacles to effectively integrate the processes and achieve the required results where the prime challenges include incompatibility due to lack of integration of different technologies and lack of technical assets to accommodate effective implementation of these technologies. An overall maturity assessment of I4.0 in the dairy sector has been assessed using the following SIRI framework based on the interview results:

Table 4.8
Application of SIRI Framework to Evaluate I4.0 Maturity at Dairy Supply Chain in India and KSA (Adapted framework from Smart Industry Readiness Index (SIRI))

Sl. No.	Dimension			Assessment Note
1	Process	Operations	Vertical Integration	The overall system is well integrated using digital technologies; however, more robust application of technologies with vertical integration are required.
2		Supply Chain	Horizontal Integration	This is a challenging area which faces difficulties of lack of integration due to diverse systems followed by different stakeholders in the entire supply chain. Major companies are in the initial phase of Horizontal Integration of their systems.
3		Product Lifecycle	Integrated Product Lifecycle	The overall product lifecycle has varying degree of integration since the processes used by different stakeholders in the supply chain are diverse. This dimension under the framework is in the lower side in almost all companies participated.
4	Technology	Automation	Shop Floor Automation	Shop Floor automation at processing plants has been reported to be higher for large companies since the processing plants normally use machinery to process the raw material of dairy products. But this is limited in medium or small firms and farming side of some of the major companies also.
5			Enterprise Automation	Processing plants in the dairy sector have been reported to be using ERP systems largely to manage their warehouse functions and inventory

				management. With this, lower human intervention is needed. Large companies are having different ERP systems, majorly SAP is used as wide application.
6			Facility Automation	The overall processes at facilities are not generally automated rather they are performed automatically. Some of the large companies are having building management systems which include most of the access control and facility requirements, fire systems etc.
7		Connectivity	Shop Floor Connectivity	Connectivity of shop floor or production facility is low with other systems due to lack of harmonization of technologies used by different units. But large companies are in the process to cover Wi-Fi coverage in the facilities incorporate all IOT devices, especially on greenfield projects.
8			Enterprise Connectivity	The processing plants are working at greater connectivity within themselves, however, their connectivity with external stakeholders has lesser degree of automation. Some of the large companies are having interconnection of process systems and Enterprise systems, but it is limited in overall both countries.
9			Facility Connectivity	The connectivity of facilities with external stakeholders is negligible, but facilities connectivity within business is in the initial phase in most of the large companies.

10		Intelligence	Shop Floor Intelligence	Processing plants are largely using AI systems for different activities that lead to greater automation at plants.
11			Enterprise Intelligence	The enterprises have lesser degree of intelligence to integrate their processes.
12			Facility Intelligence	The overall processing facilities have negligible or no intelligence to coordinate the entire supply chain.
13	Organization	Talent Readiness	Workforce Learning & Development	Workforce learning and development is quite important and needed at facilities to guide the usage of I4.0 technologies. However, this is not provided to a satisfactory level.
14			Leadership Competency	Management within the supply chain is aware of I4.0 benefits, however, due to different challenges they are reluctant to implement it.
15		Structure & Management	Inter- and Intra-company Collaboration	The inter and intra companies' collaboration is usually carried out through emails or another form of communication while the usage of I4.0 for this purpose is limited.
16			Strategy & Governance	Strategies are being formulated especially at processing plants, distribution centers, and warehouses to accelerate the application of I4.0, however, the same is not being implemented at dairy farms.

CHAPTER V:

DISCUSSION

5.1 Introduction

This chapter covers the outcomes of this research based on interviews with Automation, IT, Operations, Engineering, Projects, Supply Chain, and Farm Managers of the dairy industry in India and KSA. The responses received from interviewees about the impact of Industry 4.0 in the supply chain of the dairy sector will give us insights into driving recommendations and conclusions for better outcomes. Respondents were asked about the implementation of Industry 4.0 in the entire supply chain i.e. from supplier to customers via inbound and outbound logistics and the potential benefits of transforming the traditional supply chain into a digital supply chain. Interviewees were also asked about the issues and challenges they face in addressing the research questions and meeting research objectives.

5.2 Addressing Research Questions and Research Objectives

The study aimed to check the impact of Industry 4.0 in the Supply Chain Management of the dairy sector. For this purpose, interview sessions with 19 employees belonging to the dairy sector of India and KSA were conducted to answer the research question. The major research question that needs to be answered is: How does Industry 4.0 impact the resilience of supply chain management of the dairy sector in India and KSA? To address this research question, sub-questions have been formulated; how Industry 4.0 has affected the supply chain of the dairy sector? How can the dairy sector bring resilience into its supply chain using Industry 4.0?

There are four central objectives of this research; to investigate the Industry 4.0 technologies used in SCM of the dairy sector; to evaluate the application of Industry 4.0 in SCM of the dairy sector of Saudi Arabia and India, to understand the challenges posed to

the SCM of the dairy sector for implementation of Industry 4.0, to recommend different solutions for practical application of the fourth industrial revolution in SCM of the dairy sector of Saudi Arabia and India.

To accomplish the objectives of the research, interviews of 19 different area managers at farms, processing plants, and supply chain of dairy sector of India and KSA each were conducted. This qualitative research used coding and thematic analysis based on the structure of words used in Industry 4.0. After conducting interviews, it was observed that the operators of the large dairy units of KSA are more motivated towards Industry 4.0 as compared to those of India. Participants were asked about the technologies used in Industry 4.0, the advantages of implementing 4.0, the challenges they face for practical implementation of Industry 4.0, and the resilience bought by Industry 4.0 in the supply chain of the dairy sector. A detailed discussion of results along with the proposed objectives is done in the coming portion.

Achievement of Research Objective 1

To investigate the Industry 4.0 technologies used in SCM of the dairy sector.

The first objective of this study is to investigate the industry 4.0 technologies used in SCM of the dairy sector. Based on the interview conducted with 19 respondents, it has been observed that implementation of I4.0 at dairy sector is limited in both the countries and the dairy industry is yet to reach I3.0 level. There is negligible implementation of new technologies at dairy farms, however, at processing plants, new and latest technologies have increasingly been used. When it comes to dairy farms, few farms are willing to transform their traditional supply chain into an advanced and digital supply chain. The responses from different farms, processing plants, and supply chain managers of large dairy industries were taken by conducting one-on-one interviews. To meet this proposed objective, themes, and sub-themes were outlined. The main theme to meet this objective

was about the technologies of Industry 4.0 that are used in the supply chain of the dairy sector along with the subthemes that include the Internet of things (IoT), RFIDs, Robotics, Artificial Intelligence, Block Chain, and Big Data Analytics, and etc. The results indicate that though, KSA is ahead in adopting Industry 4.0 in its processing plants, but the dairy farms of country are not focused enough with new technologies. Most of the farms are even not reaching the level of I3.0. On the other hand, India is gradually implementing Industry 4.0 in the dairy sector, but it also needs large efforts to transform the dairy supply chain. Their results resonate with the results of previous researchers (Alessa, 2023).

According to the respondents' answers, several technologies are being used in both countries in the dairy sector to boost efficiency and to make the entire supply chain robust and effective. In this regard, first of all, Big Data Analytics are being used which provide solutions that help the dairy sector overcome barriers that are related to management, sustainability, and monitoring. The respondents greatly emphasized the perks of using big data to analyze different data in real time simultaneously. The enormous amount of data generated by the supply chain of the dairy sector is stored and updated using big data. The results conducted by Kazancoglu et al., (2021) also showed a significant positive impact of implementing big data in the dairy supply chain to mitigate risks and potential barriers that could affect the overall efficiency. Respondents increasingly reported PAT (Prediction and Analysis tool) used by them mainly at dairy processing plants to predict the total production. As concluded by (Kashyap et al., 2023) accurate forecasting of production in dairy sector is linked with three global sustainability goals: preventing a shortage of food, reducing waste, and minimizing the dairy sector's ecological footprint. The results indicate that 5 out of 10 Indian respondents and 7 out of 9 KSA respondents supported the fact that the use of big data is an effective way to increase the productivity of the dairy sector by eradicating risks.

Moving forward, according to the results of interviews, it is commonly observed that many operators at dairy processing plants are using the Internet of Things to collect and disseminate information throughout the value chain. This positive impact of IoT on improving the entire dairy supply chain and even logistics was discussed in the previous study conducted by Kazancoglu et al., (2022). The results indicate that Internet of Things-enabled technologies are already helping industrialists collect data and transform it into understandable information to minimize potential supply chain risks. Industry 4.0 paradigm is uplifting the significance of Predictive Maintenance (PdM) for production and processing of dairy goods. PdM is dependent on Internet of Things (IoT), which have digitalized connections for intelligent perceptions. IoT is empowered with the capabilities of data science, to achieve of aim of digitalization. This digitalization helps the supply chain managers to make efficient decisions for better productivity yield (Compare et al., 2019).

As discussed by Kazancoglu et al., (2022), dairy supply chains are more vulnerable because any minor roadblock in the supply chain can have bad consequences on the overall dairy industry. Regular monitoring of data by using IoT as discussed by respondents, the chance of loss decreases. It is observed that all the interviewees second the positive relationship between IoT and risk mitigation of the supply chain.

Blockchain has been widely used in the dairy supply chain of India. The respondents claim that they are using Blockchain for reliable infrastructure of the supply chain and to enhance the nutritional value of dairy products. According to respondents, they combine Blockchain and IoT to enhance the nutritional value at their plants. The same has been witnessed in a recent study about Blockchain in the dairy supply chain to bring resilience to the supply chain and mitigate risks and uncertainties (Kasten, 2019). Blockchain can be used to overcome dairy supply chain-related issues by increasing

products' traceability and safety (Vincent et al., 2022). Thus, our study is streamlined with previous research. According to the results, 5 Indian respondents and 2 KSA respondents supported the benefits of Blockchain at processing plants and supply chain while no evidence of application for Blockchain has been observed at farms in both countries.

Robotics is another technology largely discussed by the respondents. In this regard, only few respondents are currently using Robotics in their dairy supply chain and some are planning to install Robotic machines to enhance milk and cheese production and reduce labor costs. However, currently, there are not used at farms rather at warehouses for bottling, labeling, and packaging. The results are correlated to previous research where research observed that sometimes 50% of total production cost is labor cost (Spain et al., 2020). However, the respondents of current research have discussed that the implementation of robotics is the main solution to match the needs of a rapidly growing population while its use is currently negligible in dairy supply chain. Robotic automation in the dairy sector promotes more hygienic products and enhances overall productivity. This significance has been discussed by farmers during interviews, and the studies conducted by (Jayadevan et al., 2023; Prasad, 2017) also provided the same results. Interviews concluded that 4 Indian respondents and 7 KSA respondents supported the above impact of robotics on the supply chain of the dairy sector, however, their application is quite limited in processing plants while there is no application of robotics at dairy farms majorly.

Artificial Intelligence has the potential to improve the dairy supply chain by optimizing operations, enhancing quality, lowering cost, and improving the overall performance of the dairy sector. Respondents of both India and Saudi Arabia have focused on its advantages as it can monitor and analyze data for quality checks during production. The same positive points of AI have been discussed in the studies conducted by Huerta-

Soto et al., (2023) and Alsharidah et al., (2020). Respondents are using AI in dairy industries to make the supply chain visible in real time, allowing companies to follow the right track from the manufacturer to the consumer. AI-powered tools can be used to raise quality and make the entire supply chain more competitive. However, Forecasting based on AI to reduce the bullwhip effect and effectively match product supply and demand has been explained by a few respondents. It implied that the application of AI technologies though, limited but exists in dairy sector. To conclude the conducted interviews, it can be said that 5 out of 10 Indian respondents and 5 out of 9 KSA respondents agreed to the fact that artificial intelligence has a certain positive influence on the supply chain of the dairy sector.

RFID is another technology used in dairy sector. From the interviews results, it is safe to say that India and KSA, both countries are implementing RFIDs (radio frequency identification) in the dairy supply chain to enhance the quality and quantity of dairy products side by side. Moreover, the result indicates that both countries are using RFIDs to keep updated records, monitor animals, and remove all roadblocks while producing and delivering dairy products. The same results have been studied in the previous research conducted by Malik et al., (2022) where they concluded that RFIDs provide real-time data to make wise decisions. The farm manager of KSA observed a clear difference before and after implementing RFID. This up-to-date information immensely decreases fraud and increases the accountability of operations. The same conclusion was given by Rouibah et. al, (2011). The results showed that 6 respondents belonging to the dairy sector of KSA, and 5 respondents belonging to the dairy sector of India supported the direct positive impact of RFIDs on the dairy supply chain.

Today's customers have more awareness as they demand better customer services, a transparent supply chain, detailed information about the products and the resources, and

real-time location of the products they demand. The suppliers also need real-time monitoring of up-to-date information and transparency in their supply chain. These demands can only be fulfilled by utilizing I4.0 in the dairy sector. Different technologies like simulation, big data analytics, and RFIDs can be used to achieve the desired results for both suppliers and customers. Digitalizing every phase of the supply chain from sourcing, procurement, operations, and storage to delivering the dairy products to end users can make the coordination easy by integrating all steps of the value chain. The conflicts, possible hurdles or roadblocks, anticipated risks, and fluctuation in demand and supply can be stabilized and solved with the help of I4.0 (Cruz-Mejía et al., 2019). Industry 4.0 vision for the dairy sector is to bring excellence in operations and to implement information and communication technologies. The proactive maintenance, enhanced production, smooth logistical chains like automated processing and packaging lines, reinforced by sensors for quick detection of adulteration with upgraded management of real-time data. The fluctuation in consumer demand has increased the need for I4.0 to reduce the waste of perishable dairy goods and to efficiently meet the demand of consumers. With the help of I4.0, warehouses are also shifting to cloud-based services which can improve the inbound and outbound logistics because warehouse operators will have up-to-date data through real-time operational visibility that can enhance asset utilization, productivity and safety of products. The transformed warehouse can facilitate the automation in worker scheduling, aligned with automated robotic handling equipment in the processing plants which can result in immaculate interoperability between requesting, processing, stocking, and dispatching of dairy products to end consumers. Similarly, transportation and logistics with the help of RFID, GPS, and WIFI can give alert to the employees and consumers at the arrival of carrier which ultimately can save the time and unnecessary delays. The

transformed fleet management can easily track the exact location of carrier and expected time of delivery (Raparla et al., 2022).

After conducting the interview, it is admitted that price, convenience, and taste are considered “traditional” value drivers, and safety, health, wellness, experience, and social impact are the “evolving” drivers. The evolving drivers need transparency from the dairy industries. It is suggested that dairy producers should pave ways to optimize the output without giving up on safety and product quality. The industrial revolution in the dairy sector is seen in both dairy processing plants and at farm levels (Burke et al., 2018).

The results compiled after collecting qualitative information from different stakeholders of larger dairy industries show that KSA is more destined towards Industry 4.0 technologies especially those which have large distribution channels and are comparatively producing large-scale dairy products than the dairy industries of India. However, larger application of these technologies has been reported at warehouses and processing plants while dairy farms have negligible application.

Achievement of Research Objective 2

To evaluate the applications of Industry 4.0 in SCM of the dairy sector of Saudi Arabia and India.

To meet the research objective two of this study, a theme has been established which is about the benefits of implementing Industry 4.0 in the supply chain of the dairy sector. It has been observed that with the implementation of I4.0, a huge amount of dairy waste and discharge are significantly reduced in the environment especially during production, processing, storing in warehouse, logistics, distribution, retail and consumption. The transformed dairy supply chain can reduce impact to the environment, enhance output, and decrease the cost of wastewater treatment. Respondents from both countries have discussed the significance of implementing Industry 4.0 in the dairy supply

chain accordingly. The benefits of implementing Industry 4.0 based on their KPIs are discussed by respondents especially their impact on the economy, environment, operations, and overall, on the United Nations' 30 global goals of sustainability. While conducting interviews, it is observed that there is variation in implementation of I4.0 technologies in both the countries where KSA has slightly higher achievements in this regard. Therefore, the dairy sector of KSA is growing rapidly because of the benefits of I4.0 than the dairy sector of India. The smooth functioning of the dairy supply chain of KSA is making it competitive and efficient. The advantages discussed by the respondents along with the previous similar studies are mentioned below:

Efficiency Enhancement

According to the 10 respondents of India of which 3 are IT Managers, 3 are Automation Managers, each one of operations, Projects, Supply Chain and farm managers 8 respondents agreed that an increase in the efficiency of the dairy supply chain has been observed in the dairy sector. Similarly, all contestants from KSA from different stream and companies, a total of 17 respondents agreed that the implementation of I4.0 is significantly enhancing the efficiency of the dairy sector. The application of advanced technologies in the dairy sector has smoothened the operations of the supply chain and has made everything traceable. A better inventory system in warehouse, effective logistics, better processing plants with decreased wastages and overall, less waste are other pros of I4.0 in the dairy sector, as discussed by the respondents. A better inventory system results in less chance of the occurrence of the bullwhip effect and fewer supply chain-related uncertainties. The respondents claim that they have applied Artificial Intelligence, the Internet of Things, and Mathematical Modeling for an efficient supply chain. These technologies have proven to be a game changer for the Indian dairy industry, making it a top producer of dairy products. Similar results were seen in studies conducted by Malik et al., (2024); Lahane et al., (2023),

and Kaur et al., (2023). The advancements achieved through the white revolution became game changers for the Indian dairy industry, establishing it as a top producer.

IoT has been used for vertical farming and various greenhouse facilities. These benefits are contributing towards sustainability, thus, helping KSA to achieve UN global goals of sustainability.

RFIDs have enabled and empowered stakeholders to timely make decisions based on real-time data. The logistics of dairy products are now more transparent through Blockchain and traceability technology. This has ultimately gained the trust of consumers because of the accuracy of the data. Similarly, real-time data is facilitating Automation, Supply Chain, IT, and Farm Managers to timely meet the demands of consumers, to maintain the required level of inventory and to use effective mode of transportation. This result resonates with the previous research of Ahamed et al., (2024).

Improved Decision Making

The autonomy of the production system including production equipment and operators is increased due to the use of I4.0 which supports two major processes; problem-solving, and decision-making processes. Several studies have been done previously that broadly cover this benefit which industries are taking through the implementation of I4.0 (Rosin et al., 2022).

The respondents explained how their decision-making skills have improved because of I4.0 technologies. This skill has allowed them to gain a competitive advantage. Real-time monitoring, real-time data, visibility, and tracking of market uncertainties have made the dairy supply chain lean, agile, and resilient. The resilient supply chain has empowered employees to make better decisions for better handling of the external environment and unforeseen disruptions.

With the adoption of I4.0, it has become more convenient to detect problems in a broad sense. The three-step process of problem solving explained by (Rosin et al., 2022) is; Validation of problem or opportunity, solution validation, and validation of implementation. The first phase considers capture-measure and gap-recognition. The collection of real-time information in the production system is done in the capture-measure system. The discrepancy between the expected and actual results is recognized in the gap recognition stage. Diagnosing the problem, searching for possible solutions, and proper selection of the right method are done in solution validation. I4.0 has made every step clear and transparent. Among all possible solutions, one that fits the situation will be implemented. The automated technologies using codes function accordingly (Rosin et al., 2022).

The feedback taken from respondents is aligned with the research of Yadav et al., (2022), that distribution stages are assisted by technologies by giving real-time monitoring, reduction in waste, and more innovative ways for logistics operations. The interviews conducted summarize those 5 Indian respondents and 6 KSA respondents supported the statement that I4.0 has enhanced decision-making skills.

Automation

The respondents have discussed various benefits of the application of I4.0 which also include automation in the milking process, processing, packing, and even delivery of dairy products. According to the results, 6 respondents each from both countries discussed the positive aspect of automation through Industry 4.0. They elaborated that engagement in precision live stocking has empowered them to recognize the behavior and well-being of animals. They discussed that they simply attach battery-based sensors to cows to check their feeding and milking habits. This automation is more seen in dairy farms of KSA while

India is lacking it completely at its farms, but its application has been reported at farms, distribution units, and warehouses.

Respondents of KSA acknowledged that they are in the early stages of using sensory systems on animals. They have not completely implemented Industry 4.0 in the dairy supply chain, so they have a scarcity of data, making the entire supply chain less automated and opaque. They are working on it by considering all the potential benefits of an automated supply chain cost-effective, less time-consuming, and better efficient through automated technologies like IoT, AI, and Big Data Analytics.

The emerging industrial revolution has meaningfully modified the dairy industry and led to considerable consequences for human health, the economy, and the environment. Despite the vital role of every single technology of Industry 4.0, the emergence of ground-breaking sustainable solutions is by simultaneously combining different technologies. The latest trends, market competition, more awareness among consumers, worldwide opportunities, and challenges have reshaped the existing dairy strategies for the production of dairy products (Hassoun et al., 2023).

Respondents have reported the benefits, but they should also have mentioned that the only solution to satisfy the growing demand of consumers, producing dairy products organically, and meeting sustainable goals is the application of Industry 4.0 worldwide. Recent studies have also emphasized the benefits of automating everything. IoT is used to automate cow feeding, customized nutrition plans can be made for every animal, and precise forecasting of milk production can be done for each cow. The researcher also explained that budget-friendly IoT solutions for quality assurance of cows' milk, the temperature, and heart rate of cows will further give information about cows' overall health. Through this automated process, it would be convenient for the farmers to timely detect disease along with adequate treatment and deterrence methods. The automated

method can select the most suitable treatment of animals based on environmental and physiological factors for the production of superior-quality milk.

Simple know-how is not enough for the installation of intelligent automation solutions. Knowledge and experience about the complexities of the processes and structures in dairy products are equally important. Another benefit that is discussed by the respondents is the on-screen messages and online displays keep everyone updated and it proves to be real-time monitoring. Through automation, suppliers can know the stock of dairy products, dispatches/receipts, and return on investments and losses, without any lapse. Efficient filling and packaging through automation are also not discussed by the respondents (Deshmukh et al., 2015).

In a nutshell, respondents from KSA were more confident and had more knowledge about I4.0 and its benefits because they are implementing it across their supply chain for better dairy products, animals' health, and lean management, to bring agility in each step of dairy supply chain and at the same time contributing towards achieving sustainable goals. However, the country needs good investment and proper planning to apply and hit the jackpot.

Logistics Optimization

Industry 4.0 leads towards logistics 4.0 which is also the major contribution of this industrial revolution. The innovation added by Industry 4.0 combined with logistics becomes Logistics 4.0. The major benefit discussed by respondents using I4.0 is logistics 4.0 which uses "Smart Products" and "Smart Services" to explain "Smart Logistics". The better logistics management has made the logistics agile and flexible. Any minor change or roadblock is immediately traced because of RFIDs and Blockchain which helps the companies to adapt them according to the foreseen changes (Barreto et al; 2017). Smart logistics according to respondents have helped the suppliers to maintain cordial relations

with consumers by managing their operations of logistics, route management, and selection of effective routes for inbound logistics and outbound logistics and maintaining the inventory effectively. The accurate forecasting of demand using Big Data Analytics that results in effective logistics management as answered by respondents is aligned with the previous research (Papadopoulos et al., 2022). The respondents have discussed the application of Food LogiQ software for managing suppliers' relationships. This software has given access to all suppliers of dairy products to assemble on a platform for the discussion of problems and solving problems together. This approach has made the entire supply chain transparent where all data is easily consolidated, problems are timely identified, complaints are registered and solved, and all suppliers come on one page. Similar findings were seen in the research of Roy et al., (2023). The Indian respondents believed that Industry 4.0 has added value to the dairy supply chain, especially in the production and processing stage, quality checking phase, logistics, and inventory management through Simulation, Genetic Algorithm, and Blockchain. Various past researches are seen with similar results Singh et al., (2023); Narassima et al., (2023); Kazancoglu et al., (2022). The results of this study are that 7 KSA respondents and 5 Indian respondents agreed with the above positive impact.

Increased Visibility, Traceability, and Sustainability

According to the responses collected from various people conducting interviews, it is concluded that Blockchain technology plays a vital role in making every step of the dairy supply chain transparent and visible and at the same time it facilitates traceability. The increased visibility is contributing to more accountability. Respondents have discussed the visibility of the supply chain but other aspects that could also be mentioned are decentralized supply chain and milk chain. Access to real-time information has enabled every person involved in the chain to make timely decisions whenever needed. Milk and

other dairy products are perishable goods that require a certain temperature and environment for preservation, delivery, and consumption. Increased visibility through a blockchain-enabled decentralized supply chain easily recognizes and timely addresses the arising issues of malnourishment caused by consuming adulterated dairy products. Blockchain is making the dairy supply chain tamper-proof, sustainable, and transparent. A transparent quality index that is mandatory in dairy supply chain is traceability because of increased toxic substances, fraudulent products, and excessive additives. The unavoidable need of traceability is also catered by blockchain by effectively utilizing resources, eliminating waste, and adhering to ethical standards to promote safety, quality which will ultimately help the dairy sector to have better supplier-customer relationship. Traceability is helping dairy sector to ensure food safety, facilitate regulatory, and encourage sustainability.

Apart from this, its focus is also on maintaining the nutritional values of dairy products, detecting adulteration and impurities, combating counterfeit products, enhancing the economic growth of the dairy sector, and promoting the overall revenue of dairy companies. The quality of milk is also sustained through the I4.0 technologies by keeping a record of pH, color, odor, fat content, grade, and turbidity. Respondents have discussed Food LogiQ as discussed previously, but they have not mentioned CatBoost (Categorical Boosting) which is an innovative machine learning algorithm used in the dairy sector to classify milk samples into low, medium, and high grades. This gives knowledge about milk quality and paves the way to develop a reliable and robust system that can ensure the veracity of dairy products. I4.0 is not only giving benefits to the dairy sector but also to the public by keeping the nutrition of daily consumed dairy products healthy. These factors were also discussed by Nukapeyi et al., (2024) but our respondents didn't shed light on this aspect. This qualitative research summarizes those 7 Indian respondents and 9 KSA

respondents agreed that the application of I4.0 increases the visibility of every activity involved in the dairy supply chain.

Achievement of Research Objective 3

To understand the challenges posed to the SCM of the dairy sector for implementation of Industry 4.0.

The objective that has to be achieved in this study is about the challenges that the supply chain of the dairy sector has to face in the implementation of Industry 4.0. To meet this objective, a separate theme has been set about the challenges of implementing Industry 4.0 in the supply chain of the dairy industry. The growing demand of consumers, market competition, lack of integration of technologies across entire supply chain, and the ever-changing trends and preferences have become one of the biggest challenges in the dairy sector. Lack of proper record keeping also poses challenges to the supply chain. Since the latest technologies require a huge amount for implementation, few respondents believed that it is costlier than the traditional supply chain and the return on investment (ROI) is less.

Lack of Skilled Personnel/Human Resources

It has been admitted by the respondents of KSA that lack of awareness, technical issues, culture, and unavailability of integrated data are major reasons for not adopting the latest technologies, especially in the dairy sector. According to the results, 7 respondents from KSA, and 8 respondents from India believed that the lack of skilled personnel and human resources is restricting the dairy sector from implementing I4.0. One of the respondents highlighted that top management believes in traditional ways of producing dairy products and is reluctant to go with the flow by adopting I4.0. A similar result is seen in previous research where the author concluded that the major challenge posed on the supply chain of the dairy sector is because of the few companies that are engaged in

aggressive price war tactics. The development of "Nitaqat" and "Saudisation" schemes are also promoting more labor work and less technology-based work. It would be difficult for the dairy sector to deliver high-quality dairy products in the market at a sustaining labor cost (Fadil, 2023). The respondents of KSA elaborated that unskilled manpower and their hesitation to use the latest technology are also becoming one of the barriers or challenges in using I4.0. The top management wants to make decisions on their own without decentralizing the processes. This centralized system has restricted the dairy sector from competing globally by utilizing I4.0 for the smooth functioning of every step involved in the supply chain (i.e. from supplier to consumer).

Incompatible Infrastructure

The older designs of the processing plants and farm infrastructures have not designed based on the latest technologies. Most of the current installations are not capable to adopt new technologies or not able to upgrade to a newer version. Similar challenges are in the supply chains due to incompatible systems to integrate the new technologies. Also, there are external incompatibilities in the remote area such as internet connectivity and road infrastructure limitations. The results indicate that 8 KSA respondents and 7 Indian respondents agreed that incompatible infrastructure is the reason for not applying I4.0 in the dairy sector. KSA has less demand for fresh dairy products than India. Also, unhealthy cows, limited veterinary doctors, unbalanced diets, and uneducated laborers are becoming barriers to the adoption of I4.0 (Høyer et al., 2019). More light should be shed on the challenges faced in the dairy sector for adopting tracking and tracing technologies. There is a plethora of research on the benefits of I4.0 but potential challenges to implementing these technologies need further research (Høyer et al., 2019; Hassan et al., 2021).

The current infrastructure and qualifications of existing laborers working in the dairy sector are not fully compatible with I4.0. Therefore, the process of adopting or

implementing I4.0 in the supply chain of the dairy sector is comparatively low. The implied demand uncertainty may cause a bullwhip effect in the dairy sector. Thus, to mitigate such risks and to meet the inconsistent demand for dairy products in fluctuating markets, the stakeholders are using traditional ways of producing, storing, packing, and delivering dairy products to end users.

Lack of Resources

Despite the high significance of I4.0 in the dairy sector, there are still several barriers that are refraining dairy sector players from promptly implementing I4.0 in their processes. After conducting interviews, it was observed that 7 KSA interviewees and 8 Indian interviewees mentioned that lack of resources is the major reason for not implementing I4.0 in the dairy sector. Implementing the latest technologies needs high investment, more awareness, and more skilled laborers to utilize the technologies in the best possible ways. Technological immaturity, low budget, lack of proper knowledge and awareness, increased customer demands, limitations in the latest technology, and absence of eco-innovations are major reasons behind this technological lag in KSA and India. The respondent answered that the implied demand uncertainties, lack of investment, and little knowledge about the usage and benefits of the Industrial Revolution are restricting companies from adapting themselves to the change. The same reasons were given in previous research that it is not easy to implement Industry 4.0 in the dairy sector as the products are perishable and farmers are reluctant to take any risk and are following the traditional way of producing and delivering milk (Kumar et al., 2024).

Lack of Technology Integration

The respondents have highlighted one of the most important challenges of poor and lesser technology implementation is lack of technology integration across the entire supply chain. The key players of the industry have varying degrees of software and technologies

that make it difficult to coordinate and integrate the processes with each other. It results in failed implementation of I4.0 or even I3.0 and I2.0 technologies. These results have full support from literature which implies that for the implementation of I4.0 across entire supply chain, there must be harmonization of the technologies and software package between all industry players (Zielinski et al., 2019; Rejeb et al., 2021; Sahu et al., 2020). During the interviews, it was observed that 7 KSA interviewees and 8 Indian interviewees mentioned that lack of Technological Integration between stakeholders is one of the major reasons for not implementing I4.0 in the dairy sector.

Data Security and Privacy Concerns

Another challenge posed by implementing I4.0 is data and privacy concerns. The respondents defended themselves that I4.0 means that a company is willing to share its data with everyone. The connected devices, real-time monitoring, and up-to-date information of every stakeholder can invade the privacy of everyone. The chances of misusing the data to defame the dairy companies are also high. Such privacy concerns are considered a big risk to the dairy sector. So, to avoid such risk, dairy farms are following traditional ways. It is safe to say that the world has become a global village, and everything that benefits us also has certain challenges and limitations linked to it. To avail of the perks of I4.0 in the dairy sector, it is necessary to address certain issues, challenges, and barriers that are linked with it beforehand. The results show that a total of 12 respondents discussed this privacy concern of which 5 respondents belong to KSA, and 7 respondents belong to India.

The dairy sector has to consider animal health, food safety, climate changes, welfare, sustainable land management, and dynamic markets while making any major decision (Klerkx et al., 2013). To cater to these challenges, innovation is not only required in technology-based production but is also required in organizational and institutional structures like supply chains, markets, land, labor, etc. The process of co-production is also

considered an innovation, where actors work along in a specific domain, cooperate, and coordinate all activities involved in the value chain to achieve desired results (Valerio et al., 2022).

It is seen in the results that KSA is somehow more indulged in I4.0 than India, even if Indian dairy sector is contributing more towards the economy and they are making ways to achieve sustainable goals with their green practices in the industrial sector. Farmers are using traditional ways of handling their perishable products and are addressing uncertainties with old methods because they are not ready to learn new technology. Factors that could affect the dairy supply chain are variations in lead times, high perishability, fluctuation in demands, and changing trends. The above-mentioned past research and the results of this research after conducting interviews are the same. The respondents discussed that the compatibility issues are preventing the top management from implementing Industry 4.0. It has been seen and discussed while conducting interviews of the people belonging to the dairy sector of KSA that dairy farms are usually located in rural areas where animals get more land and are near to nature for their proper growth and good health. Investing in rural areas requires huge investment making the implementation of I4.0 difficult and expensive. It would be difficult for dairy farms especially small dairy farms to invest in the latest technologies for tracing and tracking of dairy products (Hassan et al., 2021).

The gist of the interview is that implementing I4.0 is not an easy task, especially in India where dairy farms are located in rural areas. Lack of expertise, centralized system, limited resources, lack of awareness, resistance to adapt to new things, lack of infrastructure and various legal, political, social, environmental, and economic factors are depriving the farmers of the dairy sector to transform their traditional supply chain into the digital supply chain. Although government bodies in India and KSA are working to

overcome these challenges more effort is required to implement the basic to advanced technologies.

Achievement of Research Objective Four

To recommend different solutions for practical application of the fourth industrial revolution in SCM of the dairy sector in Saudi Arabia and India.

To meet objective four of this research, a theme has been made about the resilient dairy supply chain through Industry 4.0. The aptitude to prepare, react, recover, and nurture a supply chain in the face of disruption is known as supply chain resilience. Four phases that are linked with this ability are readiness, reaction, recovery, and development (Ahmad, 2018). Resilient supply chain refers to the ability of the supply chain to respond quickly to changes and bring agility and leanness to the entire supply chain. The resilient supply chain is a reactive measure to help the organization mitigate the risks and effectively promote the smooth functioning of processes (Ali et al., 2017). Different questions were asked to respondents to examine whether the dairy sector has brought resilience to their supply chain or not. Implementing Industry 4.0 directly contributes to a resilient supply chain. According to the responses taken from respondents of India and KSA, the dairy supply chain is less agile and resilient because of the barriers that the dairy sector has to face for implementing I4.0. Low-level implementation results in less resilience and agility in the dairy supply chain. Respondents of KSA stated that they are well aware of the fact that I4.0 has a positive impact on the resilience of the supply chain, but they also admit the fact that it's a time-consuming process and needs good investment, ample knowledge, and consistency to utilize the benefits of I4.0. The Indian participants believed that although the application of I4.0 is costly it becomes cost-efficient if its long-term benefits are considered. Different key performance indicators were discussed in the interview session where respondents of both countries gave positive and negative reviews about KPIs which

include waste reduction, timely delivery, logistics, lead time, shipping errors, customer feedback, order fill, stock shortages, productivity, yield, processing parameters, quality, etc. The above results are aligned with the previous study where the researcher stated that digital technologies integration and implementation of Industry 4.0 can significantly transform the traditional supply chain, where the resilience of SC enables it to effectively respond to disruptions and roadblocks (Tortorella et al., 2022). The sharing of up-to-date and relevant knowledge facilitated the supply chain to become resilient. Furthermore, the coordination of the supply chain is supported by I4.0, which is vital to promote sustainability (Yadav et al., 2022). The results show that KSA is making ways to bring resilience to supply chain operations by implementing I4.0 and India is lagging because of the reluctance of top management and small-scale farmers to invest in digital technologies. I4.0 promotes smooth information sharing, real-time monitoring, timely responses to disruptions (agility), and an integrative environment. The government of KSA and public organizations have taken an initiative the smart government strategy. The goals of this initiative are to be flexible, agile, innovative and capable that can help the economy to grow by transforming old methods into digital methods. The aim of Vision 2030 is to set an example globally by bringing technology especially in citizen-centric solutions. According to the proposed plan, once the citizen will get comfortable with the digital system, more digital services will be provided. The success of KSA is dependent on smart and timely scaling (Singh & Alhabbas, 2024).

To deliver value and exclusive public and private sector services, digitalized services are provided to maintain quality, security, privacy, and authentication. KSA is trying to make smart cities by utilizing industry 4.0 in all fields to promote sustainability, improve living standards, manage and utilize resources and assets. Internet of Things, Big Data Analytics, Artificial Intelligence are being employed to boost public involvement and

to optimize entire operations. To address the urban difficulties and to cater the need of current citizens without compromising on the needs of future generation. Innovation and technologies are being promoted to stimulate economic and sustainable growth. By establishing smart technology like Big Data Analytics, Robotics, and sensors into existing infrastructure technologies, the public and private sectors are increasing effectiveness, sustainability, and safety (Alanazi, 2023).

Smooth Information Sharing

The smooth flow of information among all stakeholders (internal and external) leads to a resilient supply chain. The connected devices through IoT are bringing flexibility and responsiveness by keeping all stakeholders updated through predictive maintenance system. The strong connections, collaborations, and agility create synergy and integration which leads to resilience. Similar results were discussed previously that IoT, big data, and cloud computing are promoting smooth collaborations that ultimately bring resilience (Bigliardi, 2021). The advantages discussed while conducting the interview were: strong decision-making power, innovative strategies to gain competitive advantage, better animal health, accurate forecasting, welfare, improved working environment, transparency, application of sensors, and many more. These advantages add value to the entire chain of the dairy sector and can help farmers ensure and maintain the quality of dairy products. 19 respondents (belonging to KSA and India) were asked the same questions about smooth information sharing from which 6 respondents from India and 6 respondents from KSA agreed that smooth information sharing can bring resilience to the supply chain. These results are in line with the results of Prakash, 2022 and Sallwa, 2023.

Real-Time Monitoring

Another important factor that is important to make the supply chain resilient is real-time monitoring. Many respondents agreed that real-time monitoring has a direct positive

impact on the resilience of the supply chain. It is seen that real-time monitoring results in enhanced productivity saves cost by reducing waste, improves customers' satisfaction, helps in proactive inventory planning, maintains inventory, improves inbound and outbound logistics, strengthens decision-making skills, and increases collaboration and synergy. The efficacy of the supply chain is enhanced through real-time monitoring. Live tracking helps the company to maintain the latest record because it improves visibility and tracking. Respondents highly emphasized different technologies like Robotics, IoT, and AI that are helping dairy sectors keep an eye on every activity. The biggest benefit a dairy farm can take from real-time monitoring is to match the demand and supply and to reduce waste. Less waste will promote more green and sustainable practices, which can ultimately help the farms achieve the global sustainability goal. The results of this dissertation are aligned with the previous research (Gehlot et al., 2022; Farooq et al., 2022; Arshad et al., 2022; Alonso et al., 2020). The results show that 8 out of 10 Indian respondents and 8 out of 9 KSA respondents agreed that real-time monitoring can make the supply chain resilient. Live tracking can save time, eradicate errors, reduce cost, and enable managers to quickly make decisions at crucial times.

Timely Response to Disruption

The results indicate that a timely response to disruption can also be possible if the dairy sector has implemented I4.0 for smooth information sharing and real-time monitoring. The alignment of these activities backed by various digital technologies like robotics, automation, big data analytics, IoT, RFIDs, etc. can make the supply chain of the dairy sector resilient. Timely response to any distortion or disruption is the agility of the supply chain that shows the ability of the chain to effectively make decisions whenever required without delay to prevent loss and other risks. The collaboration among suppliers, manufacturers, consumers, and all other stakeholders to synchronize the operations, make

strategic plans, mitigate risks, and achieve mutual goals were explained by respondents. Other areas that have been improved and highlighted during the interview were knowledge management, robustness, flexibility, privacy, collaboration, and visibility. For instance, cyber threats were removed by using AI and Blockchain. Quick response to unforeseen circumstances can prevent big losses, maintain market shares and the industry's image or reputation, and satisfy customers' needs, beneficial for all stakeholders including the well-being of animals. Results show that 13 out of 19 respondents supported the concept while 2 Indian respondents and 3 Saudi respondents contradict the above-mentioned impact. The global outbreak of COVID-19 badly affected perishable goods, especially dairy products and the only solution to beat such a challenging situation is to make the supply chain resilient by timely responding to hurdles and disruptions (Shanker, 2022). Similar results were seen in past research where the author shed light on the use of Blockchain for flexible resilient strategy (Sharma et al., 2022; Abdulmalek et al., 2020).

Integrative Environment and Cost Reduction

Sustainable practices by considering three major factors (impact on environment, economy, and society) can enhance the overall productivity of dairy sector. The preservative technologies and better precautionary measures for the safety of food can reduce waste significantly. The respondents elaborated that with the implementation of I4.0 technologies, the dairy sector can make a meaningful impact on people, the planet, and overall profit. The overall supply chain expense can be reduced by transforming the traditional ways of producing, storing, and delivering milk to digital methods and processes. The interviewee believed that mass recalls can highly be avoided by using technologies to detect adulterated products. The information provided by the respondents of KSA and India highlighted strategies and ways to prevent risks, enhance milk production, effective waste management, and improve logistics. The extremely hot weather

of KSA needs many precautionary measures to safely deliver perishable dairy products without compromising on quality and quantity. The latest technologies are used to control feed waste, water waste, land, and manure. The results show that I4.0 has a significant positive impact on the environment by making the farms more environmentally friendly to protect humans and animals from extreme weather conditions. The results indicate that 8 out of 10 total Indian respondents and 4 from a total of 9 KSA respondents supported this positive impact. These results are aligned with the previous research done by Malik et al., (2024); Kumar et al., (2023) and Al-Mutairi et al., (2023).

5.3 Chapter Summary

This chapter focused on a detailed discussion of the results and the previous research that is linked with the outcome of this study. Four proposed objectives along with the themes and sub-themes were elaborated to have a detailed understanding of the opportunities and challenges a dairy sector has to face by implementing Industry 4.0. The benefits of I4.0 technologies on the supply chain have been explained to meet the objectives of the study. On the whole, it has been found that in both KSA and India, the application of I4.0 technologies in dairy supply chain is almost equivalent and is at quite lower level which needs to be enhanced by removing obstacles.

CHAPTER VI:

SUMMARY, IMPLICATIONS, AND RECOMMENDATIONS

6.1 Summary

Industry 4.0 is rapidly developing and so are theoretical and conceptual understandings. Industry 4.0 is becoming vital because the essential strategic component that is enhancing the manufacturing processes' efficiency and determining decisions regarding globalization strategies are linked with the implementation of Industry 4.0. Industry 4.0 have transformed the traditional supply chain of dairy sector by reshaping the entire dairy sector. Real-time exchange of data with the help of smart technologies also known as Industry 4.0 has provided a golden chance to reshape the conventional supply chain of dairy sector and to effectively cope with the unpredictable supply chain breakdowns. The dairy supply chain is a complex system that includes production, processing, and supply of dairy goods from farms to end users without compromising on quality of products. This research has been carried out to investigate the different technologies of the fourth industrial revolution that can be used and benefit the dairy sector. The main purpose is to get a deeper understanding of the modern technologies of Industry 4.0 and evaluate their impact on the resilience of the supply chain of the dairy sector. Specifically, this research has focused on the suitability of different technologies of Industry 4.0 in various areas of dairy sector and to evaluate their impact on overall performance and productivity. This qualitative research has also focused on the benefits of Industry 4.0 in dairy sector especially in production of dairy products, animal welfare, prevention of diseases, and effective management of waste through lean management, milking equipment management, and on the assurance of quality standards and safety of farm products.

With this aim in mind, the study has been carried out using qualitative research methodologies. In this regard, the overall research has been based on interpretivism philosophy to collect and analyze the data. An inductive research approach has been used to examine the research problem in a more detailed and flexible manner while cross-sectional research design has been used to conduct study. The sample of study consisted of 10 respondents from Indian dairy sector and 9 respondents from Saudi dairy industry consisting of both farm, dairy processing plant, and supply chain managers. The convenience sampling technique has been selected to draw samples from population while the information was collected using structured interviews technique. In this regard, the questions asked from the respondents have also been attached in the appendix section. The analysis of collected data has been carried out using thematic analysis technique which has helped to generate key themes to comprehensive address the research objectives. For the overall data collection and analysis process, ethical guidelines have been followed where information about the personal identity of respondents or their affiliations has not been obtained or discussed. Additionally, the purpose of data analysis has been to make theoretical and practical contributions which can be of significant importance.

The results of data analysis helped generate four main themes and a number of sub-themes. In this regard, the main themes of study included: Industry 4.0 technologies used in supply chain of dairy sector, benefits of implementing Industry 4.0 technologies in supply chain of dairy sector, challenges of implementing Industry 4.0 in the supply chain of dairy sector, resilience brought by Industry 4.0 in dairy sector supply chain. A further investigation has shown that the main Industry 4.0 technologies used in dairy industry supply chain consisted of Big Data, Blockchain, Internet of Things (IoT), RFIDs, and robotics. It has been observed that transparency and traceability in the supply chain of dairy sector are greatly enhanced with the implementation of I4.0 because the Blockchain, IoT

and big data are ensuring the safety and authenticity of dairy products. An increase in customer satisfaction by gaining customers' trust and plummeting contaminated dairy products have also been seen with the help of I4.0 especially in KSA. The results have indicated that the application of these technologies is more prevalent in KSA dairy sector while Indian dairy is lagging behind. Moreover, the application of these technologies has been reported at dairy processing plants to certain degree while dairy farms have no implementation of these technologies. The second themes of study which includes the benefits of I4.0 in dairy supply chain has sub-themes of efficiency enhancement, improved decision making, automation, logistics optimizations, and increased visibility, traceability, and sustainability. These benefits have been reported by respondents from both the countries to the extent to which they have implemented the mentioned technologies. Despite the unlimited benefits of I4.0, it has been observed that not all dairy industries have adopted this advanced technology because of certain limitation. This interview-based qualitative study revealed that there are still several limitations that hinder its adoptability. Among several obstacles acknowledged in the literature, installation and maintenance cost, inadequate infrastructure, and lack of experience, resistance to change and adapt according to the advanced technologies, and geographical diversity are major roadblocks for complete implementation of I4.0 in dairy sector. The challenges reported by respondents included lack of consistent infrastructure, lack of skilled human resources, lack of resources, incompatible infrastructure, data security and privacy concerns. Fear of misuse of data or the use of data without consent, information sharing, and intellectual property issues have also discouraged the respondents from implementing different technologies of I4.0. Lack of awareness, technical facilities and training, and less AI specialists are also the barriers for not applying advanced technologies in dairy sector. It has been widely provided that Indian dairy sector has been facing more challenges for implementation of

I4.0 at its dairy industry. Moreover, the incompatible infrastructure, lack of resources are more prevalent in Indian dairy industry while KSA has been facing increased shortage of skilled personnel. These barriers are affecting the effectiveness and efficiency of dairy supply chain of India and KSA. It is safe to say that developing countries like India lag when it comes to the adoption of advanced technologies as compared to KSA because of difference in economy, resources, infrastructure, awareness, and environment. India faces greater challenge due to limited access to economic incentives, advanced technologies and a smaller number of AI specialists which as a result make India second to KSA. Additionally, lack of consistent infrastructure and technologies among stakeholders in the supply chain of both the countries has been one of the most important hurdles for I4.0 implementation. Finally, the impact of I4.0 technologies in the form of resilience brought by these technologies has been investigated where it has been found that I4.0 helps in smooth information sharing, real-time monitoring, timely response to disruptions, and integrative environment which all leads to bring greater resilience. All these points have been equally highlighted by respondents from both the countries. In this way, the results helped to achieve the research objectives as outlined in Chapter 1 of this study. In brief, industry 4.0 in the dairy supply chain is reshaping the conventional way of production, processing, distribution, and delivery of milk products by bringing sustainability in production and improving overall quality of processes. This qualitative research showed a drastic improvement in management, traceability, visibility, and food quality by incorporating different technologies of Industry 4.0 in dairy sector. Fundamental pillars of dairy sector are food safety, and milk quality. This research has also covered the benefits of I4.0 in dairy sector especially in detection of contaminated products and diseases to maintain the quality and safety of dairy goods. Different technologies of I4.0 that along with their potential benefits like anticipation of risks, disease, milking-pattern, and delivery

method for dairy products have also been studied. In terms of animal welfare and automation, major tasks of dairy industry mainly monitoring of animal health, milking, promoting sustainability and improving overall productivity of dairy products, fourth industrial revolution has played a leading role in dairy industry.

6.2 Implications

This research has added to theoretical knowledge while its practical implications are also strong. In this regard, based on results and analysis of the study, several recommendations can be made for policymakers. These mainly included the following:

First of all, the implementation of I4.0 technologies requires uniformity or consistency of technological infrastructure throughout the supply chain. Thus, the players in the industry must collaborate and integrate with each other for this purpose.

Lack of resources has been reported as one of the key hurdles for the implementation of I4.0 in the supply chain of dairy industry. For this purpose, government assistance can serve to provide the key role to enhance the affordability of these technologies. The governments need to offer subsidies and collaborate to encourage implementation of I4.0 technologies.

The results of the study have also revealed that dairy farms have limited application of the latest technologies. For this purpose, there should be greater awareness and enhanced availability of key technologies for the companies. The process should be started with implementation of few important technologies that can serve as base to accelerate the implementation of further advanced technologies.

From the interview results, it has been found that the aspects of sustainability have received minimal focus from the key players in the dairy supply chain of both the countries, especially for Indian dairy industry. However, sustainability is not only an essential requirement, but it also has the potential to bring greater resilience in the dairy sector

operations. Thus, focus and awareness enhancement should be made in terms of sustainability to achieve better results.

6.3 Recommendations for Future Research

The research has been carried out to make an in-depth investigation to the role of I4.0 technologies to bring greater resilience in the dairy supply chain. The results of the study have provided important insights that are beneficial to make important recommendations for policymakers. However, the study contains certain limitations that need to be addressed, and future studies should be conducted to overcome these limitations. In this regard, the important limitations and proposed future research areas include the following:

First of all, the research has been qualitative in nature that has contributed to provide an in-depth analysis of the role of I4.0 technologies in the dairy sector. However, future research needs to be carried out to investigate the research problem in a measurable way. In this regard, a quantitative study can be conducted where the impact of I4.0 technologies on different resilience aspects can be measured to determine the magnitude of impact of different technologies.

The study has been conducted to include various stakeholders in the overall supply chain of the dairy industry in two countries that has provided a comprehensive investigation. However, future research needs to be conducted to pay more focus on each stage of the supply chain. Thus, future research can be conducted separately for dairy farms, logistics companies, warehouses, and processing plants to explore in greater detail of each stage of the supply chain.

Another important area is the sample size of study. Since the current research was focused on two countries and due to different limitations of time, cost, and geography, only 10 respondents from India and 9 respondents from KSA with a total of 19 respondents has

been selected which, despite the limitations, has helped to provide important insights into the research problem. However, future research can be carried out to include more respondents i.e. with a greater sample size to further investigate the research objectives. It is important to mention that due to geographical limitations, and a smaller number of respondents, the findings of this study cannot be generalized for other geographical regions because of different culture, economy, technology, and legal factors. Future researchers can conduct similar study but in different geographical area that have different infrastructure, economy, technology, and culture to evaluate the impact of Industry 4.0 on supply chain of dairy sector.

This research has investigated the impact of I4.0 on dairy industry of KSA and India. Future of dairy sector of KSA and India and long-term impact of applying advanced technologies of I4.0 especially on triple bottom line, operational efficiency, and sustainability can be investigated by future researchers which could encourage managers and farmers to adopt latest technologies for better output yield.

6.4 Conclusion

This thesis has examined the transformative impact of Indusrty 4.0 technologies on supply chain management within the dairy sector. The findings indicate that the integration of advanced technologies such as IoT, Big Data Analytics, Artificial Intelligence, and Blockchain has significantly enhanced the processes of dairy supply chains.

Despite these advancements, the study also highlights several challenges, inluding the high investment cost, the need for technological infrastructure, and the requirement for skilled personnel to manage and maintain these technologies.

Future research should focus on exploring long-term impacts of these technologies on the dairy supply chain and investigating the potential for integrating other emerging

technologies. Moreover, studies should consider the socio-economic implications of these advacements, particularly for the small-scale dairy farmers.

Ultimately, the transition to Industry 4.0 in the dairy sector represents a significant step towards creating more efficient, sustainable, and resilient supply chains. This thesis underscores the importance of continued innovation and investment in technology to drive the future of dairy farming and supply chain management.

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APPENDIX A

SURVEY COVER LETTER

Dear (Recipient's name)

I hope this letter finds you well. I am writing to invite you to participate in an interview I am conducting as part of my research on Industry 4.0 in Supply Chain Management in Dairy Sector. This is the part of the thesis for Doctorate in Business Administration by Nijas Pampadiyil Hameedu rawther under Swiss School of Busienss Administration, Geneva.

After the Initial survey, there will be an interview consists of ten major questions further sub-questions, and it will take approximately an hour to complete. Rest assured that your responses and your identity will remain confidential, and all information gathered will only be used for the purpose of this study. I greatly value your perspective and would appreciate your honest feedbacks.

I truly ppreciate your time in helping me with this important research. Your contribution will make a meaningful impact in the outcomes of my study.

Hoping for your active participation.

Sincerely,

Nijas Pampadiyil Hameedu Rawther

APPENDIX B

INFORMED CONSENT

Informed Consent Form for Participation in Research

Study Title: Impact of Industry 4.0 on Supply Chain Management: An Application into Dairy Sector, A research study of DBA (Doctorate in Business Administration) under SSBM (Swiss School of Business Management) University.

Interviewer/Researcher: Nijas Pampadiyil Hameedu Rawther

You are invited to participate in a research study. Before you decide whether to participate, it is important that you understand the purpose of the study and your involvement will entail. This form provides details about the study and your rights as a participant.

The purpose of this study is to investigate the impact of I4.0 on the Supply Chain in Dairy Sector in India and Kingdom of Saudi Arabia.

If you agree to participate, there is a Initial Survey questionnaire attached with this request, please complete the same and send back, further you will be asked for your avilability to have a interview session. The interview session will approximately last for an hour. Interview Questionnaire will be shared in one month advance prior to the interview.

All the data and information collected during the study will be kept confidential and use solely for research purposes. Your responses will be identified by serial numbers, not your name.

Your participation is entirely voluntary. You have the right to withdraw at any time. If you choose not to participate, your decision will not affect your relationship with me.

By signing below, you agree to participate to this study. You confirm that you have read and understood the information provided.

Participant's Name: _____

Signature:_____

Date: _____

APPENDIX C

INTERVIEW GUIDE

The participants were selected for this interview is based on their expertise, knowledge and willingness to share the information. There were two questionnaires prepared for the interviews. First questionnaire for the survey with questions to understand the basic information of the facility and interviewee related to their experience and awareness of Industry 4.0. This has helped to identify the right participants for the interviews. The following questions are used for the interview related to this study. Questions are prepared and communicated with all participants in one month prior to the interview. All interviews are conducted through physical meeting or remote meeting. All the interview notes are recorded for the analysis.

Survey Tool - Preliminary Questionnaire

- Name of the Participant ……
- Designation of the Participant…….
- Experience in years …….
- Company name ……
- Company type ……... Small (up to 500 employees) / Medium (500 to 1000 employees) / Large (more than1000 employees)

Survey Questions

1. Do you have the awareness of Industry 4.0? YES/NO
2. Are there any awareness/training programs for Industry 4.0 in your organization? YES/NO
3. Do you have the knowledge on Industry 4.0 technologies? YES/NO

4. Does your company own Farming, Process plants, Warehouses, Logistics and Supply chain of your business? YES/NO
5. Does your company have ERP implemented in all of part of supply chain? YES/NO
6. Does your company have a digitalization strategy? YES/NO
7. Does your company have any vertical and or horizontal integration? YES/NO
8. Does your company carry out any Industry 4.0 readiness assessment? YES/NO
9. Does your company have any plan for the facility upgrade to meet Industry 4.0 standard? YES/NO
10. Are you willing to join further part of this survey which will last for one hour? YES/NO

Main Interview Questionnaire

1. What are the Industry 4.0 technologies implemented in your facility? Please give brief details on their area of application. (leading I4.0 technologies are listed below as a guide)
    1.1 IoT and RFID
    1.2 Big Data and Analytics (E.g.: Blockchain technology)
    1.3 Artificial Intelligence and Machine Learning,
    1.4 Augmented Reality, Virtual Reality, Simulation and Digital Twins,
    1.5 Cyber physical systems and cyber security,
    1.6 Robotics
    1.7 Cloud Computing
    1.8 Additive manufacturing (3D Printing).
    1.9 Simulation
2. What are the benefits of Industry 4.0 implementation in your facility? Please explain in detail. Can you share your experience of implementing those technologies?

3. Did you involve in any of the I4.0 technology implementation in your company, if then what was your role? What are the challenges experienced from the I4.0 projects implemented within your facility?
4. How do Industry 4.0 components supported in terms of Quality and freshness of the products by getting the traceability, visibility and real time data throughout the supply chain?
5. Which KPIs, particularly those related to sustainability, resilience, performance and efficiency, have been significantly improved by applying those technologies?
6. Is there a vertical or horizontal integration of the technologies or systems within the plant/business, if then, can you give the brief on integration details, and also explain difficulties of integration with different suppliers/systems and the benefits obtained from it?
7. Has there been a significant/noticeable improvement in terms of performance of dairy operations and reduction in the environmental impacts after adapting the Industry 4.0 technologies in your facility?
8. Do the implemented technologies support the dairy operations in developing innovative methods/ products along the supply chain? From your perspective, which technologies/tools/software/working practices are most applicable and effective to the dairy operations in a developing country?
9. Will your suppliers and retail customers support cooperating with the adoption of new technologies to track and trace the I4.0 technologies?
10. How much do the implemented technologies support achieving the UN goal to build resilient infrastructure, promote sustainable industrialization, and foster innovation? Is there any I4.0 maturity assessment carried out in your facility like SIRI (Smart Industry Readiness Index)? If then, can you please share the details.

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