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Evaluating the Industry 4.0 Readiness of Dairy Industry: A Case Study in India

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ABSTRACT

This research paper presents a comprehensive case study aimed at evaluating the Industry 4.0 (I4.0) readiness of the dairy industry. Utilizing a survey method, the study focuses on various dairy plants situated in the Delhi/NCR region, Haryana, Mohali, and Chandigarh. The assessment is conducted through the application of a maturity model, Impuls maturity framework, enabling a nuanced examination of the readiness levels in key dimensions such as technology integration, data analytics, automation, and collaborative networks. The findings offer valuable insights into the current state of preparedness within the dairy industry, identifying potential areas for improvement and strategic advancements as it gears up for the challenges and opportunities presented by the fourth industrial revolution. This research contributes to the broader discourse on Industry 4.0 adoption in specific industrial sectors, providing stakeholders with actionable information for informed decision-making and future-proofing strategies. The overall maturity level of the dairy industry, assessed using the Impuls maturity framework, is found to be 2.60. This indicates a moderate to high level of readiness for Industry 4.0 adoption within the sector.

Keywords: *Dairy Industry, Industry 4.0, Impuls maturity framework, big data, RFID.*

I. INTRODUCTION

Industry 4.0 is the future of the world that brings a new technological paradigm in all sectors of industry. The use of cutting-edge technologies, including cyber-physical systems (CPS), the Internet of things (IoT), cognitive computing, big data analysis, etc., will be a feature of I4.0 that can bring a whole turmoil of technological paradigm in the dairy industry (Shrouf et al., 2014). As the world's top producer of milk and accounting for 23% of it, the Indian dairy sector has enormous potential. From 146.31 mn tons in 2014–15 to 209.96 mn tons in 2020–21, the country's milk output has increased at a compound annual growth rate of roughly 6.2%. With Industry 4.0, the use of cutting-edge technologies, data, and internet-connected devices that can communicate with each other and process huge amounts of information results in the high-speed production of better-quality products (Rüßmann et al., 2015). Significant infrastructure investments in processing, chilling, transport, calf feed, etc. are needed to support the dairy

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industry's market expansion. Also, there are many untapped prospects in sectors including exports, organic/farm fresh milk, and value-added dairy products. Industry 4.0 can provide firms with a variety of advantages, including enhanced productivity, reduced costs, higher profits, and more innovation.

Some research shows the method for sustainable development and anomaly detection in machinery in Industry 4.0 (Mohan et al., 2022), (Guan, 2022). Various algorithms like hybrid generic (Luo & Chen, 2022), infrared image edge recognition (Chen, 2022), and Multiple Fixed Target Location Algorithms (Yang, 2022) are used in various industries for better implementation of Industry 4.0. Various quality assessment methods for products, machinery, services, and faults are proposed for evaluating the final product to check whether it fulfills all the required benchmarks as per Industry 4.0 specifications and standards (Aljumaili et al., 2014; Amanbek et al., 2021; James et al., 2017; Kamat & Kittur, 2019; Shojaie & Kahedi, 2019).

To adapt and succeed in I4.0 deployment, industries need to advance in the following nine dimensions of I4.0 namely:

1. **Big data and analytics:** Dairy industry, supply chain, and feedback system digitalization may make massive data sets available for analytics, enabling optimization and real-time decision-making at all stages of the value chain.
2. **Autonomous robots:** Robotics have emerged in the past few years making robots more intelligent that can communicate with each other and with humans and perform actions independently. Robots can be used in the dairy industry that uses high-tech AI agents and microprocessors resulting in lower costs and improved capabilities.
3. **Simulation:** Simulations are the mechanism in which real-time situations can be run and certain uncertainty can be avoided or eliminated. Simulations enable the testing of machines, materials, and operations before running the program in real-time. This will help in low-cost operations and wastage can be minimized.
4. **Horizontal and vertical system integration:** Horizontal and vertical integration requires interconnected systems that can communicate with each other so that companies can have connections between engineering, production, management, and services. These kinds of interconnected systems are rarely possible. Application of I4.0 enables fully automated value chain connections within and between interconnected companies possible.
5. **Internet of Things (IoT):** The term "Internet of Things" refers to a category of objects or entities that may link to one another and exchange data over the Internet or other

communication networks. These smart objects possess sensors, internet connectivity, processing ability, and computing capabilities.

6. **Cyber security:** Cyber security is protecting the data, employees, their personal details, details of the organization, etc. against cyber-attacks. I4.0 brings smart machines, connected to the internet or any local network, fed with tremendous amounts of sensitive data. There is always a threat of cyber-attacks. Thus, cyber security is the need of the hour when organizations are exposed to the leakage of sensitive data hacking of systems, etc.
7. **The cloud:** I4.0 brings data sharing within and between the companies and cloud technologies consist of data sharing and computation of the data. With the application of I4.0, all the systems from production, distribution, and services share data and thus include cloud technology. For example, systems like control systems and monitoring systems, etc. require cloud technology.
8. **Additive manufacturing (3D printing):** A group of technologies known as additive manufacturing can build three-dimensional (3D) structures using digital designs. There is a limitation to using this technology in the present time but with the advancement of technology, there will be a significant development in several fields such as engineering, medicine, etc. There are two advantages of additive manufacturing: first, it allows the construction of impossible structures using conventional methods of manufacturing. The second advantage is that there would be minimal wastage of resources if the technology is handled effectively. If additive manufacturing is included in the network system, it could bring more flexibility and adaptability while designing parts.
9. **Augmented reality:** augmented reality is the technology where the visuals from the digital world are integrated with the visuals of the real world and can be applied in effective decision-making and different procedures of processes in real-time. For example, workers receive visual information regarding the repair of a specific part of their machine implanted in their site.

In addition to these technologies, another one that is frequently discussed in other studies on embedded systems and CPS (Cyber-Physical Systems) (Kagermann, Wahlster, & Helbig, 2013; Ustundag & Cevikcan, 2018) is not addressed by (Rüßmann et al., 2015). The networking platform known as CPS makes it possible to integrate the physical and digital worlds. CPS requires embedded systems with the following two features: First, a well-developed network between the physical and the digital units for the real-time transmission of information, and

Second, Secondly, intelligent data processing, decision-making, and computational capabilities that assist physical systems. To accomplish these tasks, CPS requires RTLS technologies, RFID sensors, actuators, controllers, and network systems that can link physical and digital infrastructure (Ustundag & Cevikcan, 2018).

To be successful in I4.0, companies need to be advanced in the above-mentioned dimensions of technology. The term "readiness" describes the state of being conversant with the above-mentioned dimensions but not being able to implement the same (Haddara & Elragal, 2015). If we say check the readiness then the purpose is to assess the development process and where the company or industry stands in the process. The term Maturity is a state that refers to completion, perfection, or readiness for the implementation of I4.0. Maturity models help in assessing the readiness of the industry for implementation of the I4.0 by checking the whole system in different parameters of I4.0. With this regard, the Impuls maturity framework is used for evaluating the dairy industry's readiness to implement I4.0 in this paper. The Impuls model is chosen because of its comprehensiveness and its practical implications on the dairy industry.

Numerous studies have been carried out to evaluate the level of readiness and maturity of I4.0 implementation in manufacturing companies almost all over the globe. We were unable to discover any significant studies that demonstrate how well the Indian dairy sector has used I4.0 so far.

There are several objectives of this work:

- To get a clear understanding of various maturity models.
- To collect data for checking the readiness level and maturity of Indian dairy plants adopting I4.0.
- To identify the issues regarding the implementation of I4.0.
- To help dairy plants in overcoming the issues or limitations in the implementation of I4.0.

Several studies propose novel nature-inspired metaheuristic Algorithms to predict behavior and solve real-world optimization problems are proposed in (Abualigah, Diabat, Mirjalili, et al., 2021; Abualigah et al., 2022; Abualigah, Yousri, et al., 2021; Agushaka et al., 2023; Ezugwu et al., 2022). The integration of the Internet of Things (IoT) and The Internet of Drones (IoD) into the dairy industry represents a significant stride towards Industry 4.0, fostering increased efficiency, data-driven decision-making, and innovation (Abualigah, Diabat, Sumari, et al., 2021).

The advent of Industry 4.0 has revolutionized numerous sectors, offering transformative potential through advanced technologies such as automation, data analytics, and the Internet of Things (IoT). However, the adoption and implementation of Industry 4.0 technologies within the dairy industry, particularly in developing countries like India, remain under-explored. While extensive research exists on Industry 4.0 in manufacturing and high-tech industries, there is a noticeable gap in the literature concerning its application in traditional sectors such as dairy production. This study discussed various research gaps like Regional Focus, Readiness and Maturity Levels, Factors Influencing Performance, Data-Driven Decision Making, Policy and Practical Recommendations, and Sector-Specific Insights. This research provides a nuanced understanding of the current state of technological integration, data utilization, and operational practices across various dairy plants in the Delhi/NCR region, Haryana, Mohali, and Chandigarh. It highlights the critical areas that need attention for successful Industry 4.0 implementation and provides actionable recommendations for industry stakeholders, policymakers, and researchers.

II. CONCEPTUAL FRAMEWORK AND LITERATURE REVIEW

A. Evolution of Industry 4.0

The industrial sector and its procedures are constantly changing. Historically, the development of sophisticated and efficient new production methods has been driven by the demand for competitive advantages in corporate integration and manufacturing. Since the start of industrialization, there have occasionally been technological advances that have revolutionized the idea of industrial production, known as "industrial revolutions". Figure 1 shows the history of industrial revolutions. By the end of the 18th century, mechanization and steam engines had undergone the first industrial revolution. With this, a transformation took place from agriculture to an industrial society; the second industrial revolution was based on mass production and excessive use of electrical energy which involved mechanics in manufacturing during the beginning of the 20th century; and Around 1969, the third industrial revolution began, and it was marked by the use of information and communication technologies and the widespread of digitalization to boost manufacturing process automation which largely took over and replaced labor-intensive work. The industrial sector adapts to utilizing intelligent systems, robotics, and intelligent mechatronics after the Third Industrial Revolution (Kunii, n.d.). As a result, the idea of Cyber-Physical Systems (CPS), which unites Internet of Things (IoT) technology and manufacturing systems to create a whole new age of industrialization known as Industry 4.0, was born (Lee, 2015).

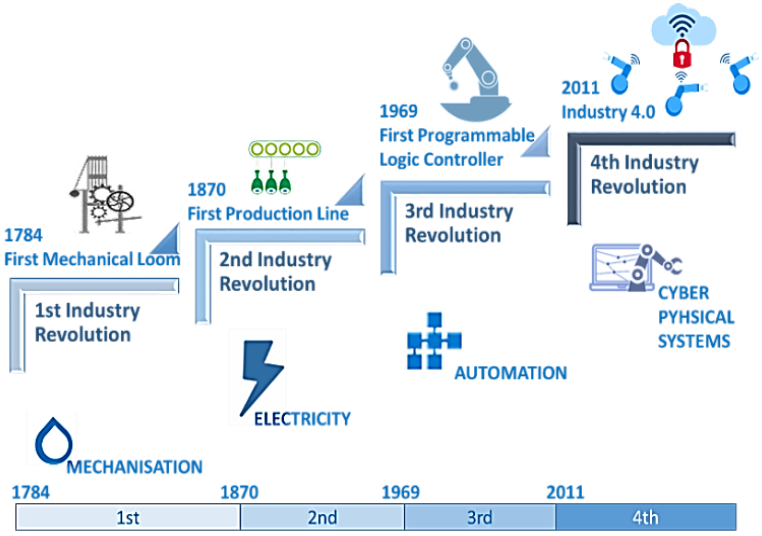

Fig. 1. History of Industrial Revolutions

B. Industry 4.0

Industry 4.0 is defined by (Kagermann, Wahlster, Helbig, et al., 2013) as "the technical integration of CPS into manufacturing and logistics and the use of the Internet of Things and Services in industrial processes. This will have implications for value creation, business models, downstream services, and work organization" (Kumar et al., 2020; Müller & Voigt, 2018). The dynamic business environment has increased the demand for smart business processes, automated systems, and utilizing smart goods to cope with advanced economies and for the growth and growth of the economy. The entire process pushes the economies to progress toward a revolution of technology named the Fourth Industrial Revolution with an advanced and digitized business world. This caused the use of smart machines, and computers and automated the whole business processes and integration which in turn enhanced the industry-specific smart data. Since the idea of industrialization has changed, technical paradigms have significantly changed the advancement of mechanization, electrical synergy, and the widespread application of digitalization (Brandherm & Kroner, 2011). With the use of smart technology, the concept of a smart factory has emerged that uses automated machines fully equipped with sensors and autonomous systems. This concept of I4.0 was first introduced in Germany and afterward, it was renowned for its high technological approach (Lasi et al., 2014). The new face of factories involves robots working with the workers facilitating them in different processes. Industry 4.0 aims to implement structures and systems that are interconnected, intelligent, and self-controlled (Anderl, 2014). As a result, processes built on Industry 4.0 technologies offer smart, innovative, value-added processes that are more flexible, reliable, and efficient, making

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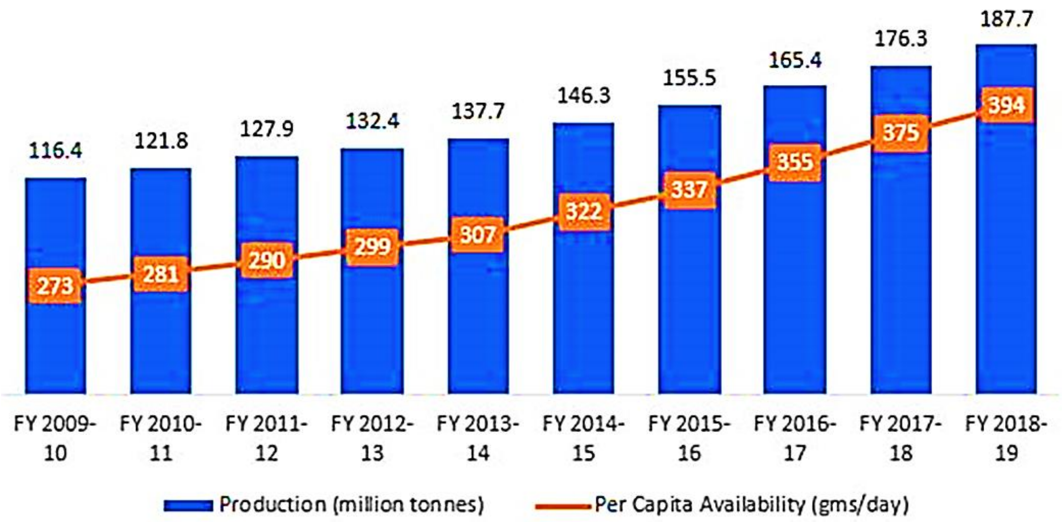
operations smart (Hermann et al., 2015, 2016). Therefore, new business opportunities and new business models are provided by technological advancement (Stock & Seliger, 2016).

C. Dairy Industry

An important factor in the growth of the Indian economy is the country's agriculture and allied sectors. The agricultural and allied industry comprises, namely, agriculture, forestry, fishing, horticulture, milk production, sugar production, etc. Around 58 % of the population in India relies on agriculture as their main source of income. Agriculture and associated sectors saw a 4% improvement in Gross Value Added (GVA) in FY20 (India Brand Equity Foundation, 2021).

At 535.78 million, or roughly 31% of the world's population, India has the greatest population of livestock. From 198 MT in FY20 to 208 MT in FY21, or 10 percent extra milk would be produced in the nation. India produces one-fifth of the world's milk, ranking among the top-producing nations in the world. With 187.7 million tons of milk produced in FY 2018–19, production rose at an average rate of 5.5% per year during the past ten years as shown in Figure 2.



(Source: National Dairy Development Board)

Figure 2: India’s Milk Production and Per Capita Availability

When compared to developed nations, where an organized sector manages 90% of the surplus milk, India's dairy industry is extremely disorganized, with milkmen handling 60% and organized co-operatives and private enterprises handling 40% of the surplus milk. Due to this technological advancement in the dairy industry is minimal resulting in insufficient milk quality and quantity, and excessive milk waste.

India is the world's largest milk producer and has immense potential for growth and sustainability. Dairy and animal farming are the secondary sources of revenue for most of the farming sector in our nation, behind crop production. The Government of India (GOI) is putting a lot of effort into launching stakeholder beneficiary schemes/programs. The Government of India has already brought some popular good dairy development schemes such as the National Programme for Bovine Breeding and Dairy Development (NPBBDD), Rashtriya Gokul Mission (RGM), National Dairy Plan (NDP), National Mission on Bovine Productivity, Dairy Processing and Infrastructure Development Fund (DIDF), Animal Husbandry Infrastructure Development Fund (AHIDF), etc., but the need of the hour is to match with the update technological level.

As an initiative under Start-up India-2020 by the Government of India (GOI) to upgrade dairy management using high-end, conventional technologies, it becomes important to assess the existing technological readiness level and pave the way for improvement. The whole globe is changing with a new technological vision under Industry 4.0. However, within the food sector, the dairy industry plays a vital role when it comes to process management. It’s a well-known fact that the effect of Industry 4.0 in shaping the dairy industry is not easy to see. After all, the dairy sector is different from other sectors like manufacturing, aviation, and some factories or warehouses, because in this case an enormous amount of information has to be processed for some significant statements for milk production. It’s evident that Industry 4.0 is already opening up massive benefits for the dairy industry and helps in predictive maintenance and to evaluate the repair and maintenance cost which makes way for estimating major financial gain/loss of dairy maintenance.

In the present research work, we will try to evaluate the present level of adoption of Industry 4.0 in the Dairy Industry by making use of an Industry 4.0 maturity framework. This will assist in the identification of the readiness level of the dairy industry to embrace the Industry 4.0 implementation strategy.

D. IMPULS Maturity Model

The framework of the maturity models has its roots in software engineering from the late 1970s (Nolan, 1973; Van Looy et al., 2013). The concept of maturity has developed into a tool for comparative, prescriptive, or descriptive procedures (Röglinger et al., 2012). Maturity models are used as a descriptive assessment when the assignments are per-circumstanced whereas, in the case of prescriptive assessment, a detailed project or a pathway of development is prescribed for benchmarking both internally and externally (Peruzzini et al., 2017). Thus, maturity models are used for measuring the maturity of the systems, processes, and whole industries.

There are digital models given by both researchers and practitioners such as Fraunhofer IFF (Schmidt et al., 2015) and Acatech (Schuh et al., 2017). All these models are based on a digital transformation. Industry 4.0 is a result of evolutionary digital transformation consisting of a series of sequential digital stages with increased complexity (Kagermann, Wahlster, & Helbig, 2013). Their foundation is based on the concept of cumulative capability perspective (Leyh et al., 2017).

Several techniques have been developed to evaluate how technology will affect businesses, in which the Technology-Organization-Environment Framework is the most popular (Depietro et al., 1990). This model is based on the conceptual framework stating "The process by which a firm adopts and implements technological innovations are influenced by the technological context, the organizational context, and the environmental context". Technology context encompasses both internal and external technologies that are significant to the company, The organization comprises the qualities and resources, and environmental factors include internal factors like competitors, size, and structure of the industry and macroeconomic factors as external environment (Tidd, 2001). Analytical maturity framework models are developed by both academicians and professionals where companies can assess their conditions on their own or collaboratively with the developers using a guided interaction (Chanias & Hess, 2016).

Different models are based on the IT architecture and capabilities of the companies concerning IoT and CPS (Jæger & Halse, 2017; Katsma et al., 2011; Lee et al., 2015; Weber et al., 2017; Westermann et al., 2016). Other kinds of models are based on manufacturing companies showing that Digital transformation has a distinctive impact on the existing business paradigms (Carolis et al., 2017; Ganzarain & Errasti, 2016; Lee et al., 2015; Schumacher et al., 2016). These maturity models are a good start offering a range of maturity measuring techniques such as strategy-specified goals, digitization checkups, guided interaction models, etc. The limitation of these maturity models is that their application is restricted to being strategy-specific and impact assessment is related to I4.0. Other models merely depict how financial decisions are linked to I4.0. The issue is that to track efficient improvements, there is no quantifiable relationship between the maturity levels and the performance indicators. Thus, after assessing different maturity models the Impulse maturity model is used for this study as it is comprehensive, practical, and most of all tried and tested. The Impuls Foundation in Germany, a think tank for the mechanical engineering industry organization, developed the Impuls maturity model (VDMA, 2019). Their motive was to assess the maturity of the manufacturing companies related to development as per I4.0 and create an I4.0 maturity model for the same

(Lichtblau, 2015). The model was constructed in two phases. The First phase involved doing a literature review, and different surveys (Motyl et al., 2017) interviews and workshops were conducted by the scientists of the Cologne Institute for Economic Research with the companies working on I4.0, and in the second phase the impact factors were selected as the dimensions of the model.

1. Smart Factory

The concept of smart factor is very well conceived in Industry 4.0, which advocates minimal human interaction in production and logistics systems with autonomous guiding, controlling, and monitoring. The Cyber-Physical system (CPS) has developed under the smart factory concept, which includes Connection, conversion, cyber, cognition, and Configuration. The industrial sector including milk plants needs to pay more attention to incorporating Industry 4.0 technology, such as the Internet of things, cyber-physical systems, augmented reality, etc. The Cyber-Physical system comprises cyber systems and physical systems with intelligent Analysis using structural equation modeling (SEM) (Jain & Ajmera, 2019), intelligent control, self-growing knowledge base, perception, and decision-making (Arumugam et al., 2022).

2. Smart Operations and Maintenance

No doubt, smart operations in Industry 4.0 have brought digital transformation for developing novel supply chain management (Weyer et al., 2015). Smart operations in Industry 4.0 opened new opportunities for digital transformation for developing entirely new supply chain management. Interestingly, smart operations are incomplete without self-maintenance systems, which take into account data acquisition systems, different smart sensors, End-user systems and processes, adaptive systems, and wireless sensor networks.

3. Smart Products

The smart products have a provision of real-time monitoring of production processes with the assistance of Information Communication and Technology (ICT) components such as RFID tags, sensors, RFID, interfaces, bar codes, etc. This use of ICT assists in better communication between customers and manufacturers.

4. Data-driven services

As mentioned in smart factories and smart operations, the industry must have better data-driven services to add value for the customer and assist customers' decision-making processes with data and analytics (Besutti et al., 2019). This domain is important from the Milk industry perspective because this domain promotes the physical goods that are sold must contain sensors so that they can transmit, receive, and process the required information.

5. Human System Integration

The system integration aspect includes user-centric design for a better human-machine system and better control of life cycle costs with improved system safety. Moreover, the term "human system integration" (HSI) refers to the process of integrating human demands and human-related considerations into the design of systems.

6. Employees

The maturity level in this domain is ascertained by determining the skills of the employees and comparing the steps taken by them to acquire new skills and qualifications.

7. Cyber Security

It has been observed in the past that all organizations are subject to operational risk and cyber-attacks. To deal with the issue of cyber security, strategies should be secure, and vigilant and Information technology strategy is essential from the outset of every business.

Based on the seven factors of assessment of readiness level, there are three categories of businesses: newbies, learners, and leaders. With the help of these levels, it becomes easier to draw conclusions and summarize the collected data results.

Objectives

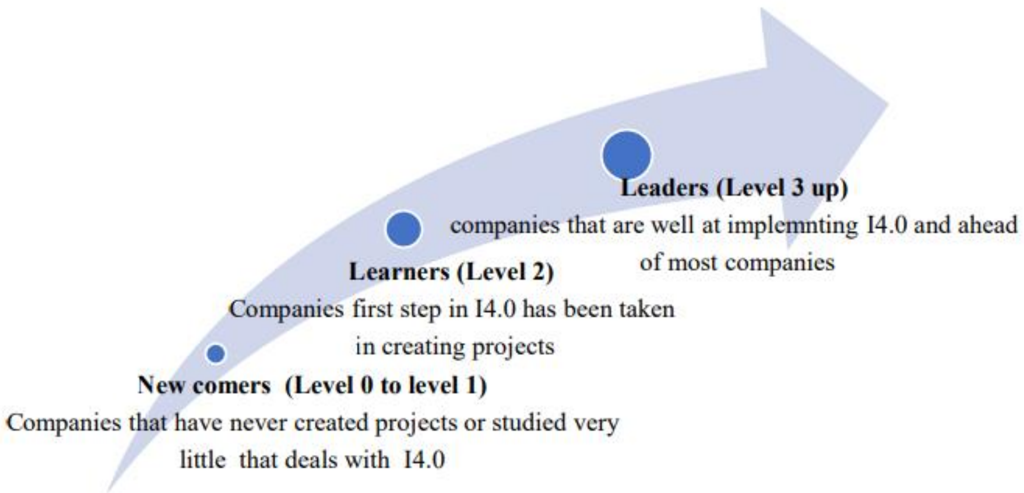


Figure 3: Impuls six Readiness Levels

Figure 3 shows the Impuls readiness levels indicating the distinguishing features of newcomers, learners, and leader organizations in Industry 4.0.

1. To evaluate the present degree of Industry 4.0 adoption within the Dairy Industry by employing an Industry 4.0 maturity framework.
2. To find out the major factors that affect the performance of dairy plants while implementing Industry 4.0.
3. To evaluate the issues and challenges faced by dairy plants while adopting Industry 4.0.

III. Research Methodology

A. Research Design

We employ a quantitative research design to evaluate the industry 4.0 readiness of dairy plants in the Delhi/NCR region. The methodology involves using a survey instrument to collect data, which is then analyzed using the Impuls maturity framework and various statistical techniques. Three criteria are used to select a maturity assessment model among the available models: comprehensiveness, practicability, and historical track record. This survey-based model is the Impuls Industry 4.0 assessment model (Lichtblau, 2015).

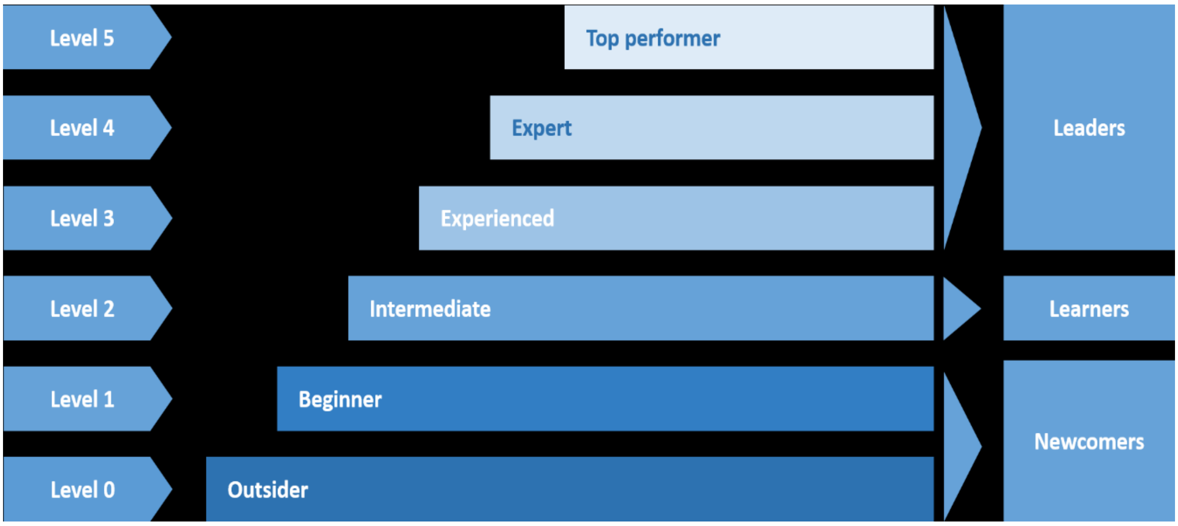


Figure 4: Six Levels of Industry 4.0 Maturity Model

Figure 4 provides more context, a generic representation of six industry 4.0 maturity model levels. The six maturity levels may be divided into three categories of a firm to help better summarize the findings and draw conclusions regarding Industry 4.0 development and circumstances (Lichtblau, 2015).

-- Newcomers (levels 0 and 1) refer to businesses that have taken very little or no action in response to Industry 4.0.

--- Learners (level 2) are businesses that have started the implementation process for Industry 4.0.

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--- Leaders (level 3 and higher) are businesses that are making good progress in implementing Industry 4.0.

B. Data Collection

Primary Sources were used to collect the data and some more data was gathered using secondary sources. This paper employed a stratified sampling technique to ensure representation from different Delhi/NCR region zones. Several dairy plants were approached, and responses were obtained from the plants, ensuring a robust sample size for statistical analysis. The survey approach is used to gather the primary data. To evaluate the current level of I4.0 adoption in the Dairy Industry, a questionnaire has been prepared using the Impuls maturity framework model and circulated among the dairy industry. The questionnaire corresponds to seven domains i.e., organization and strategy, Smart operations, smart products, data-driven services, workforce, and cyber security and smart factories. For the study, we have used only those respondents who have strategic and operational knowledge of I4.0, as the Impuls maturity model takes a comprehensive method. In accordance with the variables, we have created a questionnaire with several sections. This paper aims at evaluating the improvements in the readiness level of the dairy industry in respect of implementation of I4.0. The readiness level is investigated from a variety of angles, including those of strategy and organization, smart manufacturing, smart operations, smart products, data-driven services, employees, and cyber security.

This paper emphasizes on the development and learning component of the implementation of I4.0 in the dairy industry. Using pilot surveys and reviewing literature among the dairy plants of Punjab and Chandigarh, we have used the following domains and subdomains that impact the readiness level of the dairy industry in the implementation of I4.0.

The domain under study is Strategy and organization, Smart factory, Smart Operations, Smart Product, Data-Driven Services, Employees, and Cyber Security.

Sample data includes companies like Amul, Verka, Nandini Milk, Aavin Milk, etc. The study will include the evaluation of the current readiness of the dairy industry for the adoption of I4.0.

Collection of primary data: Between December 20, 2021, and December 25, 2022, a structured, closed-ended questionnaire with 23 items is used to collect primary data for the survey.

Sample size: Four dairy factories from the Punjab, Chandigarh, and Delhi NCR regions were used as a sample size.

Sample unit: Dairy plants, one plant considered as 1 unit.

Sample Procedure: Convenience Sampling.

C. Data Analysis

Central Tendency and Variability (Mean, median, mode, standard deviation, and variance) were calculated for key variables to summarize the data. This initial analysis provided a general overview of the industry 4.0 readiness levels across the sampled dairy plants. Arithmetic Mean and correlation are applied to 7 domain factors and 23 sub-domain variables. The weighted average method is used for calculating the industry average. Figure 5 reflects the overview of steps for the evaluation of maturity level.

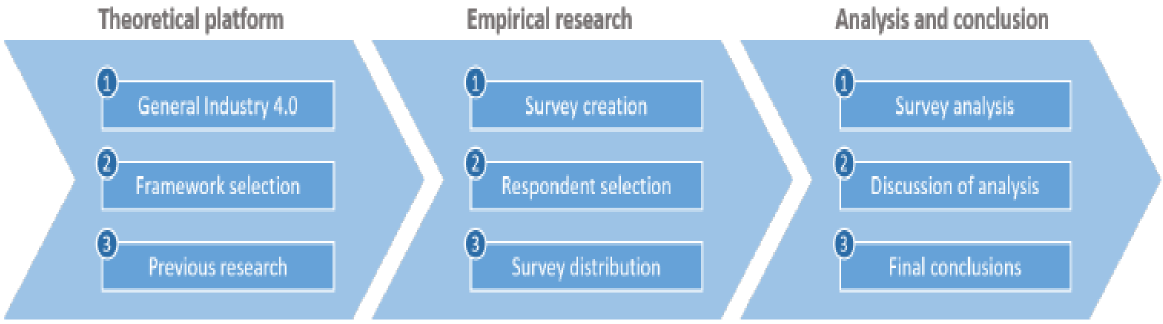

Figure 5. Overview of steps for evaluation of maturity level

After getting replies to the distributed questionnaires, we analyzed the survey. It is assumed that the results of the questionnaire will assist in the identification of the readiness level of the Dairy Industry to embrace the I4.0 implementation strategy. Moreover, this analysis helped in identifying the challenges being experienced by Dairy Industries while implementing I4.0.

Different research studies have shown that some large manufacturing companies were low in maturity levels whereas some other companies were able to achieve comparatively high maturity levels (Antonsson, 2017). Similarly, while studying the German manufacturing industry, the Impuls maturity model found that the average maturity level was as low as 0.6 (Lichtblau, 2015).

IV. Maturity co-variate analysis

The study examines the maturity concerning three covariates: revenue, size, and sub-industry.

A. Revenue

We could not find any relationship between revenue and the I4.0 maturity level as the number of companies covered may be large corporations.

1. Size

The I4.0 maturity level and the size of the company are positively correlated. By size of the corporation, we refer to both the number of employees and the company's annual revenue.

2. Empirical implementation: Impuls maturity model (Lichtblau, 2015)

For each of the domains, criteria were established to be able to assess maturity. A company must fulfill these requirements to promote to the next maturity level. In Figure 6 The maturity level that would arise from four alternative situations is illustrated (Lichtblau, 2015).

--- **Scenario A**, the maturity level 1 will be awarded to a corporation if it achieves the requirements for level 1 but not for levels 2 to 5.

--- **Scenario B**, If the company doesn't respond (Missing values), making it impossible to assess if it fulfills the requirements for level 1, Nevertheless, if the requirements for level 2 have been satisfied, the missing data from level 1 are seen as meeting level 1 requirement, and as a result, the organization will be given the maturity level 1 designation.

--- **Scenario C**, Level 1 information is not accessible, and the requirements for Level 2 are not satisfied. The firm will be given level 0 since the missing numbers at level 1 are recognized as not fulfilling the requirements for level 1.

--- **Scenario D**, The highest level among those levels will be assigned if any of the level requirements in any given sub-dimension are the same.

	Satisfaction of one or more criteria...						
	Level 0	Level 1	Level 2	Level 3	Level 4	Level 5	Result
A	Yes	Yes	No	No	No	No	Level 1
B	Yes	Missing values	Yes	No	No	No	Level 2
C	Yes	Missing values	No	No	No	No	Level 0
D	Yes	Same criterion	Same criterion	No	No	No	Level 2

Figure 6: Affirmation of one or more criteria (Lichtblau, 2015)

B. **Overall Maturity**

1. Strategy and Organization

Implementation of I4.0 is not only adopting new technology rather it requires fundamental changes on all levels of the organization. In this dimension, the maturity score is low such as 1,2, and 4 and the industry average is 2.75 which is low and the reason behind this is a lack of investments in I4.0 as listed in Table 1. Low levels of strategic implementation are a significant additional factor.

TABLE 1: STRATEGY AND ORGANIZATION DOMAIN

DOMAINS	Sub-domains	PLANTS				Mean	Median	Mode	Standard Deviation	Variance
		O	V	M	A					
Strategy and organization	Degree of Strategy	2	3	4	4	3.25	3.5	4	0.96	0.92
	Definition of Indicators	1	2	4	4	2.75	3	4	1.50	2.25
	Investments	2	3	4	4	3.25	3.5	4	0.96	0.92
	Overall Maturity Level	1	2	4	4	2.75	3	4	1.50	2.25

2. Smart Factory

The Smart Factory is the main heart of I4.0 which connects machines with products. The average industry mean is 2.5 which means that the industry is a beginner in this domain where machine-to-machine interaction is low and cannot be controlled by information technology alone. Data collecting, IT systems, and digital modeling in the subdomain are generally at a level of maturity of 2.5 as per Table 2, which means that they are beginners and need to grow in this sector.

Table 2: Smart Factory domain

DOMAINS	Sub-domains	PLANTS				Mean	Median	Mode	Standard Deviation	Variance
		O	V	M	A					
Smart Factory	**Equipment infrastructure (Existing)**	2	3	4	4	3.25	3.5	4	0.96	0.92
	Equipment infrastructure (Targeted)	4	5	5	5	4.75	5	5	0.5	0.25
	Digital Modelling	2	3	4	4	3.25	3.5	4	0.96	0.92
	Data Collection	2	2	3	4	2.75	2.5	2	0.96	0.92
	Data Usage	2	3	4	4	3.25	3.5	4	0.96	0.92
	IT Systems	2	2	3	3	2.5	2.5	2	0.58	0.33
	Overall Maturity Level	2	2	3	3	2.5	2.5	2	0.58	0.33

3. Smart Operations

Integration of physical and digital systems leads to smart operations. These systems could interact within the organization and between different companies. As per Table 3, the overall maturity of this domain is low nearly 1.5 which means that companies are running low in maturity as far as smart operations are concerned.

TABLE 3: SMART OPERATIONS DOMAIN

DOMAINS	Sub-domains	PLANTS				Mean	Median	Mode	Standard Deviation	Variance
		O	V	M	A					

Smart Operations	**System Integration information sharing**	4	5	5	5	4.75	5	5	0.50	0.25
	Automatically guided workplace	3	3	3	4	3.25	3	3	0.50	0.25
	Self-reacting processes	4	4	4	4	4	4	4	0	0
	IT Security	4	4	4	4	4	4	4	0	0
	Cloud Usage	4	4	4	4	4	4	4	0	0
	Real-time Data	1	1	2	2	1.5	1.5	1	0.58	0.33
	Overall Maturity Level	1	1	2	2	1.5	1.5	1	0.58	0.33

4. Smart Products

Smart Products are those that are well-equipped with components such as RFID, smart sensors, etc., that allow for data gathering and movement of these products in the smart factory as well as out of the factory becomes easier. Smart products have two major components: Data utilization and ICT add-on features. As we can see the maturity level of smart products is comparatively better than other domains ensuring that the products are well-equipped and the use of data is done well with a mean maturity level of 3.5 as per Table 4.

TABLE 4: SMART PRODUCT DOMAIN

DOMAINS	**Sub-domains**	**PLANTS**				**Mean**	**Median**	**Mode**	**Standard Deviation**	**Variance**
		O	**V**	**M**	**A**					

Smart Product	**Internet Communication and Technology (ICT) functionalities**	3	4	5	5	4.25	4.5	5	0.96	0.92
	Use of Data	2	4	4	4	3.5	4	4	1	1
	Overall Maturity Level	2	4	4	4	3.5	4	4	1	1

5. Data-driven Services

Data-driven services help in the transformation of companies right from the selling of products up to delivering services. Data-driven services serve as a bridge between the manufacturers and the customers, collecting customer data on customer needs and preferences, etc., through smart sensors and communicating the same through IT systems to the manufacturers. To get maximum advantage of this service, the companies must rethink the existing business model or restructure or adopt new technologies. The data listed in Table 5 shows that the maturity level of this domain is either 4 or 5 means that the companies are experienced but there is a long way to go for perfection.

TABLE 5: DATA-DRIVEN SERVICES DOMAIN

DOMAINS	**Sub-domains**	**PLANTS**				**Mean**	**Median**	**Mode**	**Standard Deviation**	**Variance**
		O	**V**	**M**	**A**					
Data-Driven Services	**Data-Driven Service**	4	4	5	5	4.5	4.5	4	0.58	0.33
	Share of revenues	4	5	5	5	4.75	5	5	0.50	0.25
	Level of data usage	5	6	6	6	5.75	6	6	0.50	0.25
	Overall Maturity	4	4	5	5	4.5	4.5	4	0.58	0.33

	Level									

6. Employees

Industry 4.0 (I4.0) application brings the biggest challenge for employees as there is technological transformation and they have to adapt to these changes. The companies implementing I4.0, and need to train their employees so that they can adapt to the changes caused due to technological transformation. The mean overall maturity level is 2.5 as shown in table 6.

TABLE 6: EMPLOYEE'S DOMAIN

DOMAINS	**Sub-domains**	**PLANTS**				**Mean**	**Median**	**Mode**	**Standard Deviation**	**Variance**
		O	**V**	**M**	**A**					
Employees	**Employee Skills**	2	2	3	3	2.5	2.5	2	0.58	0.33
	Overall Maturity Level	2	2	3	3	2.5	2.5	2	0.58	0.33

7. Cyber Security

With the digital transformation of the industry, the systems have a machine-to-machine interaction and machine-to-human interaction. These smart machines are fed with huge amounts of data and are connected to local networks and the internet, there is a risk of leakage of sensitive data, and are prone to cyber-attacks. The need of the hour is to upgrade cyber security with the I4.0 implementation. According to table 7, the maturity level of the companies is 2 which means the companies are beginners in this domain.

TABLE 7: CYBER-SECURITY DOMAIN

DOMAINS	**Sub-domains**	**PLANTS**				**Mean**	**Median**	**Mode**	**Standard Deviation**	**Variance**
		O	**V**	**M**	**A**					

Cyber Security	**Cyber Security**	2	2	2	2	2	2	2	0.00	0.00
	Overall Maturity Level	2	2	2	2	2	2	2	0.00	0.00

8. Domain-wise Average

When we talk about the statistical data of all the company's domain-wise as per the data given in Table 8, we find that:

- The companies have a 2.75 maturity level in the Strategy and organization domain on average which means that companies are just beginners in this domain and are not strategically strong for implementation of I4.0.
- Smart Factory is on the 2.5 maturity level, I.e., the companies are beginners in this domain showing that our factories are not that ready for the I4.0 application.
- Smart Operations is 1.5 on average which is quite low and shows that companies are outsiders in this domain and have a far way to go to adopt smart operations where machine-to-machine integration is high.
- Smart Products is comparatively better at 3.5 making dairy plants intermediate, equipped with smart products.
- Data-driven services are quite high at 4.5 on average making dairy plants experienced in this domain where data usage is good.
- Employee's domain is at 2.5 which means that dairy plants are beginners in this domain and skill upgradation is required.
- Cyber security is at 2 making dairy plants beginners in this domain also showing that dairy plants are not taking care of cyber security.

TABLE 8: DOMAIN-WISE INDUSTRY STATISTICAL DATA

Domains/Plants	O	V	M	A	Mean	Median	Mode	Standard Deviation	Variance
Strategy and	1	2	4	4	2.75	3	4	1.5	2.25

Organization									
Smart Factory	2	2	3	3	2.5	2.5	2	0.58	0.33
Smart Operations	1	1	2	2	1.5	1.5	1	0.58	0.33
Smart Product	2	4	4	4	3.5	4	4	1	1
Data-Driven Services	4	4	5	5	4.5	4.5	4	0.58	0.33
Employees	2	2	3	3	2.5	2.5	2	0.58	0.33
Cyber Security	2	2	2	2	2	2	2	0	0

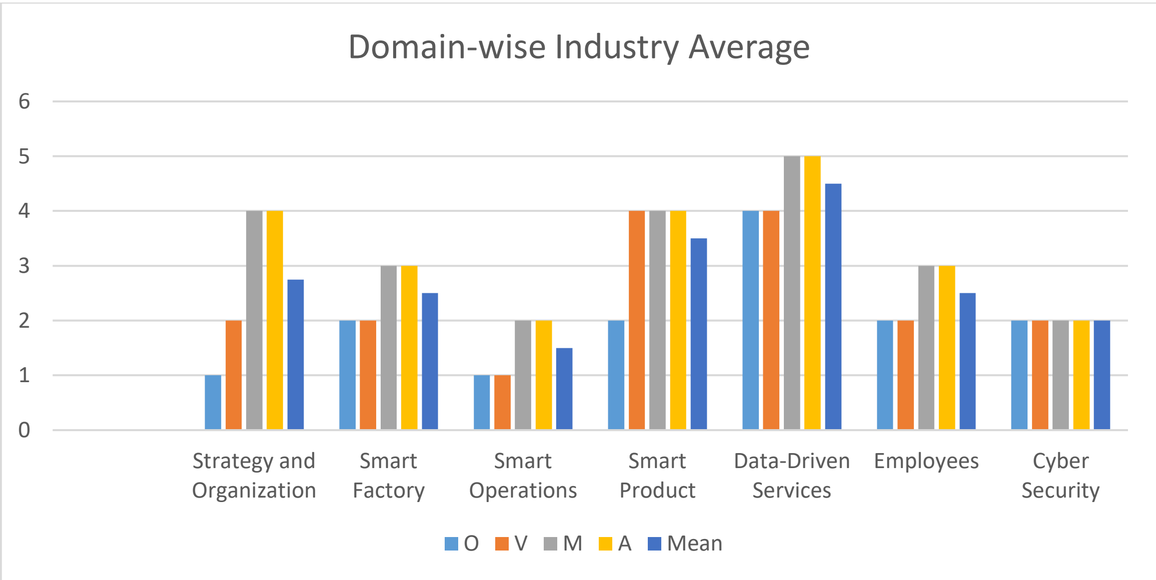

FIGURE 6: DOMAIN-WISE INDUSTRY AVERAGE

Figure 6 shows the domain-wise average of various factors including strategy & organization, smart factory, smart operations, smart product, data-driven services, employees, and cyber security based on analysis of the data obtained from various dairy plants across India.

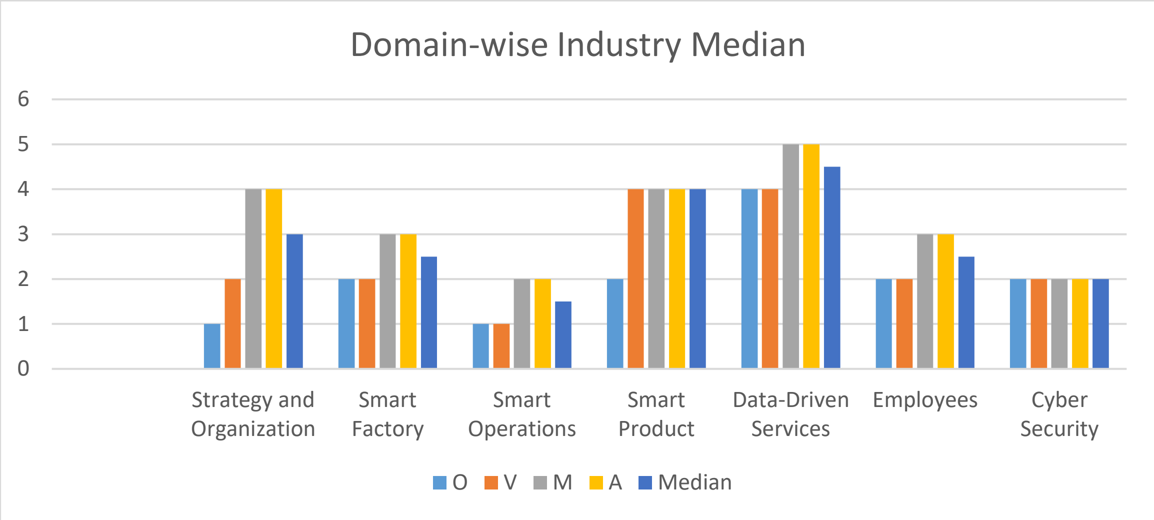

FIGURE 7: DOMAIN-WISE INDUSTRY MEDIAN

Figure 7 presents the median values for various domains, including strategy and organization, smart factory, smart operations, smart product, data-driven services, employees, and cybersecurity, based on the analysis of data collected from various dairy plants across India.

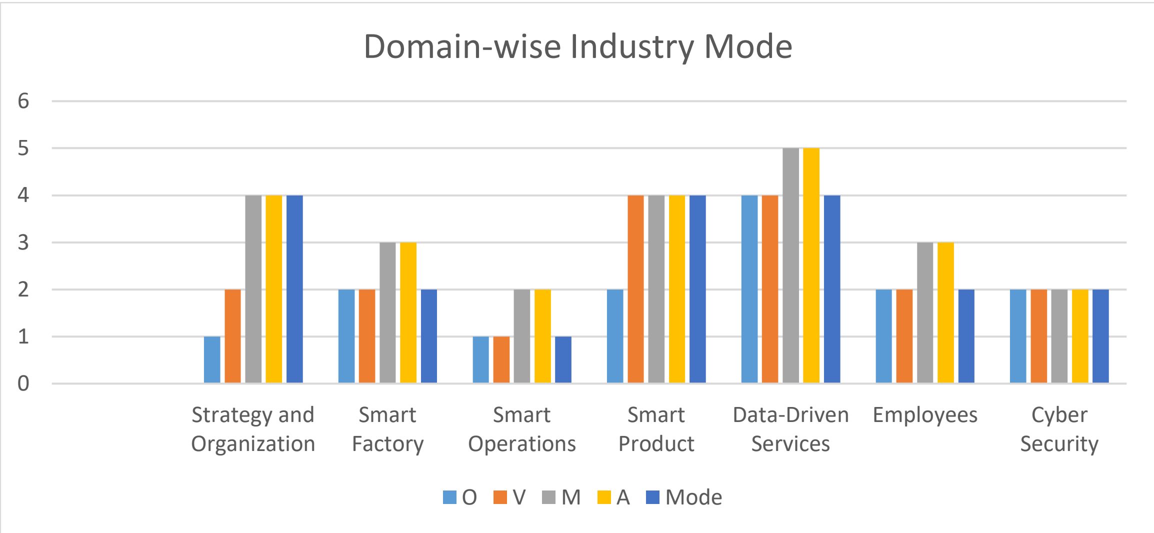

FIGURE 8: DOMAIN-WISE INDUSTRY MODE

Figure 8 displays the mode values for various domains, such as strategy and organization, smart factory, smart operations, smart product, data-driven services, employees, and cybersecurity, derived from the analysis of data collected from multiple dairy plants across India.

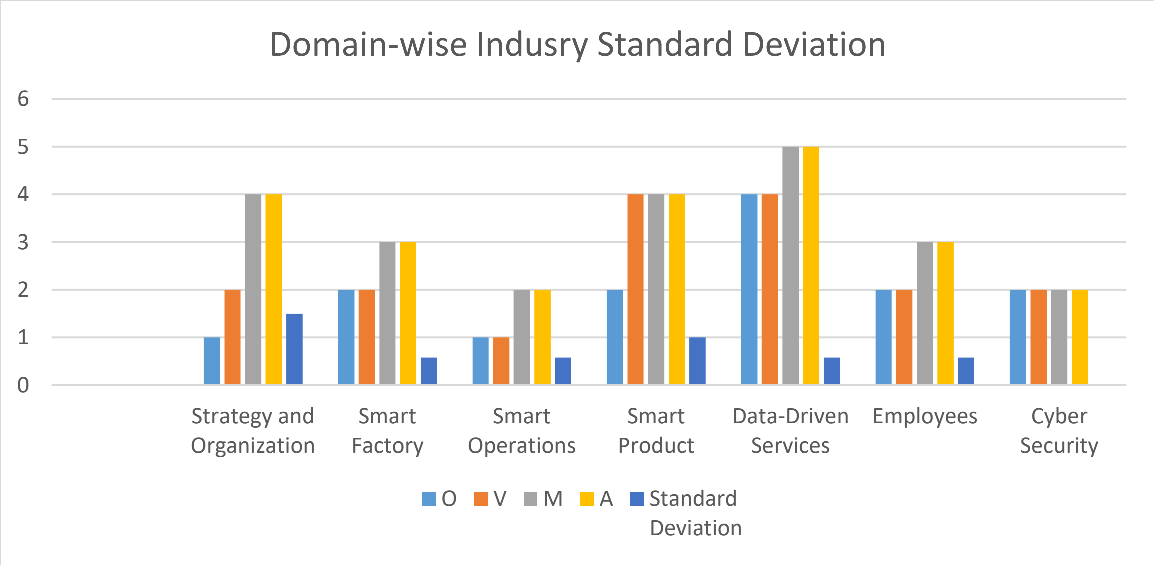

FIGURE 9: DOMAIN-WISE INDUSTRY STANDARD DEVIATION

Figure 9 illustrates the standard deviation values for various domains, including strategy and organization, smart factory, smart operations, smart product, data-driven services, employees, and cybersecurity, based on the analysis of data gathered from multiple dairy plants across India.

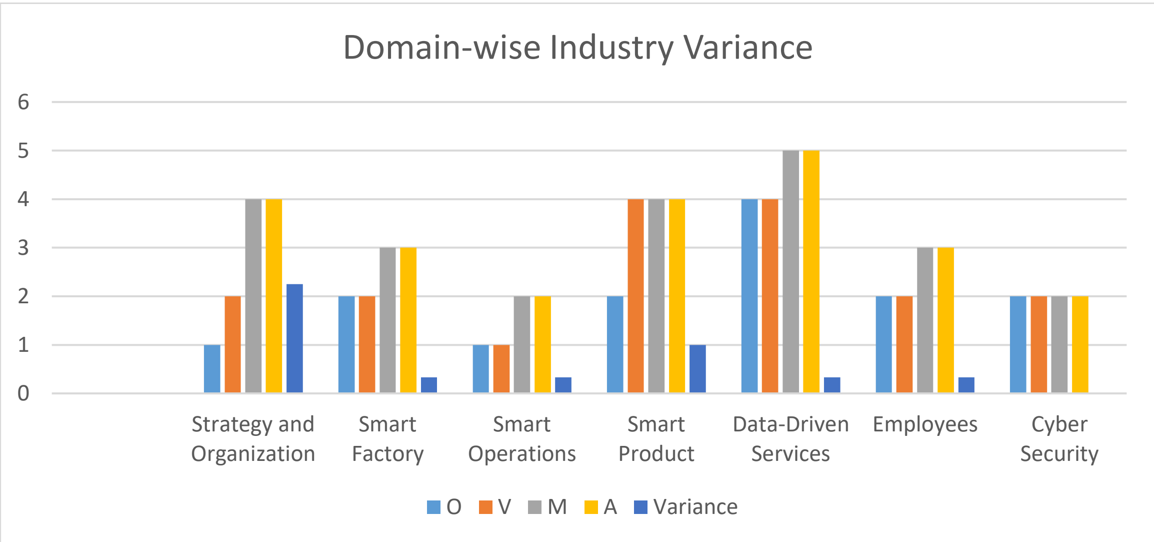

FIGURE 10: DOMAIN-WISE INDUSTRY VARIANCE

Figure 10 depicts the variance values for various domains, encompassing strategy and organization, smart factory, smart operations, smart product, data-driven services, employees, and cybersecurity. These values are derived from the analysis of data collected from multiple dairy plants across India.

D. Industry Average

The companies are assigned maturity levels based on the domain's lowest sub-dimension score for each of the seven domains. For eg: The maturity for the entire dimension would be level 1 for the domain smart operations if a company achieves level 4 in sub-dimensions under smart operations and level 1 in one sub-dimension (Lichtblau, 2015).

The weights are set by the respondent firms based on the priority they place on the characteristics, and the final maturity score for the seven dimensions is computed as a weighted average of the maturity scores for the seven dimensions. The seven dimensions were weighted in the following ways based on the average survey responses, giving a total of 100 potential points in Table 9:

Table 9: Weights assigned by respondents

DIMENSIONS	WEIGHTS
Strategy and organization	23 points
Smart factory	18 points
Smart products	16 points
Data-driven services	9 points
Smart operations	7 points
Employees	21 points
Cyber Security	6 points

If we talk about the maturity level of the dairy industry as listed in Table 10, it is only 2.60 which is quite low, making the industry a beginner in readiness level for the I4.0 application. If we look at the weighted average of different dairy plants then one can see that it ranges from 1.75 to 3.24 depending on the plant to plant.

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TABLE 10: I4.0 OVERALL MATURITY LEVEL OF THE DAIRY INDUSTRY

Dairy Plants	**O**	**V**	**M**	**A**	**Industry**
Weighted Average	1.75	2.16	3.24	3.24	2.60

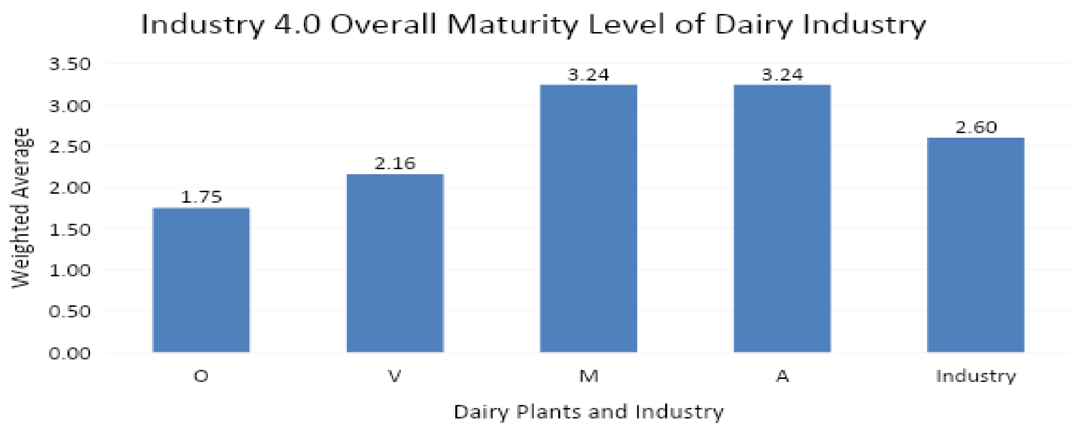

Figure 11: I4.0 Overall Maturity Level of the Dairy Industry

Figure 11 shows the overall maturity level of the dairy industry using the weighted average of different dairy plants and industries with the highest weighted average of 3.24 for M & A.

E. Simulation and System Characteristics

Simulation involves creating a model that imitates the real-world processes of the dairy industry in the context of Industry 4.0 readiness. This model is a digital representation of the industry's technological infrastructure, data analytics systems, automation processes, and collaborative networks. Relevant data about the current state of the dairy industry is collected. This includes information on existing technologies, data analytics capabilities, automation systems, and collaborative practices. The data is sourced from surveys, interviews, documentation, and other sources. Based on the collected data, a simulation model is developed that reflects the key aspects of the dairy industry's operations relevant to Industry 4.0. The model captured the complexities and interactions between different components, such as technology integration, data analytics, automation, and collaborative networks. The Impuls maturity framework is chosen as a maturity model and integrated into the simulation. This ensures that the simulation considers the specific dimensions (technology integration, data analytics, automation, and collaborative networks) and their respective maturity levels. The simulation results provide insights into how different strategies and interventions might impact the Industry 4.0 readiness of the dairy industry. Researchers then draw conclusions and make recommendations based on the simulation outcomes.

Understanding system characteristics and resource characteristics is crucial for designing effective systems, managing organizations, and making informed decisions. The system and resources used in the work have various characteristics like interconnected components, defined boundaries, input-output Relationship, hierarchy, adaptability, renewability, and Durability.

V. Conclusion & suggestions

The analysis highlights that data analytics and automation are critical factors influencing the overall Industry 4.0 readiness. Plants with higher levels of automation and sophisticated data analytics capabilities tend to exhibit greater operational efficiency and productivity. Significant differences were observed in the industry 4.0 readiness levels across different zones within the Delhi/NCR region. Urban zones with better infrastructure and access to technology tend to be more advanced in their adoption efforts compared to rural zones.

VI. Research hypotheses and questions

Hypothesis 1: Dairy plants with higher levels of technology integration will demonstrate greater Industry 4.0 readiness.

Our findings support Hypothesis 1, indicating that dairy plants with higher levels of technology integration, particularly in automation and data analytics, exhibit greater Industry 4.0 readiness. For example, Dairy Plants M and A, which have invested significantly in automation and data-driven processes, achieved weighted average scores of 3.24, indicating a relatively advanced stage of Industry 4.0 adoption. This suggests that technological investment is crucial for moving towards higher maturity levels.

Hypothesis 2: Workforce skills and training are critical determinants of successful Industry 4.0 adoption in the dairy industry.

The results corroborate Hypothesis 2, demonstrating that workforce skills and training are vital for the successful implementation of Industry 4.0 technologies. Plants that invest in continuous training programs for their employees show improved operational efficiency and adaptability. For instance, Dairy Plant V, despite moderate technology integration, scored relatively lower (2.16) due to insufficient workforce training, highlighting the importance of skill development.

Hypothesis 3: Effective management practices and strong leadership are positively correlated with higher Industry 4.0 maturity levels.

Our study confirms Hypothesis 3, showing a positive correlation between effective management practices, strong leadership, and higher Industry 4.0 maturity levels. Dairy Plants M and A, which have robust management frameworks, not only adopt new technologies but also sustain these advancements, reflecting their leadership's strategic vision and commitment to innovation.

Research Question 1: What are the current levels of Industry 4.0 adoption across different dairy plants in the Delhi/NCR region, Haryana, Mohali, and Chandigarh?

The study reveals that Industry 4.0 adoption levels vary significantly across the surveyed regions. The overall weighted average score of 2.60 suggests moderate progress, with urban areas like Delhi/NCR showing higher readiness compared to rural regions. This disparity underscores the need for targeted support and resources to bridge the gap between different areas.

Research Question 2: What are the major factors that influence the performance of dairy plants in adopting Industry 4.0 technologies?

Major Factors Influencing Performance Key factors influencing the performance of dairy plants in adopting Industry 4.0 technologies include:

- **Technology Integration:** Essential for enhancing productivity and quality control.
- **Data Analytics:** Critical for predictive maintenance and process optimization.
- **Workforce Skills:** Necessary for effective technology utilization.
- **Management Practices:** Important for strategic implementation and sustainability.
- **Collaborative Networks:** Provide support and innovation for implementation.
- **Infrastructure:** Fundamental for supporting technological advancements.

An unexpected finding was the significant role of collaborative networks in facilitating Industry 4.0 adoption. While we anticipated their importance, the extent to which collaboration impacted readiness and performance was greater than expected. This suggests that fostering industry partnerships and collaborative initiatives can be a highly effective strategy for accelerating Industry 4.0 adoption, even in regions with limited resources. The strong impact of collaborative networks can be attributed to the shared resources, expertise, and support they offer, which are especially valuable in traditional industries like dairy.

Another surprising result was the relatively lower readiness scores in some well-resourced plants due to inadequate workforce training. This indicates that merely investing in technology is insufficient without parallel investments in human capital development. The lower readiness scores in some technologically advanced plants could be due to the complexity of Industry 4.0 technologies, which require skilled personnel to operate and manage effectively. Without adequate training, even well-resourced plants struggle to realize the full potential of these technologies.

A. Maturity Level

The primary goal of the study was to find out the I4.0 readiness level of the dairy industry using the Impuls maturity framework model. The weighted average score for Dairy Plant O is 1.75, indicating that this plant is at an early stage of Industry 4.0 adoption. There is a need for significant improvements in technology integration and process optimization. With a weighted average score of 2.16, Dairy Plant V shows a moderate level of adoption, particularly in strategic planning and initial technology integration efforts. The weighted average score of 3.24 for Dairy Plant M & A highlights a relatively higher level of Industry 4.0 readiness. This plant has made substantial progress in adopting automation technologies and organizational management practices. The overall maturity level of the dairy industry is found to be 2.60, which is low. The major factors that affect the performance of dairy plants while implementing Industry 4.0 include the integration of advanced technologies such as automation, IoT devices, and data analytics, skills and training of the workforce, Strong leadership and effective management practices, adequate infrastructure, and resource availability. From the findings of this study, we can conclude that the distribution of maturity among the various factors is that the data-driven services and smart products are the most mature, and smart operations and employees are the least. The findings demonstrate that the earnings do not have a significant correlation with the I4.0 maturity levels of dairy plants but are correlated with the size of the dairy plants.

B. Challenges

The issues listed in Table 11 are discovered among several dimensions by comparing the theory and analysis used in the study:

Table 11: Challenges faced by the dairy industry in I4.0 implementation

Domains	**Sub-domains**	**Challenges**
Strategy & Organisation	• Degree of Strategy • Definition of Indicators • Investments • Innovation Management	1. Financial: Dairy products are highly perishable and the competitiveness of the markets, leads to lower profit margins. 2. Limited Resources: lack of manpower to initiate the time-consuming process of

		implementation of I4.0 in their strategy.
Smart Factory	● Equipment infrastructure (Existing) ● Equipment infrastructure (Targeted) ● Digital Modelling ● Data Collection ● Data Usage ● IT Systems	1. Lack of Knowledge: regarding the features of I4.0 and its implementation when we talk about the smart factory.
Smart Operations	● System Integration information sharing ● Automatically guided workplace ● Self-reacting processes ● IT Security ● Cloud Usage ● Real-time Data	1. Lack of Know-How: There is very little know-how regarding the implementation of smart operations. 2. Highly fluctuating demand: It is difficult to generalize the demand of the consumers in dairy products and thus this feature is difficult to implement with full advantage.
Smart Product	● Internet Communication and Technology (ICT) functionalities ● Use of Data	1. Lack of Knowledge and expertise in handling such products.
Data-Driven Services	● Data-Driven Service ● Share of revenues ● Level of data usage	1. Lack of expertise in handling customer end data
Employees	● Employee Skills	1. Barriers related to employees such as technical knowledge, and handling of high-tech machinery.

Cyber Security	● Cyber Security	1. Lack of centralized data collection: Barrier relating to cyber security as it is not centralized.

C. Limitations & Research Suggestions

The limitation of the study is that only a few states are being covered in the study, namely Delhi/ NCR, Punjab, Haryana, and Chandigarh. The research may be reiterated with a bigger sample size and other areas can be covered. In the study, major challenges are identified, and the next step could be finding the probable solutions to implement I4.0 with full effect. The study can be done for different industries also has done in the dairy industry. The road map can be taken from the government's perspective and major steps taken by the government in the I4.0 implementation.

The strengths of the method proposed in this paper are a comprehensive assessment that provides a holistic understanding of various dimensions using impuls maturity framework, strategic insights into the readiness levels, offering a nuanced understanding of technology integration, organizational change enhances the generalizability and applicability of the findings to the broader dairy industry, and alignment with industry 4.0 principle, applicability, actionable recommendations allowing stakeholders to identify specific areas for improvement and strategic planning to enhance industry 4.0 readiness. While the proposed method demonstrates notable strengths in its comprehensive approach and practical applicability, it is essential to acknowledge and address the limitations, including subjectivity in survey responses, limited scope, resource intensive, and dynamic nature of Industry 4.0.

D. Contribution

The main objective of this study is to precisely examine the I4.0 application in the Indian dairy industry.

A lot of factors show that the effective deployment of I4.0 is one of the core paths of success for the dairy industry. The study shows that the important dimensions of dairy plants have a low maturity level. More concrete steps can be taken for the implementation of I4.0 in the dairy industry to take this industry to heights. The primary accomplishment of the study is spreading awareness of the I4.0 application and providing a platform for further studies in both academia and industry.

VII. FUTURE WORK

While this study focuses on the Delhi/NCR region, Haryana, Mohali, and Chandigarh, future research could expand to include other regions within India or globally. A broader scope would offer a more comprehensive understanding of Industry 4.0 readiness in the dairy sector, considering regional variations and challenges. Additionally, longitudinal studies could track changes over time, revealing trends in technology adoption and adaptation. Future studies should explore the long-term impacts of Industry 4.0 on performance and competitiveness. Comparative studies across sectors, such as agriculture or textiles, could reveal how Industry 4.0 technologies can be adapted and assess policy effectiveness. Investigating regional readiness disparities and emerging technologies (e.g., blockchain, AI, robotics) and their consumer impact could offer deeper insights and guide further industry advancements.

The practical implications of this research suggest that dairy plants should focus on strategic planning involving technological investment, workforce training, and management practices. Tailored programs for upskilling employees in technology management, data analytics, and automation, along with collaborative networks, are key to enhancing Industry 4.0 adoption. Partnering with technology providers, research institutions, and industry peers can drive innovation, lower costs, and reduce risks. Additionally, rural dairy plants should prioritize investments in digital infrastructure like high-speed internet and IoT platforms to fully benefit from Industry 4.0.

Compliance with Ethical Standards:

Disclosure of potential conflicts of interest: There were no conflicts of interest.

Research involving Human Participants and/or Animals: Research involves Human Participants and no animals were included.

Informed consent: The participants consented to participate in the questionnaire and/or publish.

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